Q1.

Ammonia is used to make nitric acid (HNO_3) by the Ostwald Process.
Three reactions occur in this process.

Reaction **1** $4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

Reaction **2** $2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$

Reaction **3** $3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$

(a) In one production run, the gases formed in Reaction **1** occupied a total volume of 4.31 m^3 at 25 °C and 100 kPa.

Calculate the amount, in moles, of NO produced.
Give your answer to 3 significant figures.
(The gas constant R = 8.31 J K^{-1} mol^{-1})

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(4)

(b) In another production run, 3.00 kg of ammonia gas were used in Reaction **1** and all of the NO gas produced was used to make NO_2 gas in Reaction **2**.

(i) Calculate the amount, in moles, of ammonia in 3.00 kg.

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(2)

(ii) Calculate the mass of NO_2 formed from 3.00 kg of ammonia in Reaction **2** assuming an 80.0% yield.
Give your answer in kilograms.
(If you have been unable to calculate an answer for part (b)(i), you may assume a value of 163 mol. This is **not** the correct answer.)

(3)

(c) Consider Reaction **3** in this process.

$$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$$

Calculate the concentration of nitric acid produced when 0.543 mol of NO_2 is reacted with water and the solution is made up to 250 cm^3.

(2)

(d) Suggest why a leak of NO_2 gas from the Ostwald Process will cause atmospheric pollution.

(1)

(e) Give **one** reason why excess air is used in the Ostwald Process.

(1)

(f) Ammonia reacts with nitric acid as shown in this equation.

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

Deduce the type of reaction occurring.

___

(1)

(Total 14 marks)

Q2.

This question is about iron and its ions.

(a) Discuss the role of iron as a heterogeneous catalyst in the Haber process.

$$3\ H_2 + N_2 \rightleftharpoons 2\ NH_3$$

Your answer should include:

- the meaning of the term heterogeneous catalyst
- how iron acts as a heterogeneous catalyst
- the factors that affect the efficiency and lifetime of the catalyst.

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(6)

(b) Fe^{2+} ions catalyse the reaction between peroxodisulfate(VI) ions and iodide ions in aqueous solution.

$$S_2O_8^{2-}(aq) + 2\ I^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + I_2(aq)$$

Explain why this reaction is slow before the catalyst is added.
Give **two** equations to show how Fe^{2+} ions catalyse this reaction.

Why reaction is slow before catalyst added ______________________________

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Equation 1

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Equation 2

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(4)

(c) Give a reason why Zn^{2+} ions do **not** catalyse the reaction in part (b).

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(1)

(d) Iron reacts with dilute hydrochloric acid to form iron(II) chloride and hydrogen.

$$Fe(s) + 2\ HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$$

A 0.998 g sample of pure iron is added to 30.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid.

One of these reagents is in excess and the other reagent limits the amount of hydrogen produced in the reaction.

Calculate the maximum volume, in m^3, of hydrogen gas produced at 30 ^oC and 100 kPa.

Give your answer to 3 significant figures.

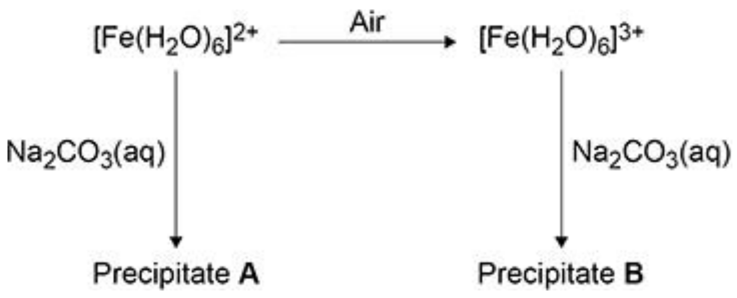
In your answer you should identify the limiting reagent in the reaction.

The gas constant, R = 8.31 J K^{-1} mol^{-1}

Volume of hydrogen _______________ m^3

(6)

The figure below shows some reactions of iron ions in aqueous solution.



(e) Identify **A** and state its colour.

Identity ____

Colour ____

(2)

(f) Give the formula of **B** and state its colour.

Give an ionic equation for the reaction of $[Fe(H_2O)_6]^{3+}$ with aqueous Na_2CO_3 to form **B**.

Formula ____

Colour ____

Ionic equation

____

(3)

(g) Explain why an aqueous solution containing $[Fe(H_2O)_6]^{3+}$ ions has a lower pH than an aqueous solution containing $[Fe(H_2O)_6]^{2+}$ ions.

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(3)

(Total 25 marks)

Q3.

This question is about sodium and some of its compounds.

(a) Use your knowledge of structure and bonding to explain why sodium bromide has a melting point that is higher than that of sodium, and higher than that of sodium iodide.

(6)

(b) When 250 mg of sodium were added to 500 cm^3 of water at 25 °C a gas was produced.

Give an equation for the reaction that occurs.
Calculate the volume, in cm^3, of the gas formed at 101 kPa

The gas constant, R = 8.31 J K^{-1} mol^{-1}

Equation ____

Volume ____________________ cm^3

(6)

(c) Calculate the concentration, in mol dm^{-3}, of sodium ions in the solution produced in the reaction in **part (b)**.

Concentration ____________________ mol dm^{-3}

(1)

(d) Sodium reacts with ammonia to form the compound $NaNH_2$ that contains the NH_2^- ion.

Draw the shape of the NH_2^- ion.
Include any lone pairs of electrons that influence the shape.

Predict the bond angle.
Justify your prediction.

Shape

Bond angle ____________________

Justification ____

____

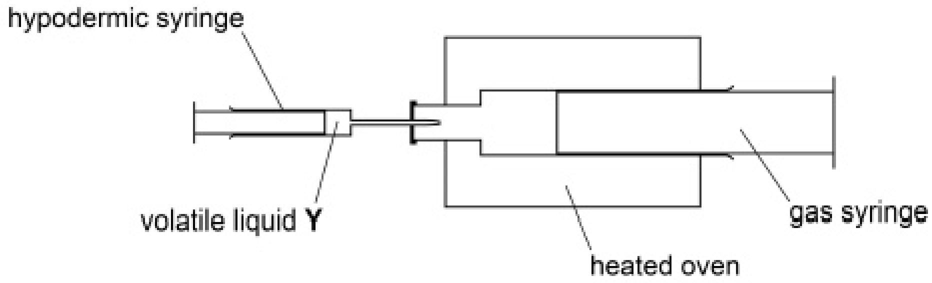
(4)

(Total 17 marks)

Q4.

A student determined the relative molecular mass, M_r, of an unknown volatile liquid Y in an experiment as shown in the diagram.
The student used a hypodermic syringe to inject a sample of liquid Y into a gas syringe in an oven.
At the temperature of the oven, liquid Y vaporised.

The student's results are shown in the table.



Mass of hypodermic syringe and liquid Y before injection	10.91 g
Mass of hypodermic syringe and liquid Y after injection	10.70 g
Oven temperature	98.1 °C
Atmospheric pressure	102 kPa
Increase in volume in gas syringe after injection of Y	85.0 cm^3

(a) Define the term relative molecular mass (M_r).

Use the experimental results in the table to determine the relative molecular mass of Y.
The gas constant R = 8.31 J K^{-1} mol^{-1}

(5)

(b) Some of the liquid injected did not evaporate because it dripped into the gas syringe nozzle outside the oven.

Explain how this would affect the value of the M_r of Y calculated from the experimental results.

(2)

(Total 7 marks)

Q5.

An experiment was carried out to determine the relative molecular mass (M_r) of a volatile hydrocarbon **X** that is a liquid at room temperature.

A known mass of **X** was vaporised at a known temperature and pressure and the volume of the gas produced was measured in a gas syringe.

Data from this experiment are shown in the table.

Mass of **X**	194 mg
Temperature	373 K
Pressure	102 kPa
Volume	72 cm^3

(a) Calculate the relative molecular mass of **X**.

Show your working.

Give your answer to the appropriate number of significant figures.

The gas constant, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

Relative molecular mass ____

(5)

(b) Analysis of a different hydrocarbon **Y** shows that it contains 83.7% by mass of carbon.

Calculate the empirical formula of **Y**.

Use this empirical formula and the relative molecular mass of **Y** (M_r = 86.0) to calculate the molecular formula of **Y**.

Empirical formula ____

Molecular formula ____

(4)

(Total 9 marks)

Mark schemes

Q1.

(a) P = 100 000 Pa and T = 298 K

Wrong conversion of V or incorrect conversion of P / T lose M1 + M3

1

$$n = \frac{PV}{RT} \text{ or } \frac{100\ 000 \times 4.31}{8.31 \times 298}$$

If not rearranged correctly then cannot score M2 and M3

1

n(total) = 174(.044)

1

n (NO) = 69.6

Allow student's M3 × 4 / 10 but must be to 3 significant figures

1

(b) (i) $\frac{3000}{17}$

Allow answer to 2 significant figures or more

1

176.5

Allow 176 − 177
But if answer = 0.176 − 0.18 (from 3 / 17) then allow 1 mark

1

(ii) 176.47 × 46 = 8117.62

M1 is for the answer to (b)(i) × 46. But lose this mark if 46 ÷ 2 at any stage
However if 92 ÷ 2 allow M1

1

$$8117.62 \times \frac{80}{100} \ (= 6494 \text{ g})$$

M2 is for M1 × 80 / 100

1

$$\frac{6494}{1000} = 6.5$$

M3 is for the answer to M2 ÷ 1000 to min 2 significant figures (kg)

OR

If 163 mol used:
163 × 46 = 7498 (1)

$$7498 \times \frac{80}{100} = 5998.4 \text{ g} (1)$$

6.00 kg (1) **1**

(c) $0.543 \times \frac{2}{3} (= 0.362)$

if not $\times \frac{2}{3}$ CE = 0/2 **1**

$0.362 \times \frac{1000}{250} = 1.45 \,(\text{mol dm}^{-3})$

Allow 1.447 − 1.5 (mol dm^{-3}) for 2 marks **1**

(d) NO_2 contributes to acid rain / is an acid gas / forms HNO_3 / NO_2 is toxic / photochemical smog

Ignore references to water, breathing problems and ozone layer.
Not greenhouse gas **1**

(e) Ensure the ammonia is used up / ensure complete reaction or combustion

OR

Maximise the yield of nitric acid or products **1**

(f) Neutralisation

Allow acid vs alkali or acid base reaction **1**

[14]

Q2.

(a)

This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.	
Level 3 **5-6 marks**	All stages are covered and the description of each stage is generally correct and virtually complete. Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 and stage 3.
Level 2 **3-4 marks**	All stages are covered but the description of each stage may be incomplete or may contain inaccuracies **OR** two stages are covered and the explanations are generally correct and virtually complete. Answer is mainly coherent and shows progression from stage 1 to stage 2 and/or stage 3.
Level 1	Two stages are covered but the description of each stage may be incomplete or may contain inaccuracies,

1-2 marks	**OR** only one stage is covered but the explanation is generally correct and virtually complete. Answer includes isolated statements and these are presented in a logical order.
Level 0	**0 marks** Insufficient correct chemistry to gain a mark.

Stage 1
1a Heterogeneous means in a different phase/state from reactants
1b Catalyst speeds up reaction and is left unchanged **OR** lowers the activation energy for the reaction

Stage 2
2a Hydrogen and nitrogen/reactants adsorb onto the surface/ active sites of the iron
2b Bonds weaken/reaction takes place
2c Products desorb/leave from the surface (of the iron)

Stage 3
3a Large surface area (of iron) by using powder or small pellets or support medium/mesh
3b Catalyst poisoned / sulfur poisons or binds to the catalyst
3c Active sites blocked

Ignore references to temperature and pressure

6

(b) Two negative ions repel

1

So activation energy is high

1

$2\ Fe^{2+} + S_2O_8^{2-} \rightarrow 2\ SO_4^{2-} + 2\ Fe^{3+}$

1

$2\ Fe^{3+} + 2\ I^- \rightarrow 2\ Fe^{2+} + I_2$

Ignore any state symbols given

Allow multiples for both equations

Allow equations in either order

1

(c) (Zn ions) have only one oxidation state
Or
Zn^{2+} is the only ion

Allow doesn't have variable oxidation state

Allow cannot be oxidised to Zn^{3+}

Ignore has a full d shell

1

(d) M1 Amount of Fe = 0.998 ÷ 55.8 = 0.0179 mol

1

M2 Amount of HCl = 0.0300 mol

1

M3 HCl is the limiting reagent **1**

M4 Amount of H_2 produced = 0.0150 mol

M4 = M2÷2 **1**

M5 T = 303 K P = 100 000 Pa **1**

M6 $V\left(=\frac{0.0150 \times 8.31 \times 303}{100\ 000}\right) = 3.78 \times 10^{-4}\ (m^3)$

M6 $V\left(=\frac{M4 \times 8.31 \times 303}{100\ 000}\right)(m^3)$ **1**

(e) $FeCO_3$ or iron(II) carbonate **1**

Green

Allow white **1**

(f) $Fe(H_2O)_3(OH)_3$

Ignore square brackets if added **1**

brown **1**

$2\ [Fe(H_2O)_6]^{3+} + 3\ CO_3^{2-} \rightarrow 2\ Fe(H_2O)_3(OH)_3 + 3\ H_2O + 3\ CO_2$

Accept multiples **1**

(g) M1 Fe^{3+} is smaller (than Fe^{2+}) **OR** Fe^{3+} has a greater charge **OR** Fe^{3+} has a greater charge density **OR** Fe^{3+} has a greater charge to size ratio

Penalise $Fe(H_2O)_6^{3+}$ ions once in M1 or M2 **1**

M2 Fe^{3+} ions are more polarising **OR** Fe^{3+} ions polarise water molecules more **1**

M3 So more O-H bonds (in the water ligands) break **OR** more H^+ ions released **OR** weaken O-H bonds in ligands more (in the Fe^{3+} solution)

Do not allow Fe^{3+} releases $3H^+$ ions **1**

[25]

Q3.

This question is marked using Levels of Response. Examiners should apply a ‘best-fit’ approach to the marking.	
Level 3	All stages are covered and the explanation of each

5-6 marks	stage is generally correct and virtually complete. Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 and then stage 3. Coherent communication requires that there is a comparison between the types of bonding and that the bonding is correct for each substance.
Level 2 3-4 marks	All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete. Answer is mainly coherent and shows some progression from stage 1 to stage 2 and then stage 3.
Level 1 1-2 marks	Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR only one stage is covered but the explanation is generally correct and virtually complete. Answer shows some progression between two stages
Level 0 0 marks	Insufficient correct chemistry to gain a mark.

Indicative chemistry content. Contradictions (eg molecules, IMFs, covalent bonding,) negate statements.

Stage 1 - **Na**
1a) Na has metallic bonding
1b) there is attraction/ bonding between the positive nucleus/ ion and the delocalised electrons in Na
1c) Na has a giant/lattice structure

Stage 2 – **NaBr or NaI**
2a) Ionic bonding in NaBr and/or NaI
2b) There is attraction/ bonding between the + and – ions in NaBr and/or NaI
2c) NaBr and/or NaI have a giant/lattice structure

Stage 2 – **comparison of bonding**
3a) The ionic bonds are stronger (or wtte) than the metallic bonds
3b) there is stronger attraction (or wtte) between the + and – ions in NaBr than in NaI
3c) since the Br^- ion is smaller than the I– ion

6

(b) **M1** $Na + H_2O \rightarrow NaOH + \frac{1}{2} H_2$

Allow multiples

1

M2 (Mass Na = 0.250 g so moles Na = 0.250/23.0) = 0.0109

CE: If not divided by 23, max 3/5 calculation marks – M3, M4 and M5

AE: If not divided by 1000 and final answer is 1.33×10^5 cm^3 4/5

1

M3 moles H_2 = 5.43×10^{-3} to 5.45×10^{-3}

M3 = M2 /2

CE: If incorrect ratio used max 3/5 calculation marks – M2, M4 and M5

1

M4 T = 298 (K) and P = 101000 (Pa)

1

M5 V = nRT/P or ($5.435 \times 10^{-3} \times 8.31 \times 298$)/101000 or 1.33×10^{-4} (m^3)

1

M6 V = 133 – 134 cm^3

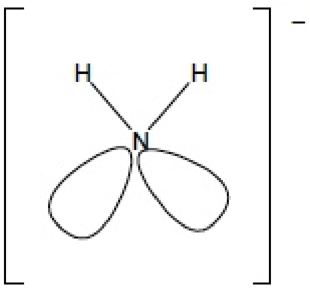
Allow to 2 significant figures or more

1

(c) Conc = 0.0109/ 500 × 10^{-3} = 0.0217-0.022 (mol dm^{-3})

Allow M2 from question (b)

1



(d) **M1**

Ignore charge and brackets

1

M2 104.5°

Allow 104-106

1

M3 (4) electron pairs repel to be as far apart as possible

1

M4 lp/lp repulsion> lp/bp repulsion (> bp/bp repulsion)

For M4 allow lone pairs repel more than bonding pairs

Mark independently

1

[16]

Q4.

(a) The sum of $\frac{\text{(weighted) average masses of atoms in formula}}{\text{1/12 mass of an atom of } ^{12}\text{C}}$

$\frac{\text{Average mass of one molecule}}{\text{1/12 mass of an atom of } ^{12}\text{C}}$

1

Method 1 **Method 2**

Mass of Y = 0.21g Mass of Y = 0.21g

If incorrect lose M5 also, unless AE

1

$M_r = \frac{mRT}{pV}$ $n = \frac{pV}{RT}$ and $M_r = \frac{m}{n}$

Can be implied in calculations

1

$M_r = \frac{0.21 \times 8.31 \times 371.1}{102000 \times 85x10^{-6}}$ $n = \frac{102000 \times 85x10^{-6}}{8.31 \times 371.1}$ (= 2.81 × 10^{-3})

M4 – awarded for all 3 unit conversions

1

M_r = 74.7 M_r = 74.7

Allow 75

1

(b) Lower volume recorded

Allow

(Evaporated) mass of gas is less than the recorded mass of liquid / 0.21g (or converse)

1

M_r would be greater (than the real M_r)

Ignore other references to mass

1

[7]

Q5.

(a) **Stage 1**

M1 $n = \frac{PV}{RT}$

1

M2 $= \frac{102 \times 10^3 \times 72 \times 10^{-6}}{8.31 \times 373}$

1

M3 = 0.0024 / 0.00237 / 0.002369 / 0.0023693 ..

1

Stage 2

M4 $M_r (= \frac{\text{mass}}{\text{moles}}) = \frac{0.194}{\textbf{M3}}$

1

M5 = 82 (**2sf only**)

1

*As this is an extended response question, each separate step of correct working is required in **M1–M5***

Correct answer with no working scores 2 marks

***M1** – If expression not written out, **M1** could score from a correct expression for **M2** (even if unit conversions are not correct for **M2**)*

M2** – allow an expression that gives correct value for **M3

***M3** should be <u>at least</u> 2sf (do not allow 0.0023 but do allow 0.00236)*

***M4** must show 0.194 or 194 × 10^{-3} in working to score*

***M5** must be 2sf*

ECF:

- *No ECF within either stage 1 or stage 2 (except for transcription errors)*
- *Allow ECF from stage 1 into stage 2, i.e for **M4** and **M5** based on incorrect **M3**, (but if expression for **M4** is inverted, cannot score **M5**)*
- *(Note that if 72 × 10^{-3} used in **M2**, then **M3** = 2.4, **M5** = 0.082)*

*Ignore units for **M3** and **M5***
*Note that if T = 273 + 373 = 646, **M5** = 140 (2sf)*

(b) **M1** dividing %s by relative atomic masses
C = 83.7/12(.0), H = 16.3/1(.0) **1**

M2 converting (C : H 6.975 : 16.3) to 3 : 7 **1**

M3 empirical formula = C_3H_7 **1**

M4 molecular formula = C_6H_{14} **1**

***M1** & **M2** are for working*

***M3** for C_3H_7 only, marked independently*

***M4** for C_6H_{14} only, marked independently (ignore additional correct structures)*

*Formulae with no working cannot score **M1** or **M2***

Alternative method:
***M1** working that shows 83.7% of 86 is 72*
***M2** idea of 72/12 gives 6 C atoms*

Alternative method:
*working that shows that C_6H_{14} (or C_3H_7) contains 83.7% C scores **M1** & **M2***

[9]