



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



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) In terms of energy, degenerate orbitals are:

- Orbitals that are all at the same energy level

OR

Orbitals that are equal in energy; [1 mark]

[Total: 1 mark]

- Although this question is unlikely in an actual exam, you do need to not about degenerate and non-degenerate orbitals



EXAM PAPERS PRACTICE

Copyright

© 2024 Exam Papers Practice



b)

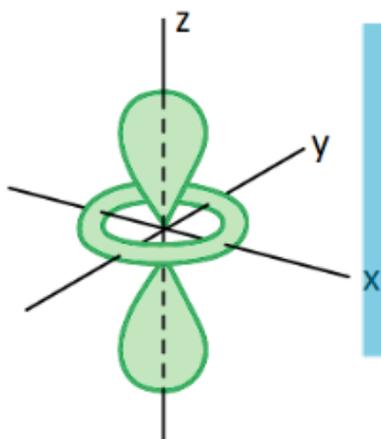
i) The difference between the shape of a d_{xy} orbital and the shape of a $d_{x^2-y^2}$ orbital is:

- The lobes of a d_{xy} orbital are between the x and y axes

AND

The lobes of a $d_{x^2-y^2}$ orbital are on the x and y axes; [1 mark]

ii) The three-dimensional diagram to show the shape of a d_{z^2} orbital is:



- Two lobes on the z-axis; [1 mark]
- Hoop / doughnut shape in the xy-plane; [1 mark]

[Total: 3 marks]

© 2024 Exam Papers Practice

- It is more common to be asked to draw the shapes of different orbitals or identify the orbital from a diagram
 - But, if you are able to describe the difference (as seen in part (i)), then you have a clear understanding of orbital shapes



c) The change of d-orbitals in a transition metal ion from degenerate orbitals to non-degenerate orbitals is caused by:

- Dative (covalent) / coordinate bonding to ligands

OR

Ligands causing the transition metal ion to not be isolated; [1 mark]

[Total: 1 mark]

- The splitting of degenerate d-orbitals into non-degenerate d-orbitals is caused by the dative covalent / coordinate bonding of a ligand
- The number / type / size of the ligand also affects how the degenerate d-orbitals split

d) The completed table is:

	Higher energy	Lower energy
Octahedral	$d_{x^2-y^2}$ AND d_{z^2}	d_{xy} AND d_{xz} AND d_{yz}
Tetrahedral	d_{xy} AND d_{xz} AND d_{yz}	$d_{x^2-y^2}$ AND d_{z^2}

- All d-orbitals correctly assigned for octahedral; [1 mark]
- All d-orbitals correctly assigned for tetrahedral;

[Total: 2 marks]

- You only need to remember the energy levels of either the octahedral non-degenerate d-orbitals or the tetrahedral non-degenerate d-orbitals because they are the opposite of each other



Answer 2.

a) A transition element is:

- (An element that can) form / has one or more stable ions with an incomplete d subshell; [1 mark]

[Total: 1 mark]

- This is a standard definition that you are required to know

b)

i) The term monodentate ligand means:

- (A species that can) form one dative / coordinate bond; [1 mark]
- That uses a lone pair of electrons to form a dative / coordinate bond to a (metal) atom / ion; [1 mark]

ii) The formula of this complex, including its charge is:

- $[\text{Ag}(\text{NH}_3)_2]^+$; [1 mark]

[Total: 3 marks]

- Monodentate ligands can form only one dative bond to the central metal ion
- Examples of monodentate ligands are:
 - Water (H_2O) molecules
 - Ammonia (NH_3) molecules
 - Chloride (Cl^-) ions
 - Cyanide (CN^-) ions
- If asked to draw the complex don't forget to show the coordinate bond by using arrows which point to the metal ion as this is the direction of donation
- You should also know examples of bidentate and polydentate ligands
- The most common examples of a linear complex are a copper (I) ion, (Cu^+), or a silver (I) ion, (Ag^+), as the central metal ion with two coordinate bonds formed to two ammonia ligands
 - They have a bond angle of 180° and have two coordinate bonds
- NH_3 does not have a charge, so the overall charge of the silver ion, Ag^+ , will remain



c)

i) The type of isomerism shown by these two complex ions is:

- Cis-trans

OR

Geometrical; [1 mark]

ii) These two complex ions are coloured and have different colours because:

- The d orbitals are split into 2 / different levels; [1 mark]
- (Colour is due to) absorption of light / photon (in the visible region); [1 mark]
- When an electron promotion / excited; [1 mark]
- The energy gap is different for the two complexes; [1 mark]

[Total: 5 marks]

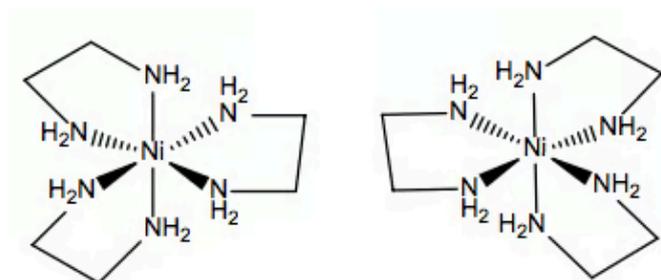
- $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$ can form two isomers
 - The dotted line represents the plane of the complex



- Part (ii) is a very common question and so it is worthwhile learning this thoroughly - the marking points will be the same!



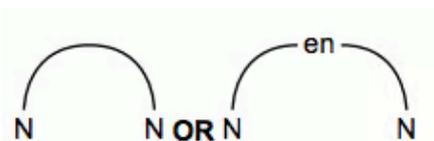
d) Three-dimensional diagrams to show the stereoisomers of $[\text{Ni}(\text{en})_3]^{2+}$ are:



- First structure correct; [1 mark]
- Second correct
AND
Mirror image of the first structure; [1 mark]

[Total: 2 marks]

- Ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ is a bidentate ligand and it can be drawn relatively simply
 - Each end of the molecule has an amine group with two carbon atoms in the middle
 - Bidentate ligands can each form two dative bonds to the central metal ion
 - This is because each ligand contains two atoms with lone pairs of electrons
 - Each NH_2 group can donate a lone pair of electrons to the central metal ion
- To make two different isomers when you have only bidentate ligands, simply draw the mirror image of one
 - This is optical isomerism
- You are also allowed to use en as a bidentate ligand (instead of $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$) as long as it correctly represented





- e)
- i) The amino groups in ethane-1,2-diamine allow the molecule to act as a Brønsted-Lowry base because:
- The nitrogen lone pair; [1 mark]
 - Accepts a proton / is a proton acceptor; [1 mark]
- ii) An equation for the reaction of ethane-1,2-diamine with an excess of hydrochloric acid is:
- $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 + 2\text{HCl} \rightarrow \text{ClH}_3\text{NCH}_2\text{CH}_2\text{NH}_3\text{Cl}$; [1 mark]

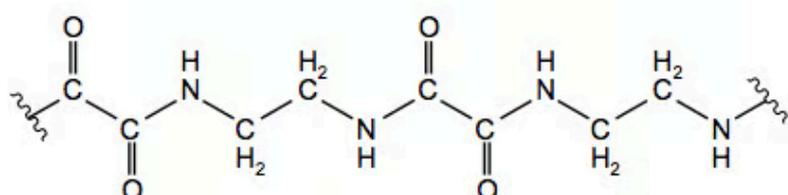
[Total: 3 marks]

- You need to know the definition of a Brønsted-Lowry acid and base and examples of each
 - Brønsted-Lowry acids donate a proton
 - Brønsted-Lowry bases accept a proton using its lone pair of electrons
- As ethane-1,2-diamine has two amine groups there are two places in which protons can be accepted
 - You can also use the ionic equation to score the mark
 - $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 + 2\text{H}^+ \rightarrow (\text{H}_3\text{NCH}_2\text{CH}_2\text{NH}_3)^{2+}$

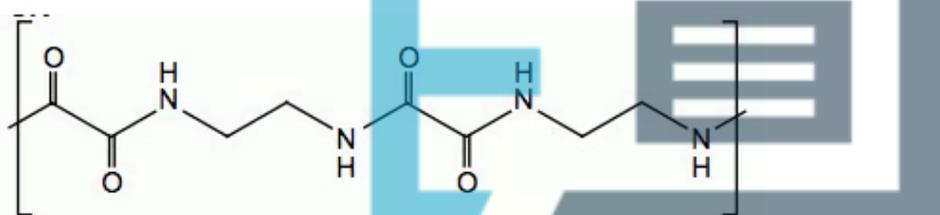


f)

i) The structure of polymer **Z**, showing two repeat units



OR



- Amide bond / CONH; [1 mark]
- Rest of the molecule with continuation bonds; [1 mark]

ii) The type of reaction occurring during this polymerisation is:

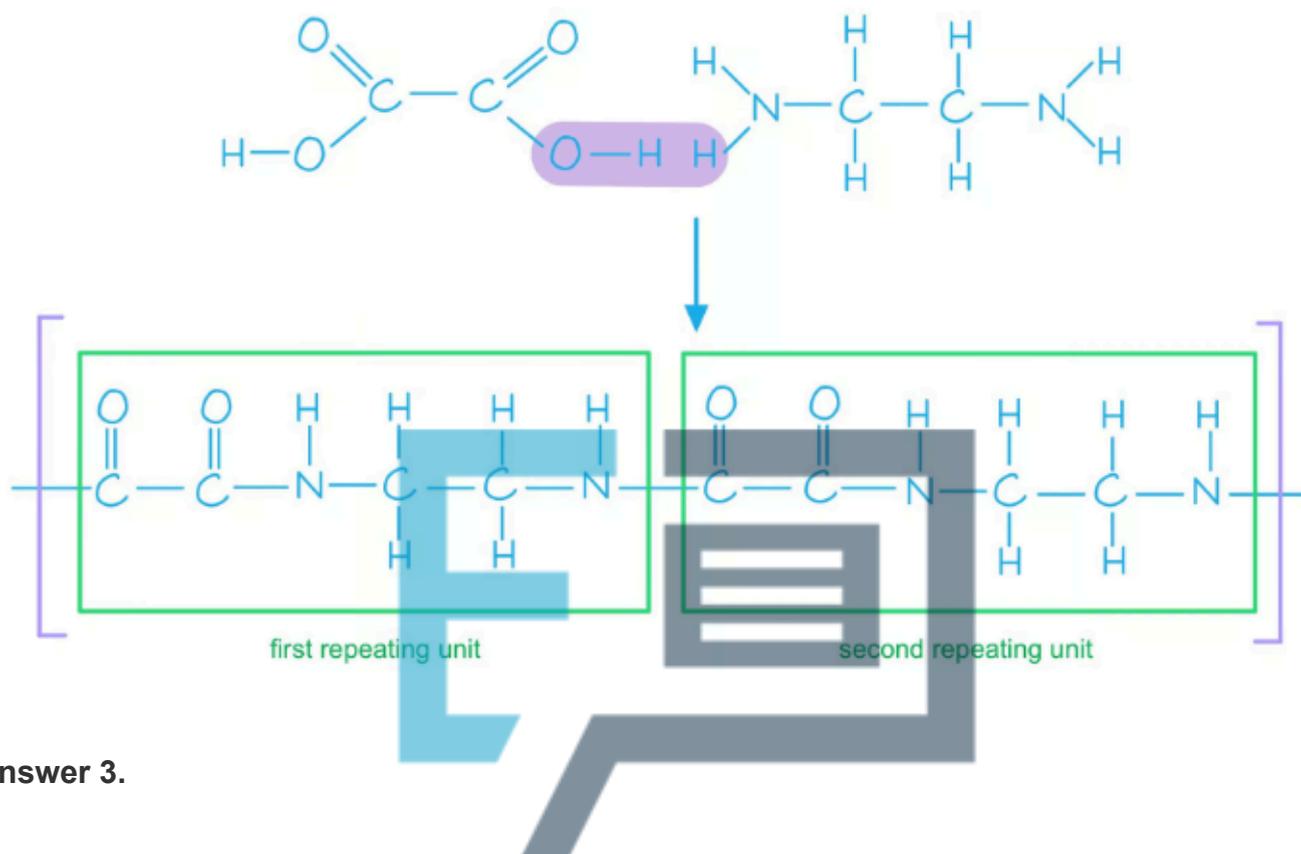
- Condensation; [1 mark]

[Total: 3 marks]

- Polyamides are also formed using **condensation** polymerisation
- We know the structure of ethane-1,2-diamine and ethanedioic acid so start by drawing these out
- You must show the correct amide link / bond and continuation bonds
- Double-check your polymer once you have drawn it as it is easy to miss out on the C=O, an H atom or even have an extra O atom in the polymer chain



EXAM PAPERS PRACTICE



Answer 3.

EXAM PAPERS PRACTICE

Copyright

© 2024 Exam Papers Practice



a) Transition metals exhibit variable oxidation states 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 states in terms of successive ionisation energies
- This is in contrast to the s-block metals, which have only one fixed oxidation state
 - For example, calcium is an alkaline earth metal and occurs with a +2 oxidation state in its ion and compounds
 - In contrast, the transition metal titanium occurs with oxidation states of +2, +3, and +4

Copyright

© 2024 Exam Papers Practice



b) Complex ions such as $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ are coloured as:

Alternative 1:

- Ligands cause the splitting of 3d orbitals into two energy levels; [1 mark]
- Energy from visible light promotes an electron from a lower energy level to a higher energy level;

OR

Colour is due to an electron transition between (split) d orbitals; [1 mark]

- The energy absorbed is in the visible region of the spectrum

AND

(So) the complementary colour is expressed **OR** the colour is due to the remaining frequencies / wavelengths; [1 mark]

Alternative 2:

- Complexes have two sets of d orbital(s) of different energy

OR

d-orbitals split into two sets (of orbitals); [1 mark]

- Visible light is absorbed

AND

The complementary colour is observed; [1 mark]

- Electron(s) are promoted / excited to a higher (d-) orbital; [1 mark]

[Total: 3 marks]

© 2024 Exam Papers Practice

- Questions about the origins of colour in transition metal complexes are typically for these same three marks
- So, it is worth taking the time to learn these points



c)

i) Water can act as a ligand because:

- Water has a non-bonding / lone pair of electrons; [1 mark]
- (Which it) donates to the metal ion

OR

(Allows it to) form a co-ordinate / dative (covalent) bond with the metal ion; [1 mark]

ii) The shape of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ would be:

- Octahedral; [1 mark]

[Total: 3 marks]

- You should be able to describe what a ligand is and how it forms coordinate bonds within a complex ion
- A Lewis base is a species which can bond by donating a lone pair of electrons
 - We can describe ligands as Lewis bases
- Since $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ has 6 water ligands, its shape has to be octahedral to spread the co-ordinate / dative covalent bonds as far apart as possible

EXAM PAPERS PRACTICE

Copyright

© 2024 Exam Papers Practice



d) Solutions containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are coloured but solutions containing $[\text{Zn}(\text{H}_2\text{O})_4]^{2+}$ are not due to:

- In transition metal complexes the d orbitals / levels are split (into two levels of different energy); [1 mark]
- In cobalt, the d levels are partially filled
AND
In zinc, they are completely filled; [1 mark]
- Visible light is absorbed when electrons move from lower to higher energy levels / transition between d orbitals (in cobalt); [1 mark]
- Transmitted light is the complementary colour; [1 mark]

[Total: 4 marks]

- You should know that zinc is not a transition metal
 - It has a complete d-sublevel, $[\text{Ar}]3d^{10}4s^2$
 - Its ion, Zn^{2+} , has the electron configuration, $[\text{Ar}]3d^{10}$
- Zinc will, therefore, not display the properties associated with transition metals such as forming coloured compounds
 - Compounds of zinc(II) are usually colourless
 - Unless the ligands in the complex have a chromophore (group of atoms responsible for the absorption of electromagnetic radiation), which can absorb in the visible region of the electromagnetic spectrum

Copyright

© 2024 Exam Papers Practice



Answer 4.

a) $\text{Ni}^{2+}(\text{aq})$ is green but $\text{Sc}^{3+}(\text{aq})$ is colourless because:

- (The colour of transition elements is) due to partially filled / incomplete d sub-levels / orbitals; [1 mark]
- The d sub-level/orbitals is/are split ; [1 mark]
- $\text{Ni}^{2+}(\text{aq})$ has incomplete 3d sub-level / orbital

AND

$\text{Sc}^{3+}(\text{aq})$ has no 3d electrons / empty d sub-level; [1 mark]

[Total: 3 marks]

- You should know scandium is not a transition metal
 - It only forms one ion, Sc^{3+} , which has no electrons in the 3d subshell
 - It has the electronic configuration of [Ar]
- Scandium will, therefore, not display the properties associated with transition metals such as forming coloured compounds

b) Adding excess ammonia to aqueous copper(II) ions causes the shade of the blue colour to change as:

- The ligands cause splitting of d-orbitals

AND

The colour depends on the movement of electrons between the d orbitals; [1 mark]

- (Four of the) water ligands are replaced by ammonia ligands

AND

The splitting of orbitals depends on the ligand present; [1 mark]

- Ammonia ligands increase the splitting of the d orbitals

OR

Ammonia ligands cause a greater splitting than water ligands; [1 mark]

[Total: 3 marks]

- We must first recognise that the addition of ammonia will mean that water ligands in the copper(II) complex are replaced with ammonia ligands
- The question relies on understanding that the ligand present affects the colour of the transition metal complex
 - Different ligands cause different amounts of splitting of the d-orbitals

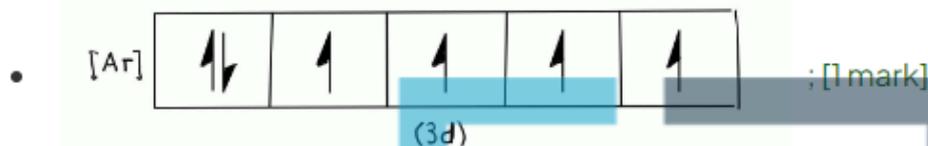


d)

i) The oxidation number of iron in $[\text{Fe}(\text{CN})_6]^{4-}$ is:

- +2; [1 mark]

ii) The abbreviated orbital diagram for the iron ion in $[\text{Fe}(\text{CN})_6]^{4-}$ should look as follows:



[Total: 2 marks]

- Iron will have an oxidation number of +2
 - $\text{Fe} + (6 \times \text{CN}) = -4$
 - $\text{Fe} + (6 \times -1) = -4$
- The abbreviated orbital diagram for iron will be:

EXAM PAPERS PRACTICE



Copyright

© 2024 Exam Papers Practice

- Iron will lose electrons from the 4s orbital
- As the question has asked for the abbreviated orbital diagram it is important to include [Ar] to show the noble gas configuration for part (ii)
- Full or half-arrows are acceptable for part (ii)
- The 3d label is not important for the mark in part (ii)