Pearson

22.6: Applications of Coordination Compounds

Coordination compounds are found in living systems, in industry, and even in household products. In this section, we describe a few applications of coordination compounds.

Chelating Agents

In Section 22.3, we introduced the chelating agent ethylenediaminetetraacetate ion $\left(\mathrm{EDTA}^{4-}\right)$. This ligand has lone pairs on six different donor atoms that can interact with a metal ion to form very stable metal complexes. EDTA is used to treat the victims of heavy metal poisoning such as lead poisoning. The patient is given $[\mathrm{Ca}(\mathrm{EDTA})]^{2-}$, and since the lead complex $\left(K_{\mathrm{f}} = 2 \times 10^{18}\right)$ is more stable than the calcium complex $\left(K_{\mathrm{f}} = 4 \times 10^{10}\right)$, the lead displaces the calcium. The body excretes the lead complex and leaves behind the calcium, which is nontoxic (and is in fact a nutrient).

Chemical Analysis

Some ligands are selective in their binding, preferring specific metal ions; these ligands can be used in chemical analysis. For example, dimethylglyoxime (dmg) is used to chemically analyze a sample for Ni^{2+} or Pd^{2+}. In the presence of Ni^{2+}, an insoluble red precipitate forms, and in the presence of Pd^{2+}, an insoluble yellow precipitate forms. Similarly, the SCN^{-} ligand is used to test for Co^{2+} or Fe^{3+}. In the presence of Co^{2+} a blue solution forms, and in the presence of Fe^{3+} a deep red solution forms (Figure 22.19).

Figure 22.19 Chemical Analysis with SCN^{-}

(**a**) Blue indicates Co^{2+}. (**b**) Red indicates Fe^{3+}.

(a) (b)

Coloring Agents

Because of the wide variety of colors found in coordination complexes, they are often used as coloring agents. For example, a commercially available agent, iron blue, is a mixture of the hexacyano complexes of iron(II) and iron(III). Iron blue is used in ink, paint, cosmetics (eye shadow), and blueprints.

Biomolecules

Living systems contain many molecules based on metal complexes. Hemoglobin (involved in oxygen transport), cytochrome c (involved in electron transport), carbonic anhydrase (involved in respiration), and chlorophyll (involved in photosynthesis) all have coordinated metal ions that are critical to their structure and function. Table 22.7 summarizes the biological significance of many of the other first-row transition metals.

Table 22.7 Transition Metals and Some of Their Functions in the Human Body

Transition Metal	Biological Function
chromium	Works with insulin to control utilization of glucose
manganese	Fat and carbohydrate synthesis
molybdenum	Involved in hemoglobin synthesis
iron	Oxygen transport
copper	Involved in hemoglobin synthesis
zinc	Involved in cell reproduction and tissue growth; part of more than 70 enzymes; assists in the utilization of carbohydrate, protein, and fat

Hemoglobin and Cytochrome c

In hemoglobin and in cytochrome c, an iron complex called a heme is connected to a protein. A heme is an iron ion coordinated to a flat, polydentate ligand called a porphyrin. The porphyrin ligand has a planar ring structure with four nitrogen atoms that can coordinate to the metal ion (Figure 22.20). Different porphyrins have different substituent groups connected around the outside of the ring.

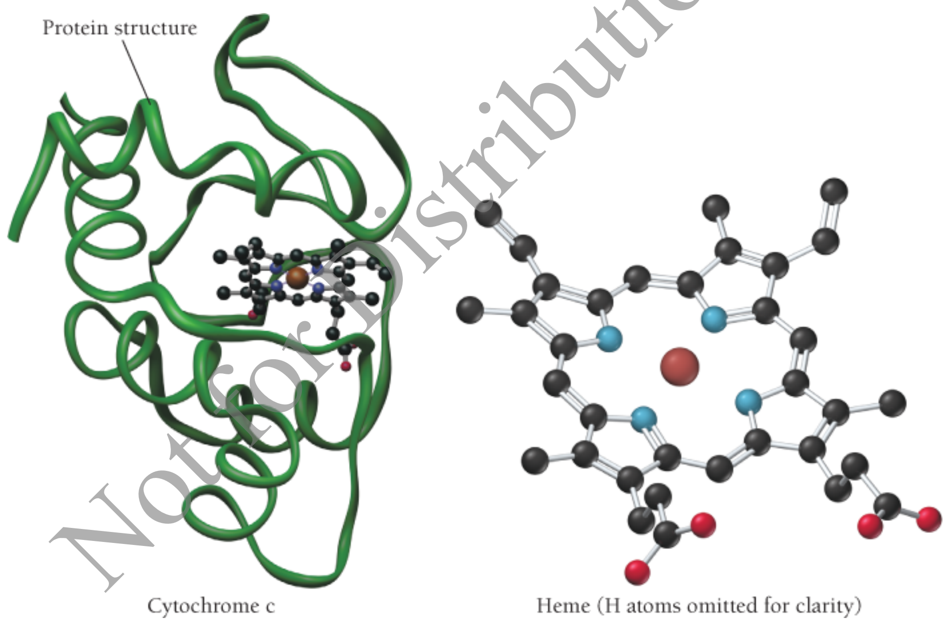
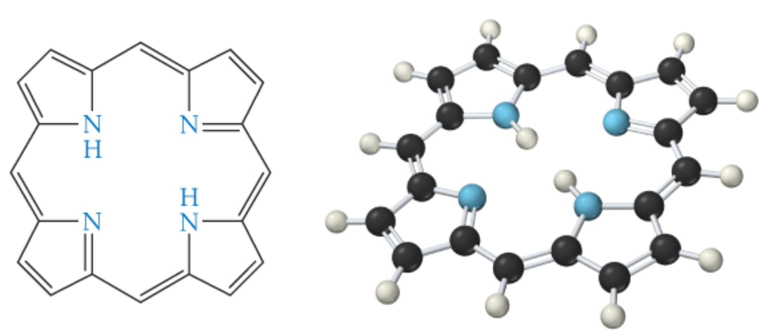


Figure 22.20 Porphyrin

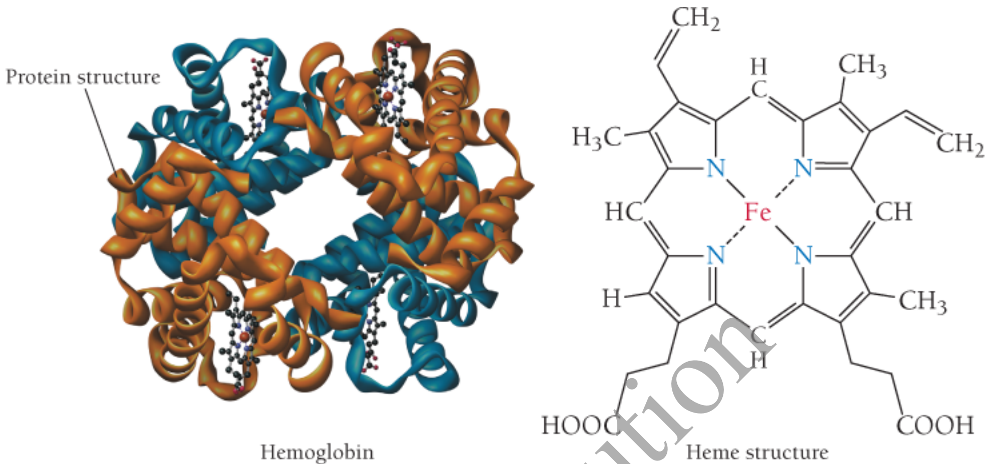
A porphyrin has four nitrogen atoms that can coordinate to a central metal atom.



In hemoglobin, the iron complex is octahedral, with the four nitrogen atoms of the porphyrin in a square planar arrangement around the metal. A nitrogen atom from the protein occupies the fifth coordination site, and either O_2 or H_2O occupies the last coordination site (Figure 22.21). In the lungs, where the oxygen content is high, the hemoglobin coordinates to an O_2 molecule. The oxygen-rich hemoglobin is carried by the bloodstream to areas throughout the body that are depleted in oxygen, where oxygen is released and replaced by a water molecule. The hemoglobin then travels back to the lungs to repeat the cycle.

Figure 22.21 Hemoglobin

In hemoglobin, the iron complex is octahedral, with the four nitrogen atoms of the porphyrin in a square planar arrangement around the metal. A nitrogen atom from a nearby amino acid of the protein occupies the fifth coordination site, and either O_2 or H_2O occupies the last coordination site.

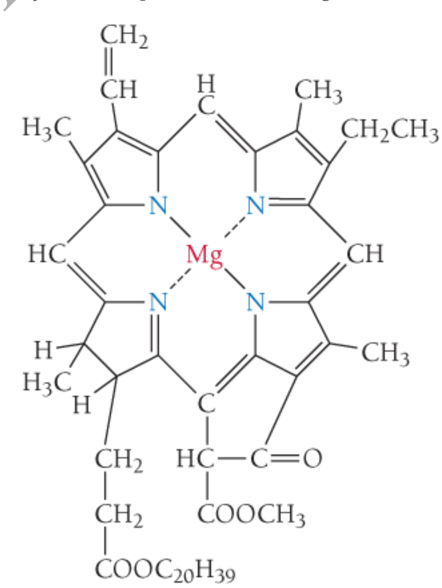


Chlorophyll

Chlorophyll, shown in Figure 22.22, is another porphyrin-based biomolecule, but in chlorophyll the porphyrin is not surrounded by a protein and the coordinated metal is magnesium (which is not a transition metal). Chlorophyll is essential for the *photosynthesis* process performed by plants, in which light energy from the sun is converted to chemical energy to fuel the plant's growth.

Figure 22.22 Chlorophyll

Chlorophyll, involved in photosynthesis in plants, contains magnesium coordinated to a porphyrin.



Carbonic Anhydrase

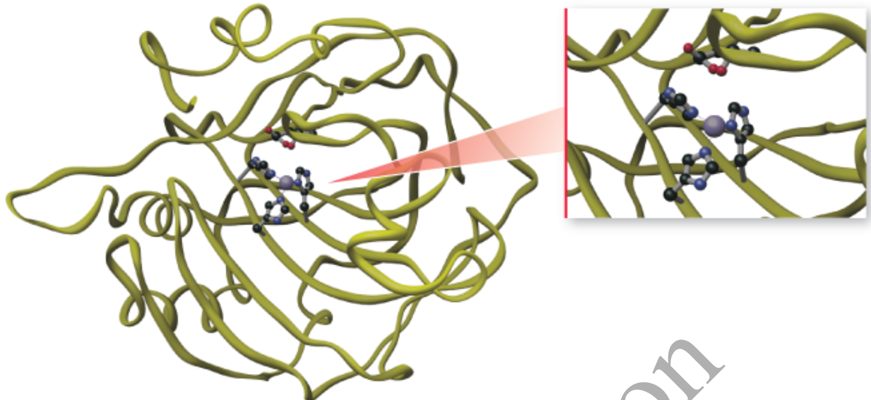
Carbonic Anhydrase

In carbonic anhydrase, the zinc ion is bound in a tetrahedral complex, with three of the coordination sites occupied by nitrogen atoms from the surrounding protein and the fourth site available to bind a water molecule (Figure 22.23). Carbonic anhydrase catalyzes the reaction between water and CO_2 in *respiration*, the process by which living organisms extract energy from glucose.

$$H_2O\,(l) + CO_2\,(aq) \rightleftharpoons H^+\,(aq) + HCO_3^-\,(aq)$$

Figure 22.23 Carbonic Anhydrase

Carbonic anhydrase contains a zinc ion that is bound in a tetrahedral complex, with three of the coordination sites occupied by nitrogen atoms from surrounding amino acids. The fourth site is available to bind a water molecule.



A water molecule alone is not acidic enough to react with a CO_2 molecule at a sufficient rate. When the water molecule is bound to the zinc ion in carbonic anhydrase, the positive charge on the metal draws electron density from the O—H bond and the H_2O becomes more acidic—sufficiently so to readily lose a proton. The resulting bound OH^- easily reacts with a CO_2 molecule, and the reaction is much faster than the uncatalyzed version.

Drugs and Therapeutic Agents

In the mid-1960s, researchers found that the platinum(II) complex *cis*-$[Pt(NH_3)_2Cl_2]$, known as cisplatin, is an effective anticancer agent (Figure 22.24). Interestingly, the closely related geometric isomer *trans*-$[Pt(NH_3)_2Cl_2]$ has little or no effect on cancer tumors. Cisplatin is believed to function by attaching itself to the cancer cell's DNA and replacing the Cl^- ligands with donor atoms from the DNA strands. The cis arrangement of the Cl^- ligands corresponds to the geometry required to bind to the DNA strands. The trans isomer, though closely related, cannot bind properly due to the arrangement of the Cl^- ligands and is therefore not an effective agent. Cisplatin and other closely related platinum(II) complexes are used in chemotherapy for certain types of cancer and are among the most effective anticancer agents available for these cases.

Figure 22.24 Cisplatin

Cisplatin is an effective anticancer agent.