

**Q1.**

Which statement about catalysts used in reactions at equilibrium, at a constant temperature, is correct?

- A They are always used in the solid state.
- B They increase the rate of the forward reaction but decrease the rate of the reverse reaction.
- C They have no effect on the value of the equilibrium constant.
- D They make the forward reaction more exothermic.

(Total 1 mark)

Q2.

Which process does **not** involve a heterogeneous catalyst?

- A catalytic cracking of alkanes
- B Contact process
- C decomposition of ozone
- D Haber process

(Total 1 mark)

Q3.

This question is about catalysis.

- (a) Zeolites are used as heterogeneous catalysts in the catalytic cracking of alkanes.

Tetradecane ($C_{14}H_{30}$) can be cracked to form octane and a cycloalkane.

Give an equation for this reaction.

State the meaning of the term heterogeneous.

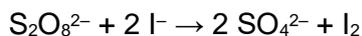
Equation

Heterogeneous _____

(2)



- (c) The reaction between peroxodisulfate ions and iodide ions in aqueous solution can be catalysed by Co^{2+} ions.



The table below gives relevant standard electrode potentials.

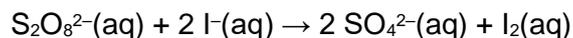
Electrode half-equation	E^\ominus / V
$\text{S}_2\text{O}_8^{2-}(\text{aq}) + 2 \text{e}^- \rightarrow 2 \text{SO}_4^{2-}(\text{aq})$	+2.01
$\text{Co}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{Co}^{2+}(\text{aq})$	+1.82
$\text{I}_2(\text{aq}) + 2 \text{e}^- \rightarrow 2 \text{I}^-(\text{aq})$	+0.54

Use the electrode potential data to suggest how Co^{2+} catalyses the reaction.

(3)
(Total 11 marks)



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



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 _____

Equation 1

Equation 2

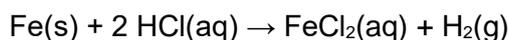
(4)

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

(1)



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



A 0.998 g sample of pure iron is added to 30.0 cm³ 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 m³, of hydrogen gas produced at 30 °C and 100 kPa.

Give your answer to 3 significant figures.

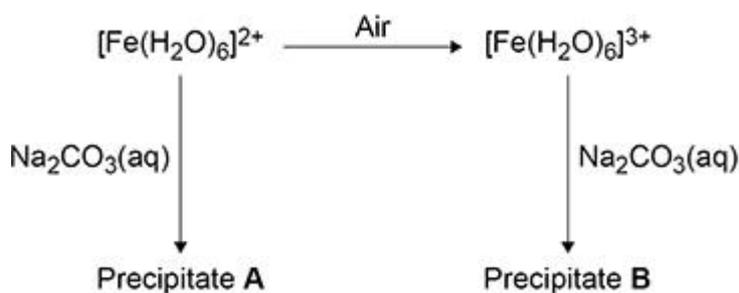
In your answer you should identify the limiting reagent in the reaction.

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

Volume of hydrogen _____ m³

(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 $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ with aqueous Na_2CO_3 to form **B**.

Formula _____

Colour _____

Ionic equation

(3)

- (g) Explain why an aqueous solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ions has a lower pH than an aqueous solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ ions.

(3)

(Total 25 marks)

Q5.

This question is about emissions of oxides of nitrogen from petrol and diesel engines.

- (a) Explain how oxides of nitrogen are formed in engines.

(2)



- (b) State why it is desirable to decrease emissions of oxides of nitrogen from vehicles.

(1)

- (c) Modern diesel vehicles use diesel exhaust fluids, such as AdBlue, to decrease emissions of oxides of nitrogen.

AdBlue reacts with water in the hot exhaust gases to form ammonia.

In the presence of a catalyst the ammonia reacts with oxides of nitrogen to form nitrogen and water.

Give the oxidation state of nitrogen in each of NO_2 , NH_3 and N_2

Complete the equation for the reaction between NO_2 and NH_3

Oxidation state of nitrogen in

NO_2 _____ NH_3 _____ N_2 _____

Equation

_____ NO_2 + _____ NH_3 → _____ N_2 + _____ H_2O

(2)

- (d) Petrol vehicles have a catalytic converter which decreases emissions of oxides of nitrogen.

Platinum in the catalytic converter acts as a heterogeneous catalyst.

State the meaning of the term heterogeneous catalyst.

(2)

- (e) Some carbon particulates are also formed in both diesel and petrol vehicles.

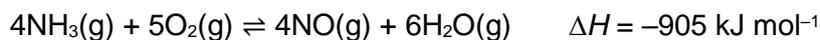
Explain why carbon particulates are formed.

(1)

(Total 8 marks)

**Q6.**

The equation for the reaction between ammonia and oxygen is shown.



Some standard entropies are given in the table.

Gas	$S^\ominus / \text{J K}^{-1} \text{ mol}^{-1}$
$\text{NH}_3(\text{g})$	193
$\text{O}_2(\text{g})$	205
$\text{NO}(\text{g})$	211
$\text{H}_2\text{O}(\text{g})$	189

- (a) Calculate the entropy change for the reaction between ammonia and oxygen.

Entropy change _____ $\text{J K}^{-1} \text{ mol}^{-1}$

(2)

- (b) Calculate a value for the Gibbs free-energy change (ΔG), in kJ mol^{-1} , for the reaction between ammonia and oxygen at 600°C

(If you were unable to obtain an answer to part (a), you should assume that the entropy change is $211 \text{ J K}^{-1} \text{ mol}^{-1}$. This is not the correct answer.)

ΔG _____ kJ mol^{-1}

(2)

**Q7.**

This question is about oxides.

- (a) Sodium oxide forms a solution with a higher pH than magnesium oxide when equal amounts, in moles, of each oxide are added separately to equal volumes of water.

State why both oxides form alkaline solutions.

Suggest why sodium oxide forms a solution with a higher pH than the solution formed from magnesium oxide.

(2)

- (b) Give an equation for the reaction between phosphorus(V) oxide and water.

(1)

- (c) In the Contact process, sulfur(IV) oxide is converted into sulfur(VI) oxide using vanadium(V) oxide as a catalyst.

Give **two** equations to show how the vanadium(V) oxide acts as a catalyst in this process.

Equation 1 _____

Equation 2 _____

(2)

(Total 5 marks)



Mark Scheme

Q1.

C

They have no effect on the value of the equilibrium constant.

[1]

Q2.

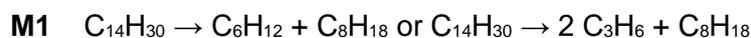
C

decomposition of ozone

[1]

Q3.

(a)



M1 *Allow any correct structural representation of tetradecane, octane, and a cycloalkane with formula C_6H_{12} OR C_3H_6*

1

M2 (catalyst is in) different phase/state (to reactants)

M2 *Assume that 'it' refers to the catalyst*

Allow to reactants and products

Not to products

1

(b)

M1 autocatalysis: product of the reaction catalyses the reaction

Not 'reactant'

1

M2 slow: negative ions repel / ions of same charge repel

1

M3 high E_a

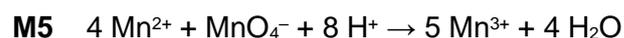
Allow *catalyst reduces E_a as an alternative for M3*

1

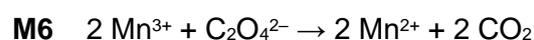
M4 attraction between oppositely charged ions / negative reactant ion(s) and positive catalyst / Mn^{2+} / Mn^{3+}

Not *catalyst reduces E_a as an alternative for M4*

1



1



Ignore *state symbols*

1

(c)

M1 idea of interchange between Co^{2+} and Co^{3+} and back to Co^{2+}

1

M2 $E_{ohbar}; S_2O_8^{2-} / SO_4^{2-} > E_{ohbar}; Co^{3+} / Co^{2+}$ and so $S_2O_8^{2-}$ ions oxidise Co^{2+}



or Co^{2+} reduce $\text{S}_2\text{O}_8^{2-}$

M2 alternatives

electrode potential for $\text{S}_2\text{O}_8^{2-}$ greater than Co^{3+} so $\text{S}_2\text{O}_8^{2-}$ ions oxidise Co^{2+}

or Co^{2+} ions reduce $\text{S}_2\text{O}_8^{2-}$

OR $2.01 \text{ (V)} > 1.82 \text{ (V)}$ so $\text{S}_2\text{O}_8^{2-}$ ions oxidise Co^{2+} or Co^{2+} ions reduce $\text{S}_2\text{O}_8^{2-}$

OR $2 \text{ Co}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2 \text{ Co}^{3+} + 2 \text{ SO}_4^{2-}$ $E_{\text{cell}} = (+)0.19 \text{ (V)}$

1

M3 $E^{\ominus}_{\text{ohbar}}; \text{Co}^{3+} / \text{Co}^{2+} > E^{\ominus}_{\text{ohbar}}; \text{I}_2 / \text{I}^-$ and so Co^{3+} ions oxidise I^- or I^- ions reduce Co^{3+}

M3 alternatives

electrode potential for Co^{3+} greater than I_2 so Co^{3+} ions oxidise I^- or I^- ions reduce Co^{3+}

OR $1.82 \text{ (V)} > 0.54 \text{ (V)}$ so Co^{3+} ions oxidise I^- or I^- ions reduce Co^{3+}

OR $2 \text{ Co}^{3+} + 2 \text{ I}^- \rightarrow 2 \text{ Co}^{2+} + \text{I}_2$ $E_{\text{cell}} = (+)1.28 \text{ (V)}$

1

for **M2** and **M3** **Allow** 1 mark (out of 2 marks) (if neither M2 or M3 already given) for combined:

Co^{2+} ions reduce $\text{S}_2\text{O}_8^{2-}$ **AND** Co^{3+} oxidises I^- ,

OR

$2 \text{ Co}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2 \text{ Co}^{3+} + 2 \text{ SO}_4^{2-}$ **AND**

$2 \text{ Co}^{3+} + 2 \text{ I}^- \rightarrow 2 \text{ Co}^{2+} + \text{I}_2$

Not if with negative E_{cell} value

Allow if incorrect positive E_{cell} values

[11]

Q4.

(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 1-2 marks	Two stages are covered but the description 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



	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



1

*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

Zn²⁺ is the only ion*Allow doesn't have variable oxidation state**Allow cannot be oxidised to Zn³⁺**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 H₂ produced = 0.0150 mol
M4 = M2 ÷ 2 1
- M5 T = 303 K P = 100 000 Pa 1
- M6 $V \left(= \frac{0.0150 \times 8.31 \times 303}{100\,000} \right) = 3.78 \times 10^{-4} \text{ (m}^3\text{)}$
M6 $V \left(= \frac{M4 \times 8.31 \times 303}{100\,000} \right) \text{ (m}^3\text{)}$ 1
- (e) FeCO₃ or iron(II) carbonate 1
 Green
Allow white 1
- (f) Fe(H₂O)₃(OH)₃ 1
Ignore square brackets if added 1
 brown 1
- $2 [\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 3 \text{CO}_3^{2-} \rightarrow 2 \text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3 + 3 \text{H}_2\text{O} + 3 \text{CO}_2$
Accept multiples 1
- (g) M1 Fe³⁺ is smaller (than Fe²⁺) **OR** Fe³⁺ has a greater charge **OR** Fe³⁺ has a greater charge density **OR** Fe³⁺ has a greater charge to size ratio
Penalise Fe(H₂O)₆³⁺ ions once in M1 or M2 1
- M2 Fe³⁺ ions are more polarising **OR** Fe³⁺ 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 Fe³⁺ solution)
Do not allow Fe³⁺ releases 3H⁺ ions 1

[25]

Q5.

- (a) **M1** reaction of nitrogen/N₂ and oxygen/O₂ from the air
Must be at least one reference to air.
NOT reference to nitrogen/oxygen from the fuel.
Allow equation plus a reference to the air.
Allow combustion of nitrogen plus reference to the air.
NOT M1 if reference to reaction taking place in the catalytic converter.



- 1
- M2** at high temperatures
Allow high energy/heat or very hot.
Allow heat/energy in the engine provides E_a
IGNORE references to pressure/spark
- 1
- (b) Formation of acid rain / causes respiratory problems
Allow (contributes to) ground level ozone / (photochemical) smog / toxic / poisonous
Allow makes water acidic / reacts with water to form nitric acid / (NO_x gases are) acidic
IGNORE greenhouse gases / global warming / damages ozone layer
IGNORE vague answers such as 'harmful to environment'/polluting/harmful
NOT reference to pH rising
- 1
- (c) **M1** $\text{NO}_2 = (+)4$ $\text{NH}_3 = -3$ $\text{N}_2 = 0$
- 1
- M2** $3\text{NO}_2 + 4\text{NH}_3 \rightarrow 7/2\text{N}_2 + 6\text{H}_2\text{O}$
ALLOW multiples/fractions
($6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}$ OR
 $1\frac{1}{2}\text{NO}_2 + 2\text{NH}_3 \rightarrow 1\frac{3}{4}\text{N}_2 + 3\text{H}_2\text{O}$)
- 1
- (d) **M1** Catalyst in different phase/state (to reactants)
*NOT (catalyst in different phase/state to) products allow catalyst in different phase/state to reactants **and** products*
- 1
- M2** Speeds up reaction without being used up
ALLOW speeds up the reaction by (providing alternative route for reaction and) lowering E_a
NOT does not take part in the reaction
- 1
- (e) incomplete combustion
ignore equations
ALLOW description of incomplete combustion (e.g. not enough oxygen)
Allow O_2 but NOT O for oxygen
- 1

[8]

Q6.

- (a)
- $(\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants}))$

$$= [(4 \times 211) + (6 \times 189)] - [(4 \times 193) + (5 \times 205)] = (1978 - 1797)$$

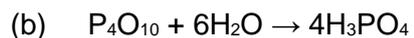
1



- 181 ($\text{J K}^{-1} \text{mol}^{-1}$) 1
- (b) ($\Delta G = \Delta H - T\Delta S$) = $-905 - (600 + 273) \times 181 \times 10^{-3}$
If answer to (a) is incorrect, mark consequentially:
 $-905 - (873 \times (a) \times 10^{-3})$ 1
- $\Delta G = -1063 / -1060$ (kJ mol^{-1})
 If alternative value of $\Delta S = 211$ used, answer = -1089 (kJ mol^{-1}) 1
- (c) ΔG becomes more negative/less positive
Ignore increase/decrease/larger/smaller ΔG 1
- The entropy change / ΔS is positive / $T\Delta S$ gets bigger / $-T\Delta S$ gets more negative.
Consequential on wrong (a)
If candidate does a calculation in (a) to produce ΔS negative then allow ΔG becomes less negative or more positive 1
- (d) Reactant(s) adsorbed onto the (platinum surface) / (platinum) provides a surface / active sites 1
- Reaction (on the surface) or bond breaking(weakening) / bond making occurs (on the surface) 1
- Desorption (of the product) or wtte 1
- (e) (Oxidation state changes from) -3 to $+2$ OR $(+)$ 5 1
- (f) $2\text{NH}_3 + 2\text{O}_2 \rightarrow \text{N}_2\text{O} + 3\text{H}_2\text{O}$
Allow multiples
Ignore state symbols 1
- [11]**

Q7.

- (a) **M1** (oxide ions react with water to) form/produce hydroxide **ions**
M1 $\text{O}^{2-} + \text{H}_2\text{O} \rightarrow 2\text{OH}^-$
Ignore all non-ionic equations 1
- M2** sodium hydroxide more soluble than magnesium hydroxide
M2 ideas that more sodium hydroxide dissolves / dissociates
 Allow sodium oxide more soluble / dissociates more than magnesium oxide NOT 'molecules' or 'atoms' 1

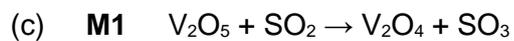


Allow multiples and fractions

Allow ionic products

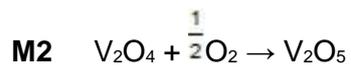
NOT P_2O_5

1



Allow 1 mark if both equations correct, but in wrong order

1



ALLOW multiples

1

[5]