EXAM PAPERS PRACTICE

Boost your performance and confidence with these topic-based exam questions

Practice questions created by actual examiners and assessment experts

Detailed mark scheme

Suitable for all boards

Designed to test your ability and thoroughly prepare you

Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme

2002

XVIII

1583

Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

Mark Scheme

Answer 1.

a) A transition metal is:

- A metal / element which forms one or more stable ions with an incomplete / partially filled d-orbital / d-subshell; [1 mark]

[Total: 1 mark]

- Transition metal chemistry has several key terms that you need to be able to define, including transition metal / element

b)

i) The electronic configuration of Ti^{2+} is:

- $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2$
  OR
  $[Ar]3d^2$; [1 mark]

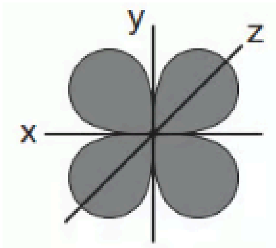
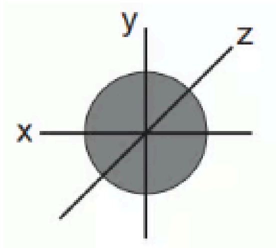
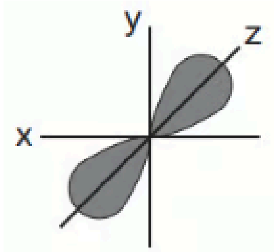
ii) Zinc is not classed as a transition metal because:

- Zinc(II) ion has a complete 3d subshell
  AND
  The electronic configuration of the zinc(II) ion is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$; [1 mark]

[Total: 2 marks]

- A transition metal is defined as an element that has an incomplete d subshell either in the element or in one of its ions, therefore:
  - Scandium(III) ion has no electrons in its d subshell
  - Zinc(II) ion has the electronic configuration of $[Ar]3d^{10}$, meaning the d subshell is complete and is also not classified as a transition metal

c) The completed table is:

Shape of orbital			
Type of orbital	d; [1 mark]	s; [1 mark]	p; [1 mark]

[Total: 3 marks]

- You need to be able to identify and draw atomic orbitals
- You should be able to further identify:
  - The d orbital as d_{xy} as the lobes are in the xy-plane
  - The p orbital as p_z as the lobes are on the z-axis

d) Other properties of transition metals and their complexes are:

Any **two** of the following:

- Form complexes / complex ions; [1 mark]
- Variable oxidation states; [1 mark]
- Behave as catalysts; [1 mark]

[Total: 2 marks]

- You need to know the characteristic properties of transition metals
- Exam questions will often go into further detail about these characteristic properties

Answer 2.

a)

i) The full electronic configuration of a Cu atom and a Cu^{2+} ion:

- $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$; [1 mark]
- $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$; [1 mark]

ii) Four characteristic features of the chemistry of copper and its compounds:

- Variable oxidation state; [1 mark]
- Form coloured ions/compounds; [1 mark]
- Form complexes / complex ions; [1 mark]
- Act as catalysts; [1 mark]

[Total: 6 marks]

- For the copper atom 3d and 4s can be switched around
- **Remember:** Copper has an unusual configuration because of the stability of filled and half-filled sub-shells
- The characteristic features are common to all transition metals

b)

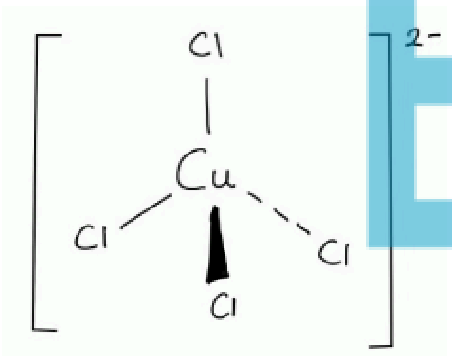
i) The term monodentate ligand means:

- A ligand that forms one coordinate bond / donates one lone pair of electrons to a metal atom or ion; [1 mark]

ii) The equation for the reaction when concentrated hydrochloric acid is added to $[Cu(H_2O)_6]^{2+}$ is:

- $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$; [1 mark]

iii) The structure of the complex ion its shape:



- Correct structure
  AND
  Correct charge; [1 mark]
- Tetrahedral shape; [1 mark]

iv) The change in coordination number is:

- 6 to 4; [1 mark]

[Total: 5 marks]

- Ligands all have at least one lone pair of electrons to form a coordinate bond
  - The term 'mono' specifically indicates that one lone pair of electrons are involved
- In the ligand substitution reaction, the six water ligands are replaced by four chloride ions
  - The original shape of the complex was octahedral due to the six bonding pairs to the water ligands
  - The shape of the complex formed with chloride ligands is tetrahedral as it has four bonding pairs of electrons around the central metal ion
  - As the chloride ion is larger than water a change in coordination number is observed

i) The overall equation for the reaction:

- $SO_2 + ½O_2 \rightarrow SO_3$
  OR
  $2SO_2 + O_2 \rightarrow 2SO_3$; [1 mark]

ii) V_2O_5 is a catalyst because:

- It takes part in the reaction but it is reformed / not used up; [1 mark]

iii) V_2O_5 is able to act as a catalyst in this reaction because:

- It has variable oxidation states; [1 mark]

[Total: 3 marks]

- To generate the overall reaction equation the two equations should be combined
  - $SO_2 + V_2O_5 + V_2O_4 + ½O_2 \rightarrow SO_3 + V_2O_4 + V_2O_5$
  - Anything present on both sides of the equation will cancel out - V_2O_5 and V_2O_4
- Catalysts speed up the rate of a reaction by providing an alternative pathway with lower activation energy - whilst they take part they are not used up, usually because they are regenerated
- Transition metals and their compounds have variable oxidation states which enable them to be catalysts

i) The full electronic configuration of an iron(II) ion:

- $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$; [1 mark]

ii) The shape, and the bond angle of the hexaaquairon(II) complex:

- Octahedral; [1 mark]
- 90°; [1 mark]

[Total: 3 marks]

- The iron(II) ion will have lost two electrons from the atom configuration, losing the two electrons from the 4s subshell
- The complex is octahedral as there are 6 bonding pairs of electrons around the central atom which repel each other equally
- The bond angle within an octahedral molecule is 90°

Answer 3.

a) Transition metals exhibit variable oxidation numbers in contrast to the elements in Group 1 as:

Transition metals:

- (Contain) d and s orbitals which are close in energy
  OR
  (Successive) ionisation energies increase gradually; [1 mark]

In Group 1 elements/ alkali metals:

- The second electron is removed from a (much) lower energy level
  OR
  The removal of the second electron requires a significant increase in ionisation energy; [1 mark]

[Total: 2 marks]

- You should be able to describe the ability of transition metals to form variable oxidation numbers in terms of successive ionisation energies
- This is in contrast to the s-block metals, which have only one fixed oxidation number
  - For example, calcium is an alkaline earth metal and occurs with a +2 oxidation number in its ion and compounds
  - In contrast, the transition metal titanium occurs with oxidation numbers of +2, +3, and +4

b) The completed table is:

ion	$[Cr(H_2O)_6]^{3+}$	$[Co(NH_3)_6]^{2+}$	$[Cr(OH)_6]^{3-}$	Mn_2O_3
oxidation number	+3; [1 mark]	+2; [1 mark]	+3; [1 mark]	+3 ; [1 mark]

[Total: 4 marks]

- You should be able to deduce the oxidation number of a transition element in a complex ion given the overall charge and ligands present
- **Careful:** Examiners will deduct often marks for writing 2+ rather than +2 for example
- For $[Cr(H_2O)_6]^{3+}$
  - $Cr + (6 \times H_2O) = +3$
  - $Cr + (6 \times 0) = +3$
  - $Cr = +3$
- For $[Co(NH_3)_6]^{2+}$
  - $Co + (6 \times NH_3) = +2$
  - $Co + (6 \times 0) = +2$
  - $Co = +2$
- For $[Cr(OH)_6]^{3-}$
  - $Cr + (6 \times OH^-) = -3$
  - $Cr + (6 \times -1) = -3$
  - $Cr = +3$
- For Mn_2O_3
  - $(2 \times Mn) + (3 \times O) = 0$
  - $(2 \times Mn) + (3 \times -2) = 0$
  - $(2 \times Mn) + (-6) = 0$
  - $Mn = +3$

c)

i) The full electronic configuration for the metal ions are:

- $[Zn(H_2O)_6]^{2+}$: $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $(4s^0)$ $3d^{10}$; [1 mark]
- $[Co(H_2O)_6]^{2+}$: $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $(4s^0)$ $3d^7$; [1 mark]

ii) Zn is not classed a transition element because:

- It also forms only one ion, Zn^{2+}
  OR
  Zn^{2+} ion has a complete 3d subshell; [1 mark]

[Total: 3 marks]

- Remember
  - When writing the **full** electronic configuration you must not use [Ar]
  - The 4s shell not only fills up first, but also empties first
- Even though zinc forms a 2+ ion, it is not classed as a transition element
- This is because it can only form one ion and the 3d shell is full, not partially full

Answer 4.

a) The completed table should look as follows:

Ion	$[Cu(Cl_4)]^{2-}$	$[Fe(H_2O)_6]^{3+}$	$Cr_2O_7^{2-}$
Oxidation state	+2; [1 mark]	+3; [1 mark]	+6; [1 mark]

[Total: 3 marks]

- You should be able to deduce the oxidation number of a transition element in a complex ion given the overall charge and ligands present
- Be careful as examiners will deduct often marks for writing 2+ rather than +2 for example
- For $Cr_2O_7^{2-}$
  - (2 x Cr) + (7 x O) = -2
  - (2 x Cr) + (7 x -2) = -2
  - (2 x Cr) + (-14) = -2
  - (2 x Cr) = +12
  - Cr = +6
- For $[Cu(Cl_4)]^{2-}$
  - Cu + (4 x C*l*) = -2
  - Cu + (4 x -1) = -2
  - Cu + (-4) = -2
  - Cu = +2
- For $[Fe(H_2O)_6]^{3+}$
  - Fe + (6 x H_2O) = +3
  - Fe + (6 x 0) = +3
  - Fe = +3

b)

i) The electron configuration of the manganese(III) ion in EUK-134 is:

- $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4$
  OR
  $[Ar]3d^4$; [1 mark]

ii) The name given to species that bond to a central metal ion and the type of bond present are:

- The name given is ligand; [1 mark]
- The type of bond present is dative / coordinate (covalent); [1 mark]

[Total: 3 marks]

- We are told in the question that EUK-134 is a complex ion of manganese (III)
- This means that manganese is in the +3 oxidation state
- The electron configuration of manganese is $[Ar]3d^5 4s^2$
- Both electrons are lost from the 4s orbital first then one electron from the 3d orbital
- The bond formed is a dative/coordinate bond as both the electrons in the bond come from the ligand

c) The two properties that are involved in EUK-134 rapidly decreasing the concentration of oxidising agents are:

- A variable oxidation state/number
  OR
  Acts as a reducing agent; [1 mark]
- Catalytic properties; [1 mark]

[Total: 2 marks]

- You should be able to apply the properties of transition metals rather than just memorising them
- Having a variable oxidation state allows transition elements to act as reducing agents in redox reactions with the oxidising agents mentioned above
- The catalytic properties of transition elements will allow EUK-134 to speed up the reaction and decrease the concentration of oxidising agents rapidly