Chapter 25 – Answers to end of chapter questions

1  a A transition metal is a metal that forms one or more stable ions with a partially filled d sub-shell.

b Only iron which forms ions with partially filled d sub-shells

\[
\text{Fe}^{2+} = [\text{Ar}] 3d^6 \text{ and Fe}^{3+} = [\text{Ar}] 3d^5.
\]

The only stable ion of scandium is Sc\(^{3+}\) with the electron structure [Ar] and the only stable ion of zinc is Zn\(^{2+}\) – [Ar]3d\(^{10}\), neither of which have partially filled d sub-shells.

c The colour in compounds of the transition metals results from partially filled d sub-shells. In copper(I) compounds, the Cu\(^+\) ion has a filled 3d sub-shell, [Ar]3d\(^{10}\), and its compounds are white.

d Moving across a period of transition elements, electrons are being added to the same d sub-shell inside the s sub-shell of the next shell. The electrons are being added at roughly the same distance from the nucleus as the positive charge from protons in the nucleus increases. Therefore, the outermost electrons are pulled closer to the nucleus and the atomic radius decreases. This allows the atoms to pack closer and the density increases.

2  a [Cu(NH\(_3\))\(_4\)]\(^{2+}\) and [CuCl\(_4\)]\(^{-}\) are suitable examples.

b Both these ions are square planar.

c The Cu\(^{2+}\) ion in each case will have the electron structure [Ar]3d\(^9\). The NH\(_3\) and Cl\(^-\) donate electrons into the fourth shell for copper.

![Copper complex](image)

The donation from all four NH\(_3\) molecules and all four Cl\(^-\) ions are similar.

3  a Transition elements are filling up a d sub-shell of electrons. Elements in the main groups of the periodic table are filling up either an s sub-shell or a p sub-shell of electrons.

b Mn is [Ar]3d\(^5\)4s\(^2\) Mn forms stable oxidation states of +2 (loss of the two 4s electrons), +4 and +7 (loss/involvement of the two 4s electrons and the five 3d electrons).
c coloured compounds, Mn\(^{2+}\) compounds are pale pink, MnO\(_4^-\) is purple.
catalytic properties, MnO\(_2\) oxidises \(\text{H}_2\text{O}_2(\text{aq})\) to \(\text{H}_2\text{O} + \text{O}_2\)
complex ions, \([\text{Mn(H}_2\text{O)}_6]^{2+}\) – hexaaquamanganese(II),
MnO\(_4^-\) – tetraoxomanganate(VII).

4 a A complex ion is an ion in which a number of molecules or anions are bound to a
central metal ion by co-ordinate bonds.
b i A ligand is a molecule or anion bound to the central metal ion in a complex
ion by co-ordinate bonding.
ii \(\text{NH}_3\) and \(\text{H}_2\text{O}\) and \(\text{Cl}^-\)
c i 6
ii Octahedral
d i +3
ii +3
iii Neither oxidised nor reduced, since the oxidation number has remained the
same.
e Compound A cannot show cis-trans isomerism since it has five ligands of one type
and one ligand of another type. For a complex ion to show cis-trans isomerism there
must be two or more ligands of each type.

5 a C, D
b A, B, E, F
c Oxidation number of metal in A is +3.

Oxidation number of metal in B is +3.
d +3
e i B and D
ii
iii A – only has one Cl\(^-\) ligand. There need to be at least two ligands of each type for cis-trans isomerism to occur.

C and E – all ligands identical.

F – only has one SCN ligand. There need to be at least two ligands of each type of cis-trans isomerism to occur.

6 a 6

b There are six electron pairs around the central ion. In an octahedral arrangement the electron pairs are repelled as far apart as possible.

c i \(1s^2, 2s^22p^6, 3s^23p^63d^8, 4s^2\)

c ii \(1s^2, 2s^22p^6, 3s^23p^6, 3d^8\)

c iii In an isolated Ni\(^{2+}\) ion, the eight electrons are in degenerate 3d orbitals, all with the same energy level. In the complex ion, the 3d orbitals split into two energy levels. The colour results from the absorption of light energy as an electron moves between two non-degenerate 3d orbitals.

c iv The size of the energy gap between non-degenerate 3d orbitals depends on the nature of the surrounding ligands, as well as the metal ion. Since the two complex ions have different ligands, the energy gap in each is different. Light of a different frequency – and so different colour – is absorbed when an electron moves between two non-degenerate 3d orbitals in each of the complex ions.

d i

\[
\begin{array}{c}
\text{NC} \\
\text{Ni} \\
\text{CN}
\end{array}
\]

\[3^{-}\]

\[\begin{array}{c}
\text{NC} \\
\text{Ni} \\
\text{CN}
\end{array}\]

\[
\text{ii} \quad 120^\circ \text{ and } 90^\circ, \text{ as shown above.}
\]

7 a \([\text{Co(H}_2\text{O)}_6]^{2+}\)

b 6

c i 4

c ii The Cl\(^-\) ions are bigger than H\(_2\)O molecules, so fewer can be fitted into the space around the central Co\(^{2+}\) ion.
8  a  \( \text{Cl}^- \)
   b  \( \text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \)
   c  i  The compound shown is the trans isomer.

   ii

9  a  i  \([\text{Co(NH}_3\text{)}_5\text{Br}]^{2+}\text{SO}_4^{2-}\) will give \([\text{Co(NH}_3\text{)}_5\text{Br}]^{2+}(\text{aq})\) and \(\text{SO}_4^{2-}(\text{aq})\)
   \([\text{Co(NH}_3\text{)}_5\text{SO}_4\text{]}^{+}\text{Br}^-\) will give \([\text{Co(NH}_3\text{)}_5\text{SO}_4\text{]}^{+}(\text{aq})\) and \(\text{Br}^-(\text{aq})\)
   ii  Dissolve a little of each compound in water. One aqueous solution will give a
   white precipitate with \(\text{Ba(NO}_3\text{)}_2(\text{aq})\) showing that it contains free \(\text{SO}_4^{2-}(\text{aq})\).
   \(\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})\)
   white ppt.
   The other aqueous solution will give a pale yellow precipitate with \(\text{AgNO}_3(\text{aq})\)
   showing that it contains free \(\text{Br}^-(\text{aq})\).
   \(\text{Ag}^+(\text{aq}) + \text{Br}^-(\text{aq}) \rightarrow \text{AgBr}(\text{s})\)
   pale yellow ppt.
   iii  In each complex, the oxidation state of cobalt is 3+ and its co-ordination
   number is 6.
   iv

   Shape – octahedral; 6 co-ordinate bonds from the 5 \(\text{NH}_3\) molecules and the \(\text{Br}^-\) ion.
b  i Square planar – this structure can have cis–trans isomers. Tetrahedral could not have isomers.

ii

\[ \text{cis-isomer} \]

\[ \text{trans-isomer} \]

10  a  1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^3\) 3d\(^9\)

b  Cu\(^{2+}\) ions probably act as catalysts by being able to change oxidation state. Cu\(^{2+}\) ions are reduced to Cu\(^+\) ions in the first part of the reaction and then oxidised back to Cu\(^{2+}\).

c  i  Without Cu\(^{2+}\) ions, the catalysis process is impossible so the enzyme-protein alone has no catalytic activity.

ii  The enzyme-protein probably allows the reactant(s) to orient itself (themselves) in the ideal position for the reaction to occur. Without this steric help from the enzyme-protein, the reaction is much less efficient, but Cu\(^{2+}\) ions alone can catalyse the reaction.

iii  Egg albumen, being a protein, is able to form interactions with the reactant(s) similar to the enzyme-protein and this helps the Cu\(^{2+}\) ions to catalyse the reaction, though not as efficiently as the specific enzyme-protein.

11  a  4+ in all the compounds.

b  A is [Pt(NH\(_3\))\(_6\)]\(^{2+}\)(Cl\(^-\)); B is [Pt(NH\(_3\))\(_5\)Cl\(_3\)]\(^{2+}\)(Cl\(^-\));

C is [Pt(NH\(_3\))\(_4\)Cl\(_2\)]\(^{2+}\)(Cl\(^-\)); D is [Pt(NH\(_3\))\(_3\)Cl\(_3\)]\(^+\)Cl\(^-\);

E is [Pt(NH\(_3\))\(_2\)Cl\(_4\)].

c, d, e (Answers continue on the next page.)
12  a  \([\text{Ni(NH}_3\text{)}_5(\text{H}_2\text{O})]^{2+}(\text{aq}) + \text{NH}_3(\text{aq}) \rightarrow [\text{Ni(NH}_3\text{)}_6]^{2+}(\text{aq}) + \text{H}_2\text{O}(l)\)

b  \(K_1 = \frac{[\text{Ni(NH}_3\text{)}(\text{H}_2\text{O})_5]^{2+}[\text{H}_2\text{O}]}{[\text{Ni(H}_2\text{O})_6]^{2+}[\text{NH}_3]}\)

\(K_6 = \frac{[\text{Ni(NH}_3\text{)}_6]^{2+}[\text{H}_2\text{O}]}{[\text{Ni(NH}_3\text{)}_5(\text{H}_2\text{O})]^{2+}[\text{NH}_3]}\)

c  i  Since both \(K_1\) and \(K_6\) are both greater than 1, the complex ion product in each case is more stable than the complex ion reactant.

ii  The position of the equilibrium for step 6 lies less in favour of the products than the position of the equilibrium for step 1.