



VICTORIA JUNIOR COLLEGE  
JC 2 PRELIMINARY EXAMINATION  
Higher 2

CANDIDATE  
NAME .....

CT GROUP .....

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**CHEMISTRY**

**9729/02**

Paper 2 Structured Questions

**29 August 2025**

**2 hours**

Additional Materials: Data Booklet

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**READ THESE INSTRUCTIONS FIRST**

Write your name and CT group on this cover page.  
Write in dark blue or black pen on both sides of the paper.  
You may use a soft pencil for any diagrams, graphs or rough working.  
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer all questions in the spaces provided on the Question Paper.

A Data Booklet is provided.  
The use of an approved scientific calculator is expected, where appropriate.

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

For Examiner's Use	
<b>1</b>	<b>/ 18</b>
<b>2</b>	<b>/ 16</b>
<b>3</b>	<b>/ 17</b>
<b>4</b>	<b>/ 9</b>
<b>5</b>	<b>/ 15</b>
<b>Total</b>	<b>/ 75</b>

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This document consists of **19** printed pages and **1** blank page

Answer **all** the questions in the spaces provided.

1 Alkynes are a class of organic compounds with the general formula  $C_nH_{2n-2}$ .

- (a) (i) With the aid of a labelled diagram, explain how the orbitals overlap to form the  $C\equiv C$  bond in ethyne,  $H-C\equiv C-H$ .

.....

.....

.....

..... [3]

- (ii) Table 1.1 shows the carbon-hydrogen bond length in ethane, ethene and ethyne.

**Table 1.1**

Molecule	Carbon-hydrogen bond length / nm
ethane	0.114
ethene	0.109
ethyne	0.106

Use the concept of hybridisation to explain the difference in bond length of the carbon-hydrogen bond between the molecules as shown in Table 1.1.

.....

.....

.....

..... [2]

(b) Table 1.2 contains data that is relevant for this question.

**Table 1.2**

Equation	$\Delta H^\ominus / \text{kJ mol}^{-1}$
$3\text{C(s)} + \text{H}_2\text{O(l)} \rightarrow \text{CO(g)} + \text{C}_2\text{H}_2\text{(g)}$	+401
$2\text{C(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{CO(g)}$	-221
$2\text{H}_2\text{O(l)} \rightarrow 2\text{H}_2\text{(g)} + \text{O}_2\text{(g)}$	+572

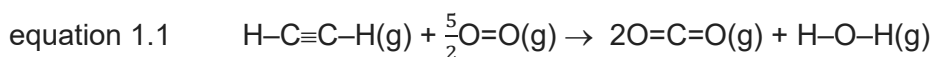
(i) Write an equation to represent the standard enthalpy change of formation of  $\text{C}_2\text{H}_2\text{(g)}$ .

..... [1]

(ii) Use data from Table 1.2 to calculate the standard enthalpy change of formation of  $\text{C}_2\text{H}_2\text{(g)}$ .

[2]

- (c) (i) Using the bond energies in the *Data Booklet*, calculate the enthalpy change of combustion of ethyne shown in equation 1.1.



[2]

- (ii) The entropy change of combustion of ethyne is  $-2150 \text{ J K}^{-1} \text{ mol}^{-1}$  at  $305^\circ\text{C}$ .

Explain what is meant by the term *entropy*.

.....  
 ..... [1]

- (iii) With reference to equation 1.1, explain why the entropy change of combustion of ethyne has a negative sign.

.....  
 ..... [1]

- (d) Alkynes undergo similar reactions as alkenes. Ethyne can be reduced to ethane in a two-stage process using a transition metal as the *heterogeneous catalyst* as shown in Fig. 1.1.

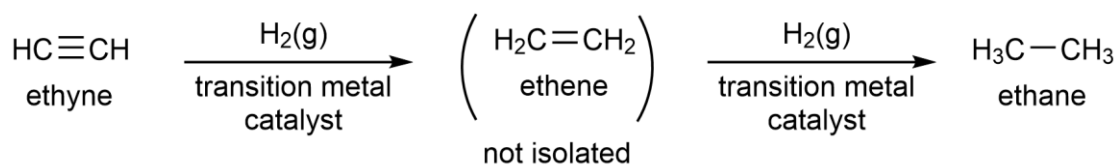


Fig. 1.1

The higher the activity of a catalyst, the more effective it is at catalysing the reaction.

Fig.1.2 shows the relative activity of each catalyst against  $\Delta H_{\text{ads}}$ , the enthalpy change of adsorption of hydrogen gas onto the catalyst surface in the reduction of alkyne.

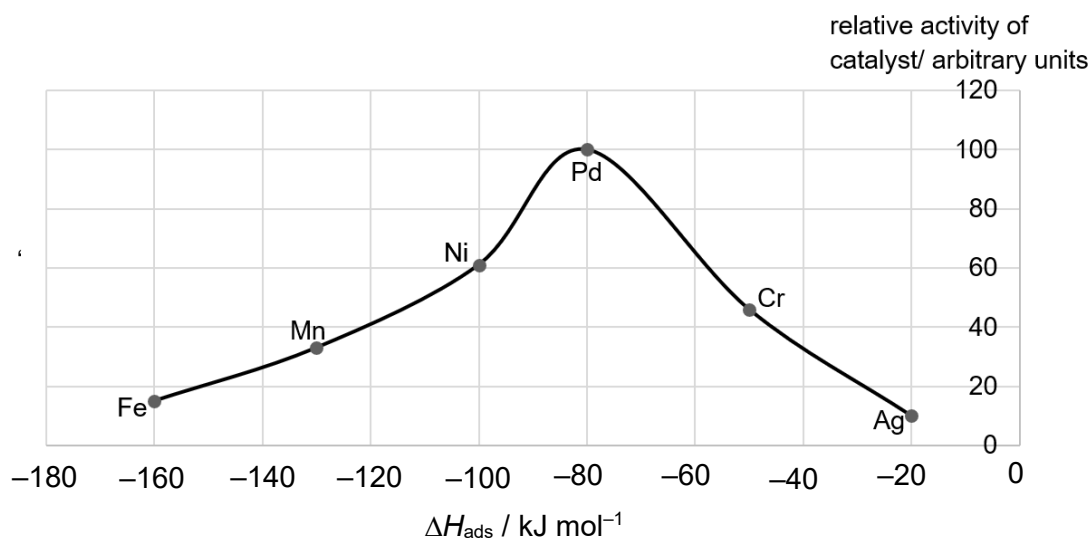


Fig. 1.2

- (i) State the meaning of the term *heterogenous catalyst*.

.....  
 .....  
 ..... [1]

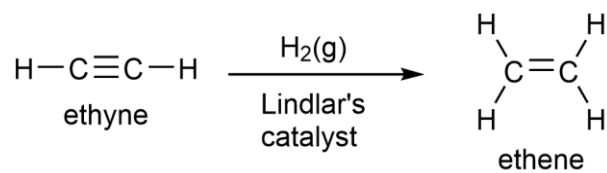
- (ii) State which catalyst is the most effective in the reduction of alkyne.

..... [1]

- (iii) Use your knowledge of the mode of action of heterogenous catalysts, suggest an explanation for the trend observed in Fig.1.2.

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

- (iv) In 1952, Herbert Lindlar found that adding a thin layer of impurity, such as lead(II) oxide, to palladium catalyst reduced its activity, allowing the reaction to stop at the alkene stage rather than reducing to the alkane as shown in Fig. 1.3.



**Fig. 1.3**

This is also known as “poisoning” the catalyst.

By considering the shape of the molecules in Fig.1.3, suggest how the addition of lead(II) oxide “poisons” the palladium catalyst.

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

[Total: 18]

**2** An aquatic system thrives on a delicate balance based on key chemical processes.

- (a)** Ammonia is the primary component of fish waste. When the concentration of ammonia in an aquatic system is too high, aquatic life is adversely affected.

Ammonia can be removed with oxygen, in the presence of nitrifying bacteria, to form nitrite,  $\text{NO}_2^-$ , and water.

- (i)** Write a balanced equation for the reaction of ammonia and oxygen.

..... [1]

- (ii)** Draw the dot-and-cross diagram of nitrite ion,  $\text{NO}_2^-$ .

[1]

- (iii)** Some  $\text{NO}_3^-$  ions may also be formed from ammonia by the action of nitrifying bacteria. Given that the shape of  $\text{NO}_3^-$  ion is trigonal planar, use VSEPR theory to explain the difference in the bond angles between  $\text{NO}_2^-$  and  $\text{NO}_3^-$  ion.

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

- (iv)** The ammonia levels in a  $50 \text{ dm}^3$  freshwater aquarium tank was investigated. It is found that the concentration of dissolved ammonia and oxygen in the tank were  $0.020 \text{ mol dm}^{-3}$  and  $0.030 \text{ mol dm}^{-3}$  respectively. Upon adding nitrifying bacteria, 50% of ammonia was converted to  $\text{NO}_2^-$  ions after one hour.

Use your answer to **(a)(i)** and the information given, determine the mass of  $\text{NO}_2^-$  ions formed.

[2]

- (b) Calcium and magnesium ions can be used to estimate the total dissolved solids (TDS) in an aquatic system. Different aquatic species require different TDS levels for optimal health and survival.

(i) Explain why calcium has a lower first ionisation energy than magnesium.

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

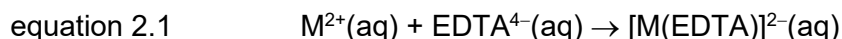
(ii) State two reasons why magnesium and calcium tend to form cations with +2 charge.

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

- (c) An aquarist wishes to determine the TDS in a freshwater aquarium. For this investigation, the TDS is taken to be the combined amount of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions, in mol, present in the water.

The ethylenediaminetetraacetate ion ( $\text{EDTA}^{4-}$ ) was used as a reagent to analyse a sample of tank water.

$\text{EDTA}^{4-}$  reacts with  $\text{M}^{2+}$  ions ( $\text{M}$  = metal) to form complexes according to equation 2.1.



A  $25.0 \text{ cm}^3$  sample of tank water was treated with an excess of  $50.0 \text{ cm}^3$  of  $0.0500 \text{ mol dm}^{-3}$   $\text{EDTA}^{4-}$  solution.  $10.0 \text{ cm}^3$  of the resulting reaction mixture then required  $19.40 \text{ cm}^3$  of  $0.0100 \text{ mol dm}^{-3}$  zinc nitrate solution to react completely with the unreacted  $\text{EDTA}^{4-}$  solution.

(i) Determine the TDS that were originally present in the  $25.0 \text{ cm}^3$  sample of tank water.

[3]



- (ii) A list of aquatic species is shown below in Table 2.1 with their recommended TDS ranges in ppm. (1 ppm = 1 g per 1000 dm<sup>3</sup> of water)

**Table 2.1**

Species	Recommended TDS Range (ppm)
Cherry Shrimp	150 – 350
African Cichlid	300 – 600
Guppy	700 – 1500
Mollies	1000 – 2800
Archerfish	1500 – 5000
Green Spotted Puffer	5000 – 15000
Marine Reef Tank (Clownfish + Corals)	30000 – 40000

Using your answer in **(d)(i)**, determine the TDS in ppm in the tank water and hence state the species that is best suited for the tank.

If you were unable to obtain the answer in **(d)(i)**, use  $1.50 \times 10^{-3}$  mol in your calculation. This is **not** the correct value.

Assume that the concentrations of Mg<sup>2+</sup> and Ca<sup>2+</sup> contributing to the TDS are in a 1:1 ratio.

Best suited species: .....

[3]

[Total: 16]

3 Pyruvic acid,  $\text{CH}_3\text{COCO}_2\text{H}$ , is an important intermediate in several metabolic pathways.

(a) A synthetic pathway involving pyruvic acid and other organic compounds is shown in Fig. 3.1.

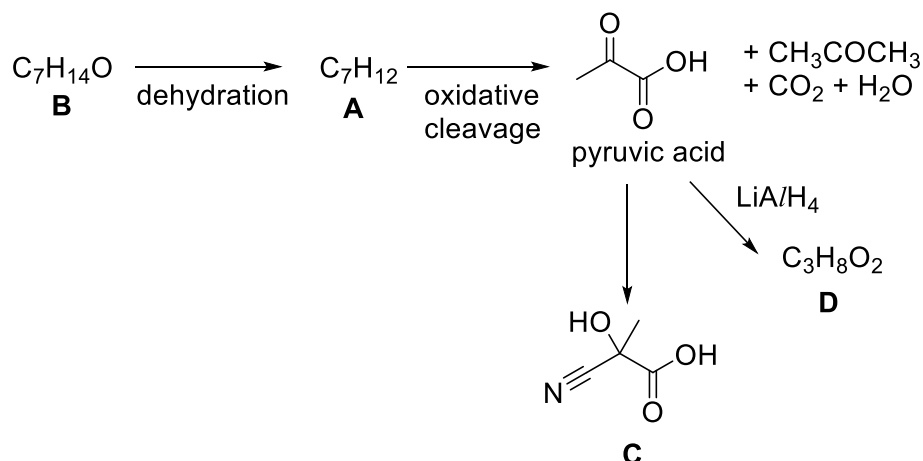


Fig. 3.1

(i) Suggest two possible structures of **A**.

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[2]

(ii) **B** is non-chiral and does not react with acidified  $\text{K}_2\text{Cr}_2\text{O}_7$ .

Use your answer in (a)(i), suggest a structure for **B**.

[1]

(iii) Name the type of reaction, and state the reagents and conditions, for the conversion of pyruvic acid to **C**.

Type of reaction: .....

Reagents and conditions: .....

[2]

(iv) State and explain whether **C** synthesised from pyruvic acid is optically active.

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

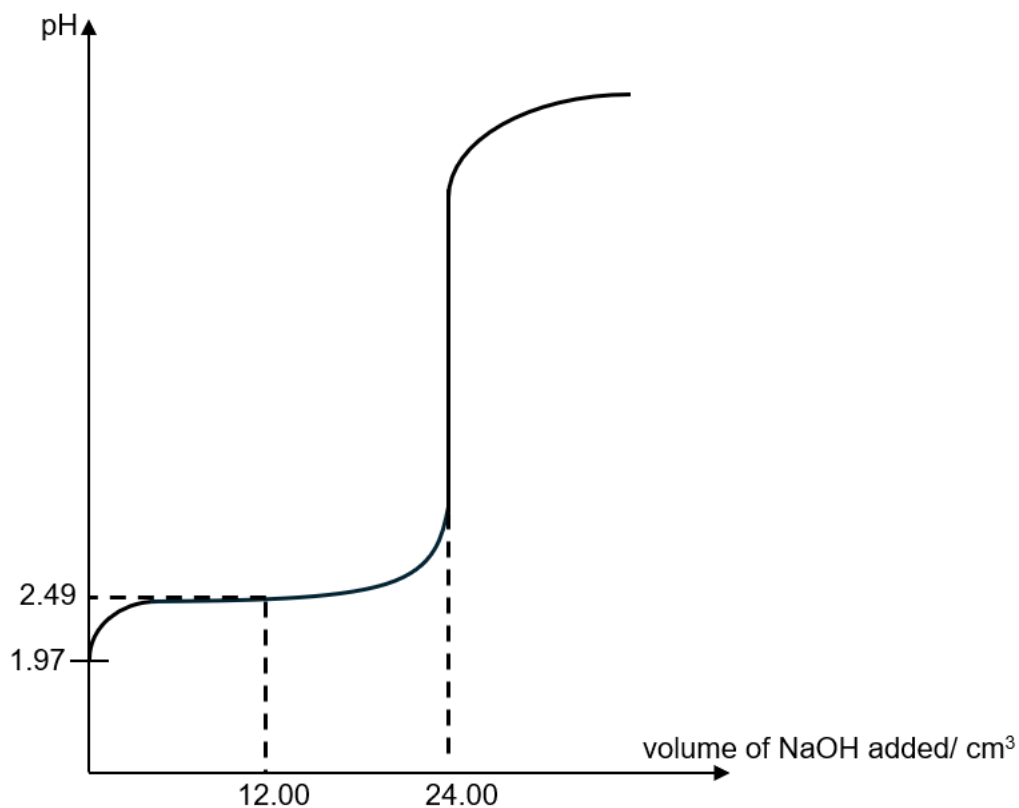
(v) When pyruvic acid reacts with  $\text{LiAlH}_4$ , **D** is produced.

Name **D**.

..... [1]

(b) Pyruvic acid behaves as a weak *Brønsted–Lowry acid* in water.

Fig 3.2 shows the pH curve when aqueous pyruvic acid was titrated with aqueous sodium hydroxide. The equivalence point was reached when  $24.00\text{ cm}^3$  of aqueous sodium hydroxide had been added.



**Fig. 3.2**

(i) Define the term *Brønsted–Lowry acid*.

..... [1]

(ii) Calculate the acid dissociation constant,  $K_a$ , of pyruvic acid.

[1]

(iii) Calculate the concentration of aqueous pyruvic acid.

[2]

(iv) Explain, with the aid of an equation, why pH at the equivalent point is more than 7.

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

(v) Use your value of  $K_a$  calculated in (b)(ii) to determine the pH of the solution when 0.300 g of solid sodium hydroxide is dissolved in 500 cm<sup>3</sup> of 0.080 mol dm<sup>-3</sup> aqueous pyruvic acid.

If you were unable to obtain a value of  $K_a$  in (b)(ii), use  $K_a = 3.0 \times 10^{-3}$  mol dm<sup>-3</sup> in your calculation. This is **not** the correct value.

[3]

[Total: 17]

**[Turn over**

- 4 *p*-Coumaric acid,  $C_9H_8O_3$ , occurs in some fruits and is thought to help prevent the development of stomach cancer.

*p*-Coumaric acid is an aromatic organic compound with two substituents occupying positions 1 and 4 of the benzene ring. Four possible structures of *p*-coumaric acid are given in Fig. 4.1.

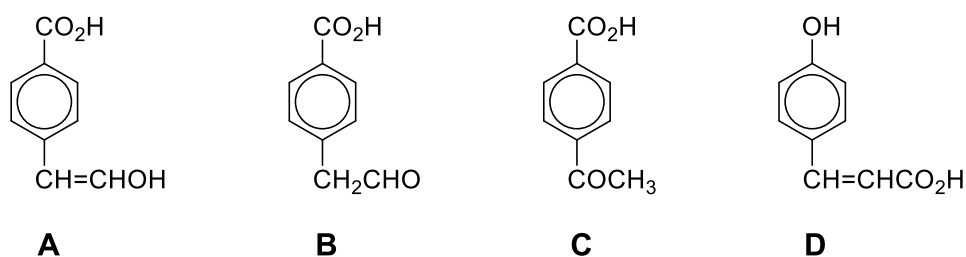


Fig. 4.1

- (a) A series of tests are carried out on *p*-coumaric acid. Table 4.1 shows the compound formed, when *p*-coumaric is added to different reagents under specific conditions.

- (i) Complete the last column of Table 4.1 by using **only** the letters **A**, **B**, **C** or **D** to represent structures in Fig. 4.1 that give the results as described in each test.

Table 4.1

test	reagents and conditions	compound formed	possible compound(s)
1	Tollens' reagent	no reaction	
2	2,4-dinitrophenylhydrazine	no reaction	
3	HBr	$C_9H_9O_3Br$	
4	Na	$C_9H_6O_3Na_2$	
5	NaOH(aq)	$C_9H_6O_3Na_2$	

[5]

- (ii) One of the tests in Table 4.1 confirms the structure of *p*-coumaric acid.

Suggest the structural formula of the product formed in this test.

[1]

- (b) When compounds **A**, **B** and **C** are heated separately under reflux with alkaline  $\text{KMnO}_4$ , the same compound is formed in each case.

Suggest the structure of this compound.

[1]

- (c) Draw the structures of the compound formed when **A** and **D** are separately reacted with  $\text{Na}_2\text{CO}_3$ .

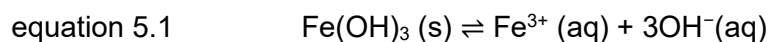
<b>A</b> produces	<b>D</b> produces

[2]

[Total: 9]

5 This question is about Fe and its compounds.

- (a) In human blood plasma under physiological condition of pH 7.4,  $\text{Fe}^{3+}$  has low solubility due to its tendency to form insoluble  $\text{Fe}(\text{OH})_3$ . The dissolution of  $\text{Fe}(\text{OH})_3$  is represented by the equation 5.1.



The solubility product of  $\text{Fe}(\text{OH})_3$  at 25 °C is  $2.6 \times 10^{-39} \text{ mol}^4 \text{ dm}^{-12}$ .

- (i) Write the expression for the solubility product of  $\text{Fe}(\text{OH})_3$ .

..... [1]

- (ii) Calculate the concentration of  $\text{Fe}^{3+}$  in blood plasma at 25 °C, assuming the pH remains constant at 7.4.

[2]

- (b)  $\text{Fe}^{2+}$  is able to form complexes with various ligands. Fig. 5.1 shows how the d orbitals of  $\text{Fe}^{2+}$  are split when the shape of the complex formed is octahedral.

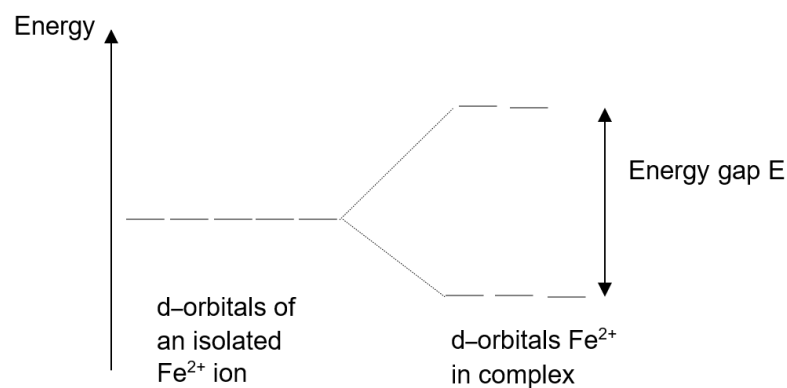


Fig. 5.1

- (i) State the full electronic configuration of  $\text{Fe}^{2+}$ .

..... [1]



- (ii) Using the axes below in Fig. 5.2, draw the shape of a 3d orbital of a higher energy level and of a lower energy level, in the octahedral  $\text{Fe}^{2+}$  complex.

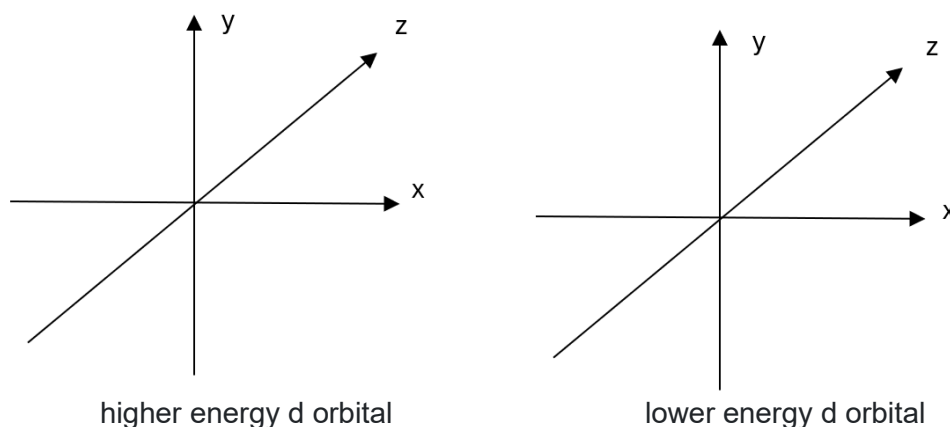


Fig. 5.2

[2]

- (c) Ligands can be classified as strong field or weak field. In an octahedral complex, strong field ligands are known to give rise to a larger energy gap  $E$  between the two sets of d orbitals as compared to weak field ligands.

Octahedral complexes can be classified as either high spin or low spin state.

In the high spin state, the electrons occupy all the d orbitals singly before starting to pair up in the lower energy d orbitals.

In the low spin state, the lower energy d orbitals are filled first, by pairing up, if necessary, before the higher energy d orbitals are used.

- (i) Using  $\uparrow$  or  $\downarrow$  to represent electrons, complete the two diagrams in Fig. 5.3 to show the electronic distribution of  $\text{Fe}^{2+}$  in a high spin and in a low spin state.

The energy axis is not drawn to scale, i.e.  $E_1 \neq E_2$ .

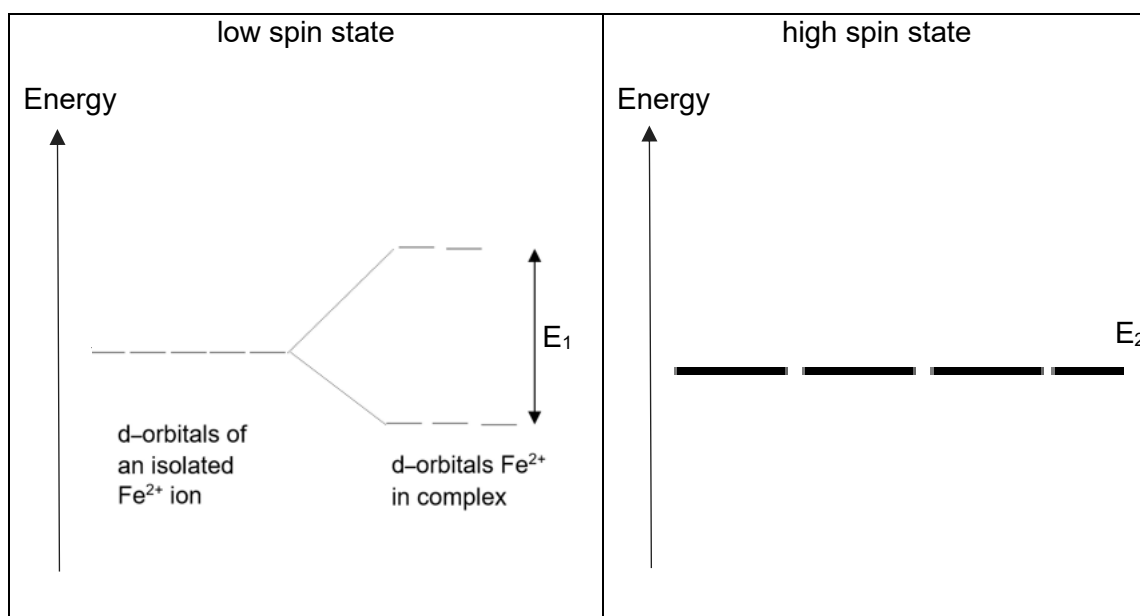


Fig. 5.3

[2]

- (ii) Suggest why electrons usually prefer to occupy orbitals singly, rather than in pairs.

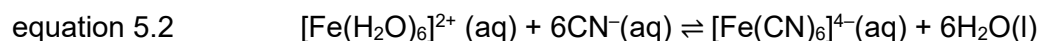
.....  
 ..... [1]

- (ii)  $\text{Fe}^{2+}$  in  $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$  has a high spin state while in  $[\text{Fe}(\text{CN})_6]^{4-}$  has a low spin state.

State and explain which of the above two complexes will contain the larger energy gap,  $E$ , between the d orbitals of  $\text{Fe}^{2+}$  and hence predict which is a strong field ligand.

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

- (d) The equilibrium constant,  $K_{\text{stab}}$ , measures the stability of a complex. For equation 5.2 below,



$$K_{\text{stab}} = \frac{[\text{Fe}(\text{CN})_6]^{4-}}{[\text{Fe}(\text{H}_2\text{O})_6]^{2+} [\text{CN}^{-}]^6}$$

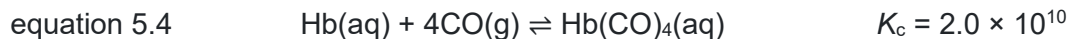
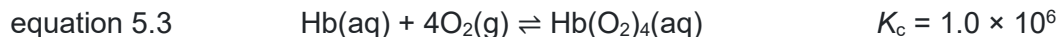
It is given that the  $\log_{10} K_{\text{stab}}$  values of  $[\text{Fe}(\text{CN})_6]^{4-}$  and  $[\text{FeF}_6]^{4-}$  are 35 and 15 respectively.

Using only the information above, explain which ligand is better able to stabilise  $\text{Fe}^{2+}$ .

.....  
 .....  
 ..... [1]

- (e) Haemoglobin (Hb) is a large protein complex that contains an  $\text{Fe}^{2+}$  centre that can bind to ligands such as  $\text{O}_2$  and  $\text{CO}$ . In the lungs,  $\text{O}_2$  binds to Hb to form oxyhaemoglobin,  $\text{Hb}(\text{O}_2)_4$  as shown in equation 5.3.  $\text{Hb}(\text{O}_2)_4$  is essential in transporting oxygen to the rest of the human body.

$\text{CO}$  competes with  $\text{O}_2$  in the lungs, binding with Hb to form carboxyhaemoglobin,  $\text{Hb}(\text{CO})_4$  as shown in equation 5.4.

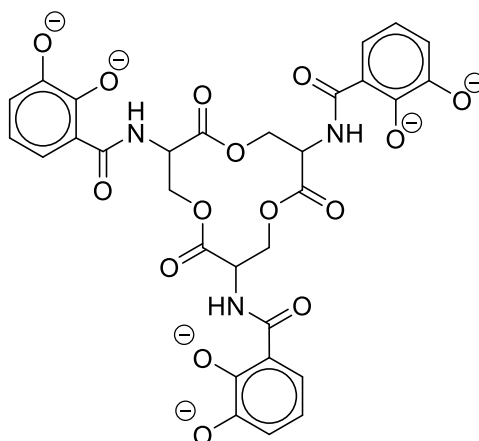


Use the above information to explain why exposure to carbon monoxide can be potentially life threatening.

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

- (f) Iron deficiency in bacterial cells trigger secretion of enterobactin, a hexadentate ligand, which combines with one  $\text{Fe}^{3+}$ . Enterobactin is a very strong field ligand and forms very stable  $\text{Fe}^{3+}$  complex with a  $K_{\text{stab}}$  value of approximately  $1 \times 10^{49}$ .

Fig. 5.4 shows the structure of the deprotonated form of enterobactin.



**Fig. 5.4**

Circle on the structure of the deprotonated form of enterobactin in Fig. 5.4 the six atoms that form bonds with  $\text{Fe}^{3+}$ . [1]

[Total: 15]

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