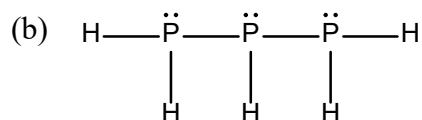
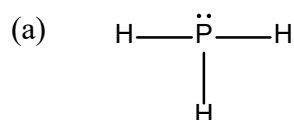


Answers to Practice Test Questions 12

Co-ordination Chemistry and Colour

Some explanations are longer than others. This is because they were real test questions out of different numbers of marks. More detail is expected for a 5 mark answer than for a 2 mark answer.

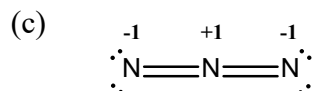
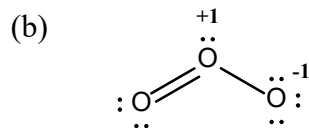
1.



- (c) They are good ligands because they are good Lewis bases. The lone pair on each phosphorus atom (an electron-rich atom that is not overly electronegative) can be donated to a transition metal in order to form a co-ordination complex.

2.

- (a) A monodentate ligand donates electrons to a transition metal cation through one atom. A bidentate ligand donates electrons to a transition metal cation through two atoms.



- (d) Ozone is bent, so it is possible for both terminal oxygen atoms to reach the same transition metal cation at the same time.

Azide is linear, so it is not possible for both terminal nitrogen atoms to reach the same transition metal cation at the same time.

3.

Formula	Oxidation State of Transition Metal
$MgK[Co(CO_3)_3]$	+3
$[Cr(H_2O)_2(NH_3)_4]^{3+}$	+3
$[NiBr_2(CN)_2]^{2-}$	+2
$[Cu(H_2O)_4]SO_4 \cdot H_2O$	+2

Approach:

1. Determine overall charge of complex ion (if counterions are present)
2. Determine charges of ligands
3. Total ligand charge + oxidation state of transition metal = overall charge of complex ion

e.g. $\text{MgK}[\text{Co}(\text{CO}_3)_3]$ consists of Mg^{2+} , K^+ , and $[\text{Co}(\text{CO}_3)_3]^{3-}$
carbonate is CO_3^{2-} therefore three carbonate ions contribute a total charge of -6
therefore $[\text{Co}(\text{CO}_3)_3]^{3-}$ consists of Co^{3+} and three CO_3^{2-}

e.g. $[\text{Cr}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{3+}$
water and ammonia are both neutral therefore the ligands contribute no charge
therefore $[\text{Cr}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{3+}$ consists of Cr^{3+} , two H_2O and four NH_3

e.g. $[\text{NiBr}_2(\text{CN})_2]^{2-}$
bromide is Br^- and cyanide is CN^- therefore the ligands contribute a total charge of -4
therefore $[\text{NiBr}_2(\text{CN})_2]^{2-}$ consists of Ni^{2+} , two Br^- and two CN^-

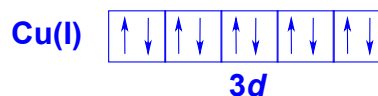
e.g. $[\text{Cu}(\text{H}_2\text{O})_4]\text{SO}_4 \cdot \text{H}_2\text{O}$ consists of $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$, SO_4^{2-} and H_2O
water is neutral therefore the ligands contribute no charge
therefore $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$ consists of Cu^{2+} and four H_2O

4.

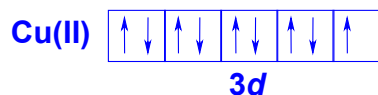
- | | |
|--------------------|-----------------|
| (a) iron (Fe) | (b) zinc (Zn) |
| (c) manganese (Mn) | (d) nickel (Ni) |

5.

(a) Cu(I) has electron configuration $[\text{Ar}]3d^{10}$.



Cu(II) has electron configuration $[\text{Ar}]3d^9$.



- (b) Cu(I) is diamagnetic (all electrons are spin paired)
Cu(II) is paramagnetic (not all electrons are spin paired; one is unpaired)
- (c) Cu(I) has a full d subshell, so its compounds are not expected to be particularly colourful.
Cu(II) has electron configuration $[\text{Ar}]3d^9$ so its valence d subshell is not full. Thus, coordination compounds of Cu(II) are expected to be coloured (most often, they are bright shades of blue).

The answer above would suffice for a 2 mark question, but it would not get full marks if it were a 5 mark question. See the answer to question 10(b) for the level of detail expected for 5-10 marks.

If this question were out of 5-10 marks, you should also include an explanation of how crystal field splitting leads to breaking the degeneracy of the 3d orbitals (i.e. splitting the 3d orbitals into “sets” with different energies). When an electron in a lower energy d orbital absorbs light, it is excited into a higher energy d orbital. Thus, the compound absorbs light of certain wavelengths “removing them” from the spectrum and making the compound appear to be a mixture of the remaining colours. (e.g. If red light is absorbed, the compound appears green-blue.)

Using diagrams in this type of explanation is always a good thing!



Both Lewis structures are valid and thiocyanate can donate electrons from either the sulfur atom or the nitrogen atom, depending on the complex being formed.

(b) SCN^- is linear therefore it must be monodentate. The linear geometry makes it impossible for both the sulfur atom and the nitrogen atom to donate electrons to the same transition metal cation at the same time.

(c) orange

447 nm light is blue. If a complex absorbs blue light, it will appear orange in colour since the perceived colour is a mix of those colours of light *not* absorbed.

7.

(a) +2

(b) $[\text{Ar}] 3d^6$

(c) 4

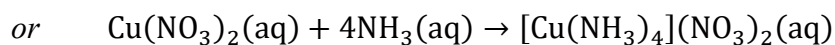
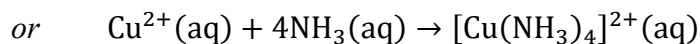
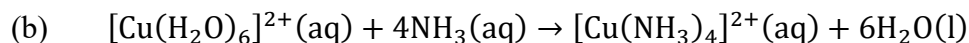
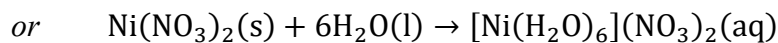
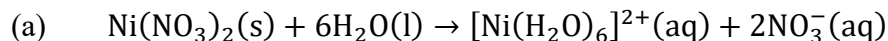
(d) trigonal planar

(e) a little smaller than 109.5°

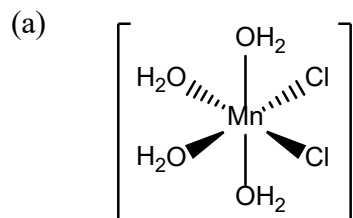
(f) No. Exchanging the position of any two of the co-ordinating atoms would give the same structure.

Tetrahedral atoms like the Fe shown here don't have cis- and trans- isomers. These compounds usually only have stereoisomers if all four groups attached to the tetrahedral atom are different.

8.



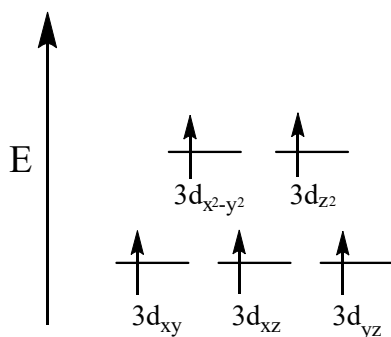
9.



(b) 6

(c) [Ar] 3d⁵

(d)



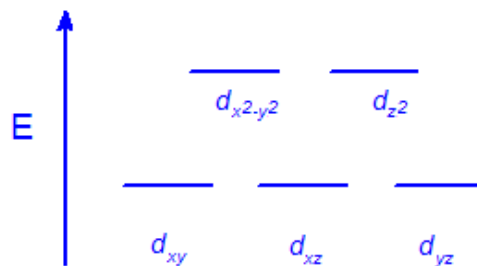
- (e) The 3d orbitals of Mn(II) do not all have the same energy as each other in this complex. An electron in one of the lower-energy 3d orbitals can absorb a photon of light and be excited into one of the higher-energy 3d orbitals. The colour of a complex is a combination of the colours of light not absorbed by it. If one colour is absorbed, the remaining colours will be transmitted and the complex will therefore appear to be the complementary colour of the absorbed light.

10.

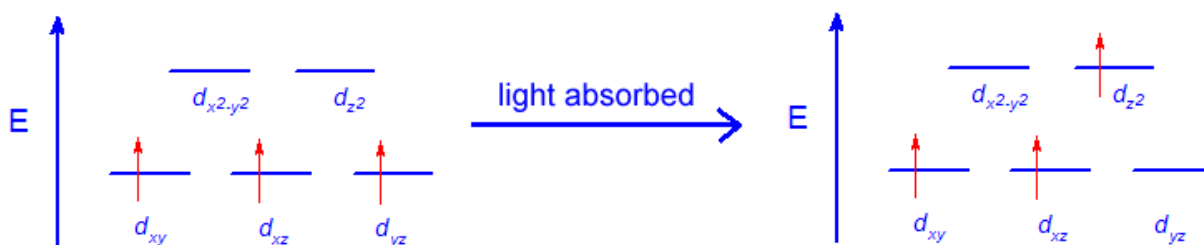
- (a) violet = chromium(III) sulfate
colourless = scandium(III) sulfate

(b) Sc³⁺ [Ne] 3s² 3p⁶ Cr³⁺ [Ar] 3d³
[Cr(OH₂)₆]³⁺ is coloured because Cr³⁺ has a partially filled 3d subshell.
[Sc(OH₂)₆]³⁺ is colourless because Sc³⁺ does not have a partially filled d (or f) subshell.

The ligands cause crystal field splitting, a phenomenon in which some d orbitals interact more strongly with the electrons of the ligands than others. This results in different energy levels for different d orbitals. In the case of a symmetric octahedral complex, the resulting energy levels are as follows:



The three 3d electrons in Cr^{3+} will each be in one of the three lower-energy 3d orbitals; however, when the complex absorbs a photon of light with energy equal to the difference between the lower- and upper- 3d energy levels, an electron is excited from a lower-energy 3d orbital into an upper-energy 3d orbital:



By absorbing one colour of visible light in this way (in this case, yellow light) and transmitting all other colours of light, the complex appears to be violet (the complementary colour of the yellow light absorbed).

Since Sc^{3+} has no 3d electrons, it does not absorb visible light, transmitting all colours of light and therefore appears colourless.

This is the 5-10 mark explanation.

Note that, if this much detail is expected, you will be given a lot of space for your answer! Probably close to a page! Don't try to squeeze this much detail into a 5cm space!

11.

(a) A yellow solution absorbs purple light.

A blue solution absorbs orange light.

Purple light is higher energy than orange light.

So, the yellow solution is absorbing higher energy light.

(b) The blue solution is absorbing lower energy light, so the gap between the lower energy and higher energy orbitals in the 3d subshell is smaller.

Therefore, the blue solution contains the complex with the weaker field ligand.

Therefore, the blue solution is $[\text{Co}(\text{H}_2\text{O})_6]^{3+}$.

12.

(a) i. isomer

ii. resonance structure

iii. neither

iv. isomer

(b) i. *trans*

ii. *trans*

iii. n/a

iv. *cis*