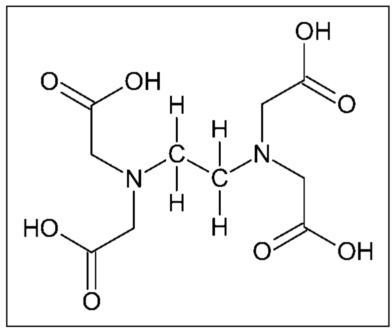
39. Ethylenediaminetetraacetic Acid (EDTA)

CHEMICAL NAME = ethylenediaminetetraacetic acid
CAS NUMBER = 60–00–4
MOLECULAR FORMULA = $C_{10}H_{16}N_2O_8$
MOLAR MASS = 292.3 g/mol
COMPOSITION = C(41.1%) H(5.5%) N(9.6%) O(43.8%)
MELTING POINT = decomposes at 240°C
BOILING POINT = decomposes at 240°C
DENSITY = 0.86 g/cm^3



EDTA, also known as editic acid, is a colorless crystalline substance widely used to chelate metal ions. Before discussing EDTA, a brief overview of chelation is presented. The term *chelation* comes from the Greek word *chele or khele,* which means claw; it is used to describe the ability of some substances to grab atoms or ions to form complexes. Chelation occurs when a ligand binds to a metal ion. Ligand is derived from the Latin word *ligare* meaning to bind. A ligand is a chemical species (atom, ion, or molecule) that acts as a Lewis base. Lewis bases are electron pair donors. Water often acts as a Lewis base when salts dissolve in water, and water molecules donate a pair of electrons to form a coordinate covalent bond with the metal ion from the salt. For example, when a Cu^{2+} compound dissolves in water, four water molecules will each donate a pair of electrons binding to copper to form the complex ion $Cu(H_2O)_4^{2+}$. In this example, a single oxygen atom from each water molecule attaches to the metal ion, making water a monodentate ligand. Monodentate means it has "one tooth" with which to bite into the metal ion. Polydentate ligands have more than one electron pair donor atoms with which to bind (bite) into a metal.

EDTA is a common polydentate ligand. In EDTA, the hydrogen atoms are easily removed in solution to produce anionic $EDTA^{4-}$. In its anionic form EDTA has six binding atoms, two nitrogen and four oxygen as depicted in Figure 39.1.

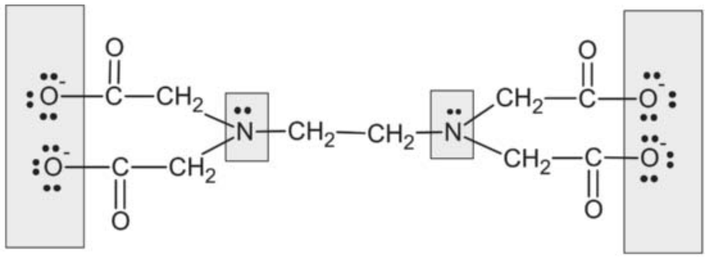


Figure 39.1 Potential binding sites in EDTA.

EDTA binds to a metal ion at the six binding sites, wrapping itself around the metal ion, forming a very stable complex. The strong grasp of EDTA on the metal ion is analogous to a crab or lobster clamping down on an object with its claw, hence the name chelation. EDTA is such an effective chelating agent because it can deactivate a metal at up to six sites (Figure 39.2).

EDTA was first synthesized in the early 1930s by the German chemist Ferdinand Münz working for I. G. Farben. Münz, who was looking for a substitute for citric acid to use with dye solutions in the textile industry, was the first to patent a process for EDTA synthesis in Germany in 1935. Münz subsequently applied for United States patents in 1936 and 1937 (U.S. Patent Number 2130505); his method involved reacting monochloroacetic acid ($C_2H_3ClO_2$) and ethylene diamine ($C_2H_8N_2$). Concurrent with Münz's work, Frederick C. Bersworth in the United States synthesized EDTA using different methods that gave greater yields and made EDTA's commercial production economically viable. Bersworth syntheses involved reacting formaldehyde, amines, and hydrogen cyanide. Bersworth and Münz obtained patents for EDTA production in the 1940s (U.S. Patent Numbers 2407645 and 2461519).

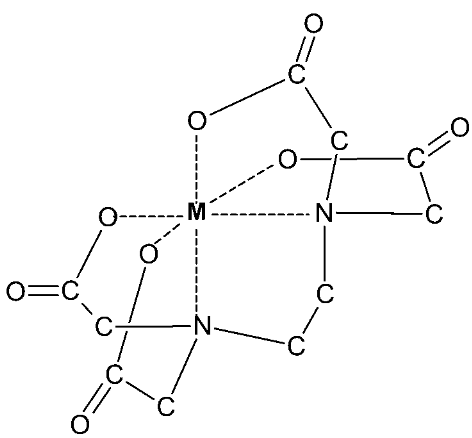


Figure 39.2 EDTA^{-4} chelating a metal, M.

EDTA is marketed in its salt forms such as sodium EDTA or calcium EDTA. EDTA has industrial and medical uses as a chelating agent. Much of its utility is related to the fact that metals and metal compounds are important catalysts in numerous reactions. By chelating metals, EDTA prevents the metal from catalyzing reactions, thereby limiting degradation, oxidation, and other undesirable reactions. The major industries using EDTA and other chelating agents are paper and pulp, cleaning products, chemicals, agriculture, and water treatment. The paper and pulp industry is the major user of EDTA, where it is used to stabilize bleaches by sequestering metals that catalyze the degradation of bleaches. EDTA's ability to stabilize bleaches also makes them useful in laundry detergents and various other cleaning products. In addition to improving bleaching efficiency, EDTA use in detergents and cleansers also softens hard water by tying up divalent metal ions responsible for water hardness, primarily Ca^{2+} and Mg^{2+}. Its softening ability helps EDTA reduce scale formation and improves foaming properties in cleaning formulations. EDTA is applied in general water treatment to soften water, helping to prevent scale and corrosion. EDTA has low toxicity and is used in the food and beverage industry. Foods naturally contain small traces of metals and small quantities are added during food processing. EDTA is used with foods to preserve color and preserve flavor, prevent odors, maintain nutrient content, and extend shelf life. When used in beverages, EDTA preserves color and stabilizes other ingredients such as citric acid and benzoates. In the chemical industry, EDTA is used to control metal catalytic processes during reactions. EDTA salts are used in agriculture to provide metal micronutrients in fertilizers.

EDTA has been used in the medicine since the 1950s in chelation therapy. Chelation therapy involves administering a calcium EDTA salt solution intravenously to patients to remove metal toxins from the bloodstream. The Food and Drug Administration has approved chelation therapy using EDTA for the treatment of heavy metal (lead, mercury) poisoning for more than 40 years. Hundreds of thousands of patients are treated annually using chelation therapy. EDTA is administered to patients over a variable number of sessions, with sessions lasting from an hour to several hours. Because EDTA chelation therapy removes nutrients and vitamins from the body with the target toxic substances, chelation solutions contain supplements in addition to EDTA.

Chelation therapy has been used for numerous treatments other than heavy metal poisoning, which has created controversy among the medical community. It is most often used as an alternative treatment for heart disease, atherosclerosis, and cancer, but it has also been advocated for numerous other diseases. Chelation therapy's use for clearing arteries is based on EDTA's ability to remove calcium and other substances that contribute to plaque in blood vessels. Proponents of chelation therapy claim that it is an alternative to standard coronary procedures such as bypass surgery or angioplasty. National health organizations such as the American Heart Association and American Cancer Society do not recommend it as an alternative treatment owing to the lack of scientific support for its efficacy. A five-year study launched in 2003 by the National Institute of Health to examine EDTA chelation therapy for individuals with coronary artery disease is currently in progress.