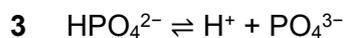
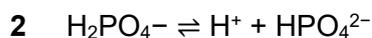
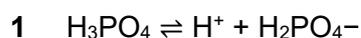


**1(a).** This question is about the chemistry of compounds containing phosphorus.

Phosphorus forms several acids including  $\text{H}_3\text{PO}_4$  and  $\text{H}_3\text{PO}_3$ .

$\text{H}_3\text{PO}_4$  is a tribasic acid. The equilibria for the dissociations are shown below.



i. During the equilibria,  $\text{H}_2\text{PO}_4^-$  behaves both as an acid and as a base.

Explain this statement, using the equilibria **1**, **2** and **3**, as required.

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-----**[2]**

ii. In a  $\text{H}_3\text{PO}_3$  molecule, the O atoms are covalently bonded to the P atom. The H atoms are bonded to the O atoms.

Draw the structure of a  $\text{H}_3\text{PO}_3$  molecule, showing all the bonds.

On your diagram, add the values for the O–P–O and P–O–H bond angles.

**[3]**

iii. The systematic name of  $\text{H}_3\text{PO}_4$  is phosphoric(V) acid.

What is the systematic name of  $\text{H}_3\text{PO}_3$ ?

-----**[1]**

**(b).** Phosphine,  $\text{PH}_3$ , is a poisonous gas.

i. Phosphine reacts with oxygen gas to form phosphorus(V) oxide and water.

Write the equation for this reaction.

-----**[1]**

- ii. Aqueous silver nitrate,  $\text{AgNO}_3$ , is reduced by  $\text{PH}_3$ .  
The unbalanced equation is shown below.

Balance the equation and use oxidation numbers to explain why this is a redox reaction.



Explanation \_\_\_\_\_

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----- [3]

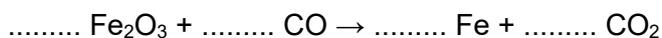
2. This question is about iron.

Iron can be extracted from iron ores containing the oxide  $\text{Fe}_2\text{O}_3$ .

- i. What is the systematic name for  $\text{Fe}_2\text{O}_3$ ?

----- [1]

- ii. Balance the equation for the reduction of  $\text{Fe}_2\text{O}_3$  with carbon monoxide.



[1]

3. Which reaction does **not** show disproportionation of chlorine?

- A**  $\text{MnO}_2 + 4\text{HCl} \rightarrow \text{MnCl}_2 + \text{Cl}_2 + 2\text{H}_2\text{O}$
- B**  $\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HCl} + \text{HClO}$
- C**  $2\text{ClO}_2 + 2\text{NaOH} \rightarrow \text{NaClO}_2 + \text{NaClO}_3 + \text{H}_2\text{O}$
- D**  $2\text{NaOH} + \text{Cl}_2 \rightarrow \text{NaCl} + \text{NaClO} + \text{H}_2\text{O}$

Your answer

[1]

**4(a).** This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.



**Reaction 16.1**

The table shows enthalpy changes of formation and entropies.

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	-188	110
$\text{H}_2\text{O}(\text{l})$	-286	70.0
$\text{O}_2(\text{g})$	0	205

i. Calculate the free-energy change,  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , of **Reaction 16.1** at  $25^\circ\text{C}$ .

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

$\Delta G = \dots\dots\dots \text{kJ mol}^{-1}$  **[4]**

ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at  $25^\circ\text{C}$  despite being feasible.

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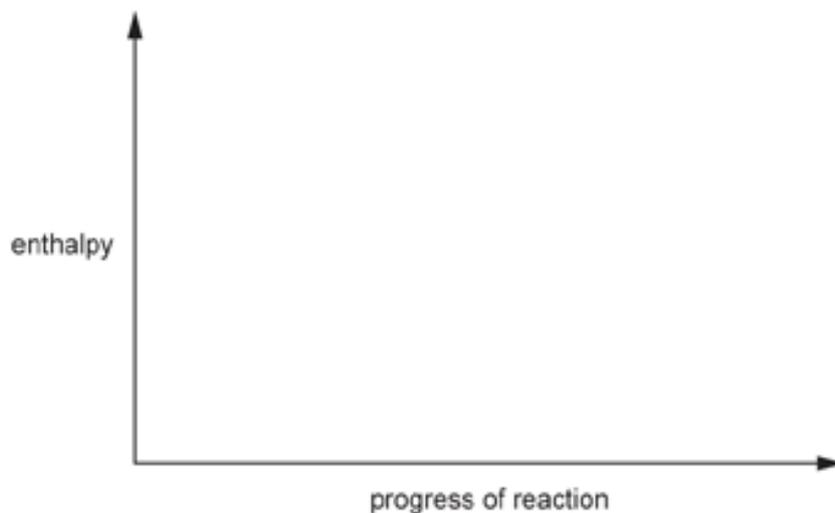
**[1]**

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide,  $\text{MnO}_2$ .

The  $\text{MnO}_2$  acts as a catalyst.

i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use  $E_a$  to label the activation energy **without**  $\text{MnO}_2$ .
- Use  $E_c$  to label the activation energy **with**  $\text{MnO}_2$ .
- Use  $\Delta H$  to label the enthalpy change of reaction.



[3]

ii. Explain why  $\text{MnO}_2$  is described as a **heterogeneous** catalyst for this reaction.

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[1]

iii.  $\text{Mn}_3\text{O}_4$  is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in  $\text{MnO}_2$ .

Suggest the two oxidation states of manganese in  $\text{Mn}_3\text{O}_4$ .

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[1]

5. Which equation does **not** represent a disproportionation reaction?

- A  $\text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HClO} + \text{HCl}$   
B  $\text{Cl}_2 + 2\text{NaOH} \rightarrow \text{NaClO} + \text{NaCl} + \text{H}_2\text{O}$   
C  $4\text{KClO}_3 \rightarrow \text{KCl} + 3\text{KClO}_4$   
D  $4\text{HCl} + \text{MnO}_2 \rightarrow \text{MnCl}_2 + \text{Cl}_2 + 2\text{H}_2\text{O}$

Your answer

[1]

6. The reaction between calcium and hydrochloric acid is a redox reaction.



**Equation 2.1**

- i. Explain, in terms of electron transfer, why the reaction shown in **equation 2.1** is a redox reaction.

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[2]

- ii. A student plans to add 0.0100 mol of Ca to 120 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> HCl (aq).

When the student carries out this reaction, they are surprised that all the calcium reacts, despite being in excess of the HCl(aq).

- Show by calculation that calcium is in excess of the HCl(aq).
- Suggest a reason for this unexpected result.

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[3]

7. These questions are from different areas of chemistry.

This question is about two salts of rubidium (atomic number 37):  $\text{RbClO}_3$  and  $\text{RbClO}_4$ .

- i. The oxidation number of chlorine is different in the two rubidium salts,  $\text{RbClO}_3$  and  $\text{RbClO}_4$ .

What is the name of  $\text{RbClO}_4$ ?

----- [1]

- ii. A student carries out an experiment to determine the enthalpy change of solution of  $\text{RbClO}_3$  using the method below.

- A 2.00 g sample of solid  $\text{RbClO}_3$  is added to water in a well-insulated container.  
The initial temperature is 23.0 °C.  
The mixture is stirred until all the  $\text{RbClO}_3$  has dissolved.
- The final temperature is 21.5 °C.  
The final solution has a mass of 102 g.

Determine the enthalpy change of solution,  $\Delta_{\text{sol}} H$ , of  $\text{RbClO}_3$  in  $\text{kJ mol}^{-1}$ .

Assume that the specific heat capacity of the solution is the same as that of pure water.

$\Delta_{\text{sol}} H (\text{RbClO}_3) = \dots\dots\dots \text{kJ mol}^{-1}$  [3]

8. The equations show the electrode potentials of the half-cells used in a lithium-ion cell.

	$E^\circ / \text{V}$
$\text{Li}^+ + \text{e}^- \rightleftharpoons \text{Li}$	-3.04
$\text{Li}^+ + \text{CoO}_2 + \text{e}^- \rightleftharpoons \text{LiCoO}_2$	+1.16

Which statement is correct in a lithium-ion cell?

- A The cell potential is 2.88 V.
- B The reaction at the positive electrode is:  $\text{LiCoO}_2 \rightarrow \text{Li}^+ + \text{CoO}_2 + \text{e}^-$
- C The overall cell reaction is:  $\text{Li} + \text{CoO}_2 \rightarrow \text{LiCoO}_2$
- D The oxidation number of Co changes from +2 to +1.

Your answer

[1]

9. Which statement(s) is/are correct for the anti-cancer complex  $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ ?

- 1 It has bond angles of  $90^\circ$ .
  - 2 The oxidation number of Pt is +4.
  - 3 It forms both optical and *cis-trans* isomers.
- A 1, 2 and 3
  - B Only 1 and 2
  - C Only 2 and 3
  - D Only 1

Your answer

[1]

10. This question is about reactions involving acids.

Write equations for the reactions below. State symbols are **not** required.

- i. The reaction of copper(II) oxide with dilute hydrochloric acid.

----- [1]

- ii. The reaction of ammonium carbonate with dilute nitric acid.

----- [2]

11. Which substance has the lowest oxidation number for sulfur?

- A  $\text{Na}_2\text{SO}_4$
- B  $\text{S}_8$
- C  $\text{SF}_2$
- D  $\text{SO}_2$

Your answer

[1]

12. This question is about halogens and halogen compounds.

Chlorine reacts with calcium hydroxide to form  $\text{Ca}(\text{OCl})_2$ , which is the active ingredient in bleaching powder.



This is a disproportionation reaction.

State what is meant by **disproportionation** and use oxidation numbers to show that disproportionation has taken place.

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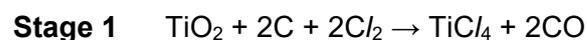
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[3]

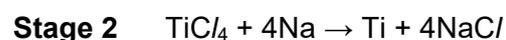
13. This question is about titanium (atomic number 22) and its compounds.

An ore of titanium contains impure  $\text{TiO}_2$ .

Titanium is manufactured from  $\text{TiO}_2$  in a two-stage process.



**Reaction 1.1**



**Reaction 1.2**

- i. The common name for  $\text{TiO}_2$  is titanium dioxide.

What is the systematic name of  $\text{TiO}_2$ ?

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[1]

- ii. In **Reaction 1.2**, the percentage yield of titanium from  $\text{TiCl}_4$  is 72.0%.

Calculate the minimum mass, in kg, of sodium that is needed to produce 1.00 kg of titanium.

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

mass of sodium = ..... kg **[4]**

- iii. **Reaction 1.2** produces a mixture of titanium and sodium chloride.

Suggest how titanium could be separated from this mixture at room temperature.

Explain your answer.

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..... **[2]**

**14.** This question is about compounds that contain the carboxylic acid functional group.

Carboxylic acids react with alkalis, metals and carbonates to form salts.

Write full equations for the following **three** reactions. Show structures for organic compounds.

- the reaction of propanoic acid with aqueous potassium hydroxide:
- the reaction of aqueous methanoic acid with magnesium:
- the reaction of the  $\alpha$ -amino acid, aspartic acid ( $\text{R}=\text{CH}_2\text{COOH}$ ), with an excess of aqueous sodium carbonate,  $\text{Na}_2\text{CO}_3$ :

**[4]**

15. This question is about different types of bonding.

'Oxyanions' are ions containing oxygen combined with atoms of other elements.

Roman numerals are used to show the oxidation state of the element in the oxyanion.

Complete the table below for three oxyanions.

One row has been completed as an example.

Name of oxyanion	Ionic charge	Formula of oxyanion
.....	1-	BrO <sub>2</sub> <sup>-</sup>
Sulfate(VI)	2-	SO <sub>4</sub> <sup>2-</sup>
Phosphate(V)	3-	.....

[2]

16. This question is about halogens and practical tests

Chlorine gas reacts with dilute sodium hydroxide, NaOH(aq). This is a disproportionation reaction. One of the products has the formula NaClO.

i. What is meant by the term **disproportionation**?

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[1]

ii. Construct the equation for the reaction of chlorine with dilute sodium hydroxide.

Use your equation to explain that disproportionation has taken place.

Equation .....

Explanation .....

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[3]

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

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

2

\_\_\_\_\_

\_\_\_\_\_

[1]

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

Oxidation half-equation: \_\_\_\_\_

Reduction half-equation: \_\_\_\_\_

[2]

18. This question is about some Group 2 elements and their compounds.

Strontium and calcium both react with water.

- i. Write an equation for the reaction of strontium with water.

\_\_\_\_\_

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[1]

- ii. Using oxidation numbers, explain why the reaction of strontium with water is a redox reaction.

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\_\_\_\_\_

\_\_\_\_\_

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[2]

- iii. Explain why calcium reacts more slowly with water than strontium does.

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\_\_\_\_\_

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[3]

19. Ammonia,  $\text{NH}_3$ , and ammonium nitrate,  $\text{NH}_4\text{NO}_3$ , are compounds of nitrogen.

- i. The boiling point of  $\text{NH}_3$  is  $-33\text{ }^\circ\text{C}$ .

The boiling point of  $\text{NH}_4\text{NO}_3$  is  $210\text{ }^\circ\text{C}$ .

Explain why there is a large difference in boiling points.

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----- [2]

- ii. Two students discuss the oxidation numbers in ammonium nitrate,  $\text{NH}_4\text{NO}_3$ .

One student claims that the two nitrogen atoms have the same oxidation number. The other student disagrees and claims that the nitrogen atoms have different oxidation numbers.

Explain with reasons which student is correct.

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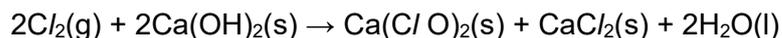
----- [1]

20. This question is about redox reactions.

'Calcium hypochlorite',  $\text{Ca}(\text{ClO})_2$ , is an ionic compound used in 'bleaching powder'.

The  $\text{ClO}^-$  ion in  $\text{Ca}(\text{ClO})_2$  is the active ingredient that kills bacteria.

Calcium hypochlorite is prepared by reacting chlorine gas with calcium hydroxide.



**Equation 2.1**

- i. 420 dm<sup>3</sup> of chlorine, measured at RTP, is reacted with an excess of Ca(OH)<sub>2</sub>.

The solid products are dissolved in water to form 4.00 m<sup>3</sup> of solution.

Calculate the concentration of Ca(ClO)<sub>2</sub>(aq) in this solution, in mol dm<sup>-3</sup>.

Give your answer to an **appropriate** number of significant figures and in standard form.

concentration = ..... mol dm<sup>-3</sup> **[3]**

- ii. Calcium hypochlorite, Ca(ClO)<sub>2</sub>, is heated. The Ca(ClO)<sub>2</sub> decomposes to form CaCl<sub>2</sub> and Ca(ClO<sub>3</sub>)<sub>2</sub>. This is a disproportionation reaction.

Write an equation for this decomposition and explain, using oxidation numbers, why this is a disproportionation reaction.

equation

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explanation

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..... **[3]**

**END OF QUESTION PAPER**