Example 3

Topic
Uses of EDTA

Subtopics
1. Treatment of lead poisoning
2. Inhibition of oxidation of omega-3 fatty acids
3. Improvement of the bleaching process in pulp and paper industry

Level
Secondary 6-7

Curriculum Links
Chemistry of the d-block elements
Complex formation
Multidentate ligands

Medium of instruction
English
1. Treatment of lead poisoning

Lead is a toxic metal. Although lead plays no role in the human biological systems, it can be absorbed into the body through a gastrointestinal route or inhalation. Workers at lead smelting factories or battery recycling plants are potential victims. Other occupations with exposure to lead include house painting, automotive repair, and ceramics. For example, according to *South China Morning Post* (27 March 2007), a smelting factory in Hunan, China was shut down after it had been open for 14 years. The land and water near the smelting plant had been seriously contaminated with lead. More than 30 villagers suffered from lead poisoning. Four villagers died of cancer. Children had symptoms such as stomach pain, poor memory, and physical weakness.

Young children can easily absorb lead when they are exposed to decaying fragments of lead-based paint in old houses. In the USA, flaking, dusting, and peeling leaded paint is the main source of lead exposure in children. There is no lead in petrol sold in Hong Kong, but lead particles emitted by cars in the 1990s may still persist in some soil near roadways. Tap water may also be contaminated with lead if there are lead-soldered pipes or lead-containing taps inside old buildings.

In 2007, 7% of children (aged 0-6 years) in Beijing, China have excessive lead content in their blood. Because most children with slightly high blood lead levels show few symptoms, their parents generally did not recognize the problem. Following absorption, lead enters the blood that distributes it to various tissues and organs such as the liver, lungs, kidneys, bones, teeth, and brain. Children with serious lead poisoning can suffer permanent brain damage. Other symptoms include abdominal pain, loss of appetite, vomiting, constipation, headache, and coma. To treat lead poisoning, calcium disodium ethylenediamine tetra-acetate, CaNa$_2$EDTA, may be injected within a vein to let the compound go into the blood stream.

![CaNa$_2$EDTA Structure](image)

CaNa$_2$EDTA is a metal chelating agent. Pb$^{2+}$ ions can displace the weakly bonded Ca$^{2+}$ ions in CaNa$_2$EDTA to form a highly soluble complex, [PbEDTA]$^{2-}$. The complex is filtered out of
the blood by the kidneys and excreted in the urine. This kind of treatment for lead poisoning is called chelation therapy.

\[
Pb^{2+} + [\text{CaEDTA}]^{2-} \rightleftharpoons Ca^{2+} + [\text{PbEDTA}]^{2-}
\]

CaNa$_2$EDTA should not be taken orally because lead will be absorbed from the gut. Dimercaptosuccinic acid is an oral chelating agent approved for treatment of lead poisoning. However, CaNa$_2$EDTA cannot cross the blood-brain barrier. For patients with high lead content in the brain, dimercaprol should be used.

\[
\begin{align*}
\text{dimercaptosuccinic acid} & \\
\text{dimercaprol} & \\
\end{align*}
\]

The major harmful effect of CaNa$_2$EDTA is degeneration of kidney cells, especially with high-dose and prolonged therapy. Other side effects include numbness, nasal congestion, prolonged sneezing, fatigue, thirst, fever, headache, nausea, vomiting, and urinary urgency. Although CaNa$_2$EDTA and Na$_2$EDTA are related compounds, Na$_2$EDTA should not be used to treat lead poisoning because it will bind with Ca$^{2+}$ ions. As a result, the body will lose a lot of calcium and the effect can be fatal.

\[
Ca^{2+} + \text{EDTA}^{2-} \rightleftharpoons [\text{CaEDTA}]^{2-} + 2 \text{H}^+
\]

**Questions**
1. All causes of lead poisoning are environmental. Why?
2. Why can CaNa$_2$EDTA cure lead poisoning?
3. Why is Na$_2$EDTA not suitable for treating lead poisoning?
2. Inhibition of oxidation of omega-3 fatty acids

The omega-3 (ω-3) fatty acids found in fish oil are good for the health. Benefits include reduced cholesterol in the bloodstream, protection against heart disease, and improved brain and eye function in children. Trials have also indicated that omega-3 fatty acids may help to protect against cancer by making cells with a healthy membrane.

Omega-3 fatty acids are polyunsaturated carboxylic acids with a long hydrocarbon chain. For humans, the three most nutritionally important omega-3 fatty acids are α-linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid. These three molecules have a common chemical structure; that is, there is a carbon-carbon double bond between the third carbon and fourth carbon. The C=C bonds are in the cis-configuration (i.e., the two hydrogen atoms are on the same side of the double bond). The structure of α-linolenic acid is shown below:

α-linolenic acid

α-linolenic acid is particularly essential because the human body cannot make it. Therefore, we have to obtain α-linolenic acid from food such as salmon, tuna, flaxseeds, walnuts, and soybean. The human body can make eicosapentaenoic acid and docosahexaenoic acid from α-linolenic acid (all the other necessary omega-3 fatty acids??). So, it is most important to get sufficient α-linolenic acid from our diet.

To improve the nutritional value of food products, many food companies are adding omega-3 fatty acids to their products such as bread, pizza, yoghurt, fruit juice, milk, and infant formula/milk powder. But omega-3 fatty acids are easily oxidized by exposure to heat during food processing. The oxidation reactions are catalyzed by metal ions.

The lipids in many foods exist in the form of small oil droplets dispersed in water. In 2006, scientists found that disodium ethylenediamine tetra-acetate (Na₂EDTA) can effectively inhibit oxidation of omega-3 fatty acids in salmon oil-in-water emulsions by removing Fe³⁺ and Fe²⁺ ions from the oil droplet surface. They found that the addition of Na₂EDTA to food before heat-processing is more effective than adding Na₂EDTA after heat-processing. Thus, high-quality heat-processed salmon oil can be produced with the help of Na₂EDTA, which not only serves as a chelating agent but also an anti-oxidant in food processing.
The structure of ethylene diamine tetra-acetate ion

\[
\text{Fe}^{3+} + \text{EDTA}^{4-} = [\text{FeEDTA}]^{-}
\]

\[
\text{Fe}^{2+} + \text{EDTA}^{4-} = [\text{FeEDTA}]^{2-}
\]

Without Na\textsubscript{2}EDTA, the oxidation of omega-3 fatty acids in salmon oil will result in products that can damage the flavour and nutritional value of salmon oil. More importantly, the oxidation of omega-3 fatty acids will produce free radicals. Doctors believe that these free radicals may cause cancers.

Questions
1. What are the chemical characteristics of omega-3 fatty acids?
2. Why do food companies want to prevent the oxidation of omega-3 fatty acids in processed food?
3. Why can EDTA inhibit the oxidation of omega-3 fatty acids in heat-processed food?

However, many people do not eat enough omega-3 fatty acids. The symptoms of deficiency of omega-3 fatty acids include fatigue, dry skin, brittle hair and nails, constipation, frequent colds, depression, poor concentration, and joint pain.
3. Improvement of the bleaching process in pulp and paper industry

When factories make paper from trees, bleaching is a very important step. High-quality papers require a pulp which does not discolour during storage or go yellow when exposed to sunlight.

To protect the environment, chlorine gas, chlorine dioxide, or other chlorine compounds are no longer used by some paper manufacturers. The use of chlorine gas as a bleaching agent is the most harmful for the environment because chlorine gas releases dioxins and other toxic waste materials during the bleaching process. The harmful effects of dioxins on humans include abnormal development of teeth and damage to the immune systems.

Common bleaching agents of today are hydrogen peroxide (H$_2$O$_2$) and ozone (O$_3$), which break down into harmless water and oxygen. For example, Nordic Paper, a paper factory in Sweden, has replaced chlorine with H$_2$O$_2$ to whiten the pulp. Nordic Paper is the world’s largest manufacturer of greaseproof paper (http://www.nordic-paper.com/products.asp). However, metal ions (e.g., Mn$^{2+}$, Cu$^{2+}$, and Fe$^{3+}$) in the pulp can lower the efficiency of hydrogen peroxide because they catalyze the decomposition of hydrogen peroxide. Metal ions also promote the formation of hydroxyl radical (HO·), which destroys the cellulose fiber.

To deactivate metal ions, Nordic Paper has used ethylenediaminetetraacetic acid (EDTA) to form anionic complexes with metal ions in the pulp suspension. EDTA is a hexadentate chelating agent produced as salts such as tetrasodium EDTA (Na$_4$EDTA). Chemical companies synthesize EDTA by reacting ethylenediamine with methanal, cyanide and sodium hydroxide to produce Na$_4$EDTA. Other salts of EDTA (e.g., K$_4$EDTA, CaNa$_2$EDTA) are produced from Na$_4$EDTA.

Salts of EDTA are useful to get rid of metal ions in the pulp suspensions because the EDTA molecule can lock a metal ion into a “cage” structure, forming a water-soluble anionic complex. The anionic complexes of Mn$^{2+}$, Cu$^{2+}$, and Fe$^{3+}$ ions can be washed out prior to
bleaching. Nordic Paper reported that with the aid of EDTA, they can increase the efficiency of every kg of hydrogen peroxide with 50%.

![Complex ion formed by manganese(II) ions and EDTA](image)

Unfortunately, EDTA is not easily degradable in nature. It is one of the organic pollutants found in the highest proportions in surface waters in Europe. Thus, Nordic Paper has applied new biotechnology to treat the EDTA in wastewater. Special bacteria have to be used to break down EDTA molecules into simple chemicals such as CO₂, H₂O, and NH₄⁺ (http://www.biored.se/index_en.html).

Every year, about 30% of EDTA sold worldwide is used by the pulp and paper industry (http://www.dow.com/productsafety/finder/edta.htm). This proportion is expected to increase because more and more paper factories want to whiten the pulp without the use of chlorine gas or chlorine compounds.

Questions
1. Why is chlorine gas seldom used in the pulp and paper industry?
2. Why can metal ions lower the efficiency of hydrogen peroxide during the pulp bleaching process?
3. Why is EDTA useful to reduce the amount of hydrogen peroxide used in the pulp bleaching process?