Lesson 13: Transition Metal Complexes

*Read through the lesson notes. You can write them out, print them or save them.

*Once you have tried to understand the lesson answer the questions that follow at the end.

*The answers to the question sheet(s) will be posted later and this will allow you to self-evaluate your learning.

Learning Intentions

-Learn how to name transition metal complexes.

-Learn to write the formula of transition metal complexes.

Background

In this lesson we build on the knowledge we gained about oxidation number/oxidation state. Together with the previous lesson about ligands we will learn about the names and formulae of transition metal complexes.

The previous lesson taught us that when ligands donate lone pairs of electrons to a transition metal they form a TRANSITION METAL COMPLEX. These are important group of chemicals as they have a wide variety of applications.

In a similar way to lesson 11, there is a set of rules which will help us to name transition metal complexes. The rules will at first glance appear difficult, however, with practice you will become confident and skilled at naming transition metal complexes and writing their formulae.

The rules are set out by the International Union of Pure and Applied Chemistry (IUPAC). There are a great number of rules, however, for Advanced Higher Chemistry the main ones are given below.

1. The symbol of the metal is written first, followed by the symbols of the ligands in alphabetical order according to which atom of the ligand binds. For water as a ligand, OH_2 is used, rather than H_2O, since it is the oxygen atom that binds to the metal. Similarly, for oxalate, $O_2C_2O_2$ is used in the formula, rather than C_2O_4.

2. The formula of the complex ion is enclosed within square brackets $\left[FeCl_2(OH_2)_4\right]^+$ with the charge outside the square brackets.

3. Ligands are named in alphabetical order followed by the name of the metal and its oxidation state. If there is more than one of a ligand it is preceded by the prefix for the number di, tri, tetra etc.

   A list of ligand names and their charges was given in lesson 12.

Ligand Name	Ligand Formula	Charge
aqua	OH_2	0
*ammine	NH_3	0
cyanido	CN^-	-1
chlorido	Cl^-	-1
fluorido	F^-	-1
bromido	Br^-	-1
iodido	I^-	-1
hydroxido	OH^-	-1
oxalato	$O_2C_2O_2$	-2

*ammine as a ligand has two m's

4. If the complex is a negative ion overall the name of the complex ends in -ate. Cobaltate would be for a negative ion containing cobalt. However for copper cuprate is used and for iron ferrate is used.

5. If the complex is a salt the name of the positive ion precedes the name of the negative ion.

Example 1

Give the name of the following transition metal complex.

$[Cu(NH_3)_4]^{2+}$ → Tetraamminecopper (II)

4 ammine ligands give prefix tetra

copper has +2 oxidation state as overall charge of complex is 2^+

Example 2

Give the name of the following transition metal complex.

$[Fe(CN)_6]^{3-}$ → Hexacyanidoferrate (III)

6 cyanido ligands give prefix hexa

Each cyanido ligand is -1, therefore oxidation state of Fe must be +3.

As complex is overall negative, don't use iron but ferrate.

Example 3

As well as having transition metal complexes, there are also salts of transition metal complexes. This involves an extra step when deciding the name of the overall salt.

$Na_2[FeCl_4]$ This is a salt of a transition metal complex. The two sodium ions indicate the first part to the salt and the square brackets indicate the transition metal complex part of the salt.

NaCl: In some respects it is similar to the simple salt, sodium chloride. It is made up of sodium ions and chloride ions. The only difference in example 3 is that instead of chloride ions you need to work out the name of the transition metal complex in square brackets and put the whole name together.

$Na_2[FeCl_4]$ ⟶ Sodium tetrachloridoferrate(II)

-This is a salt as it has sodium outside the complex part.

-The complex part (square brackets) is overall negative, therefore use ferrate and not iron.

-The entire salt is overall neutral:

4 chlorido ligands (-4) / Na_2 (+2)

Iron must have an oxidation state of +2 so use Roman numerals (II).

Example 4

$[Co(Cl)_2(NH_3)_4]Cl$ ⟶ Tetraamminedichloridocobalt(III) chloride

-This is a salt as it has chlorine outside the complex part.

-Ligands are named in alphabetical order, ammine before chlorido.

-Note that for the formula, Cl appears before NH_3 as C comes before N in the alphabet.

-The overall salt is neutral:

ammine ligand is neutral (0) / 3 x Cl in total (-3)
Co must be in an oxidation state of +3

-As complex part (inside square brackets) is positive, use cobalt and not cobaltate.

Example 5

Write the formula for the complex diaquadicyanidocuprate(I)

*For this example, we are working from the other direction, i.e. we have the name of the complex and we need to provide the formula.
Moreover, this example is a straight forward complex and NOT a salt as no metal appears before the complex or a non-metal after the name of the complex.

diaquadicyanidocuprate(I) → $[Cu(CN)_2(OH_2)_2]^-$

-cuprate → Cu (this also indicates that the complex is negatively charged).

-diaqua → $(OH_2)_2$ / dicyanido $(CN)_2$

-CN appears before OH_2 as C comes before O in the alphabet.

-Both OH_2 ligands are neutral in charge, the two CN ligands each carry a -1 charge i.e. -2 in total.

-Copper is in an oxidation state +1 as indicated by the Roman numeral (I).

-Overall charge of the complex is -2 +1 = -1 (written outside square brackets).

Example 6

Write the formula for the salt pentaammineoxalatotitanium(IV) chloride. In this example, we can see that we are dealing with a salt as we have the complex part followed by chloride.

pentaammineoxalatotitanium(IV) chloride → $[Ti(NH_3)_5\ O_2C_2O_2]\ Cl_2$

-titanium → Ti (this also indicates that the complex is positively charged).

-pentaammine → $(NH_3)_5$ / oxalato $O_2C_2O_2$

-NH_3 appears before $O_2C_2O_2$ as N comes before O in the alphabet.

-All five NH_3 ligands are neutral in charge, the $O_2C_2O_2$ ligand carries a -2 charge i.e. -2 in total.

-Titanium is in an oxidation state +4 as indicated by the Roman numeral (IV).

-Overall charge of the complex is -2 +4 = +2.

-If the complex part has a charge of +2 then there must be two chloride ions as this will make the salt overall neutral.

Additional Resources

-Watch the clip from East Renfrewshire videos

https://drive.google.com/file/d/167rOTxqG9znoTOAhqg93LB8ZhgaJ4ozt/view?usp=sharing

-Read Scholar Section 3.3.2

-Answer the questions from Sheets 1.16 and 1.17 and check the answers when you have completed them.

-If there are any questions regarding this lesson or the questions from sheets 1.16 1.17, then please leave a post on Microsoft Teams.

1.16 Transition Metal Complexes (I)

1. For each of the complexes below give the name of the compound and the coordination number of the metal in the complex

(a)	$[CoCl_4]^{2-}$	(b)	$[Ni(OH_2)_6]^{2+}$
(c)	$[Fe(CN)_6]^{4-}$	(d)	$[Ti(NH_3)_6]^{3+}$
(e)	$[NiCl_6]^{2-}$	(f)	$[CrCl_2(OH_2)_2]^{+}$
(g)	$[Cu(NH_3)_2(OH_2)_2]^{2+}$	(h)	$[CuCl(OH_2)_3]^{+}$

2. Name the following salts.

(a)	$K_4[Fe(CN)_6]$	(b)	$Na_2[Cu(CN)_3]$
(c)	$Li_2[TiCl_4]$	(d)	$Na_3[CoCl_6]$
(e)	$[FeCl_2(NH_3)_2]$ Cl	(f)	$[Cr(O_2C_2O_2)(OH_2)_5]$ Br

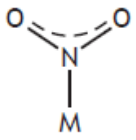
3. Give the formula of the following complexes and salts.

(a) hexaamminechromium(III)
(b) pentaaquachloridoiron(III)
(c) tetraamminedicyanidocobalt(III)
(d) pentaaquachloridonickel(III) bromide
(e) potassium diaqaudioxalatocuprate(I)
(f) sodium diaqautetrachloridotitaniumate(II)

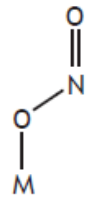
4. An atom forms a complex with eight d electrons can be written in shorthand as d^8.

(a) Using orbital box notation, show the arrangement of the d electrons.
(b) How many unpaired electrons are there in the d^8 complex?

5. The nitrite ion, NO_2^-, can bind to transition metal ions M^{3+}, in two different ways as shown.

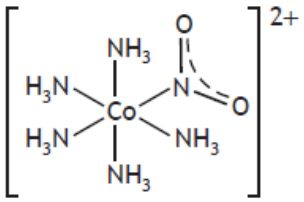


ligand name - nitro



ligand name - nitrito

Give the name and formula for the following complex.



1.17 Transition Metal Complexes (II)

1. The questions below relate to the complex ion $[Cu(CN)_4]^{3-}$.

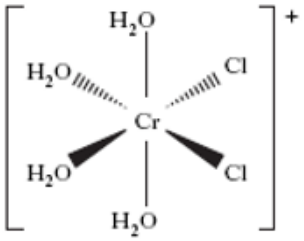
(a) What is the oxidation state of copper in the above ion?
(b) How many electrons occupy the 3d energy levels of copper in this complex ion?

2. A solution contains the complex ion $\left[CoCl_2(NH_3)_4\right]^+$

(a) What is the oxidation number of cobalt in this complex ion?
(b) Name this complex ion.
(c) Write down the electronic configuration of cobalt in this complex in terms of s, p and d orbitals.

3. Complex ions A and B are isomeric and have the formula $\left[CrCl_2(OH_2)_4\right]^+$

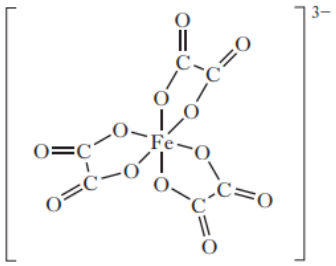
(a) Calculate the oxidation number of chromium in the complex.
(b) Name the complex ion.
(c) The structural formula of complex ion A is



Draw the structural formula of complex B.

(d) Give the shape that complex A adopts.

4. A student made the salt potassium trioxalatoferrate(III) as part of a project. The oxalate ligands bond to iron in the following way.



(a) To which class of ligands does oxalate belong?
(b) Write the formula for potassium trioxalatoferrate(III).
(c) Write down the electronic configuration of iron in this complex in terms of s, p and d orbitals.