Unit 18: Coordination Chemistry

Physical Properties

This worksheet will cover the physical properties of coordination complexes, including color and geometry. It will discuss the Crystal Field Theory, wavelength and energy, and the valence bond theory. As you progress through the worksheet, you will develop the skills necessary to determine the geometries of coordination complexes and ions and utilize the relationship between the Crystal Field Theory and complex ligands.

Practice Problems:

1. How does Crystal Field Theory explain the color of coordination complexes, and what factors influence the observed colors?

2. The _______ (greater/smaller) the charge on the metal, the stronger the splitting. Explain your choice.

3. Compounds of copper (II) are generally colored, but compounds of copper (I) are not. Explain.

4. An octahedral metal complex absorbs light with a wavelength of 530 nm. What is the crystal field splitting Δ_o for the complex? What color is it to the eye?

5. Explain the concept of coordination number in the context of coordination complex geometry.

6. Determine the coordination number and geometries around each of the following complexes.

a. $[Cu(CN)_3]^{2-}$

b. $[Ni(H_2O)_6]Cl_2$

c. $[CoCl_6]^{3-}$

ANSWER KEY

Practice Problems:

1. How does Crystal Field Theory explain the color of coordination complexes, and what factors influence the observed colors?

The Crystal Field Theory explains the splitting of d orbitals in coordination complexes by considering the interaction between metals ions and ligands. When ligands approach the central metal ion, the degenerate d orbitals of the metal atom split into higher energy and lower energy sets. This is due to the repulsion between the ligands' electrons and those in the metal's d orbitals. Δ_o refers to the energy required to promote electrons from the lower energy orbitals to the high energy orbitals. The energy (photons) absorbed or emitted during electronic transitions between these energy levels determines the color of the complex. If a complex absorbs a particular color, it will have the appearance of the color opposite it on a color wheel.

2. The _greater_ (greater/smaller) the charge on the metal, the stronger the splitting. Explain your choice.

When ligands approach the metal ion, repulsion occurs between the electrons in the ligands and the electrons in the metal's d orbitals. The magnitude of the electrostatic repulsion is related to the charge on the metal ion. A higher positive charge on the metal results in a stronger electrostatic interaction between the metal atom and the ligands (which are donating electron pairs), which leads to greater splitting.

3. Compounds of copper (II) are generally colored, but compounds of copper (I) are not. Explain.

Copper (II) ions have partially filled d orbitals (d^9). In octahedral coordination complexes, the d orbitals split into higher and lower energy sets due to the presence of ligands. When the complex absorbs energy, electrons may undergo transitions between lower and higher energy sets. When the electrons fall back down, they release energy (observed colors).
However, copper (I) ions have a filled d^{10} electron configuration, so all of the d orbitals are occupied. No electrons may undergo the transitions in response to the crystal field splitting. As a result, copper (I) compounds are generally colorless because they do not absorb visible light, and thus cannot release energy when electrons fall back down.

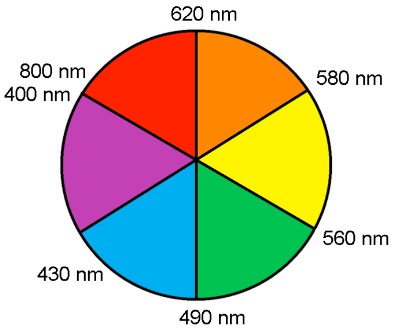
4. A metal complex absorbs light with a wavelength of 530 nm. What is the crystal field splitting Δ_o for the complex? What color is it to the eye?

We must use the equation $\Delta_o = \frac{hc}{\lambda}$. *h* refers to Planck's constant (6.625×10^{-34} J · s) and *c* refers to the speed of light ($2.998\text{x}10^{8}$ m/s). λ is 530 nm, but we must convert it to meters, so we can cancel the units out with the speed of light value.

$$(530\ \text{nm})\left(\frac{1\ m}{1\ x\ 10^{9}\ nm}\right) = 5.3\text{x}10^{-7}\ \text{m}$$

$$\Delta_o = \frac{hc}{\lambda}$$

$$\Delta_o = \frac{(6.625\ x\ 10^{-34}\ J{*}s)(2.998.\ x\ 10^{8} m/s)}{5.3\ x\ 10^{-7} m} = 3.7\ \text{x}\ 10^{-19}\ \text{J}$$



Since the complex absorbs light with a wavelength of 530 nm (green), the complex appears red, as red is across green on the color wheel.

5. Explain the concept of coordination number in the context of coordination complex geometry.

The coordination number refers to the number of bonds formed by a central metal ion to its surrounding ligands, which defines the geometry of the complex. A coordination number of six corresponds to octahedral geometry, for instance, as there are six bonds formed by the metal ion. An example of this is $[Co(NH_3)_4Cl_2]NO_3$. The coordination number of the central metal ion, Co, is 6 because 4 ammonia ligands and 2 chloride ions are donating lone pairs. Thus, its geometry is octahedral.

6. Determine the coordination number and geometries around each of the following complexes.

a. $[Cu(CN)_3]^{2-}$

The metal atom, Cu, is bonded to three CN^- ligands. Thus, its coordination number is 3, and its geometry is trigonal planar.

b. $[Ni(H_2O)_6]Cl_2$

The metal atom, Ni, is bonded to six H_2O ligands. Its coordination number is 6, and its geometry is octahedral.

c. $[CoCl_6]^{3-}$

The metal ion, Co, is bonded to six chloride ions, so its coordination number is 6 and the geometry is octahedral.