8.2: Minerals: basic Concepts

Skills to Develop

- Define the term "mineral" and understand how a mineral is different from a vitamin
- Know the difference between major and trace minerals
- For each mineral, know what the mineral does and what happens to the human body if: the mineral is **too low in the diet for too long** (deficiency); the mineral is **too high in the diet for too long** (toxicity) and be able to list some food sources that are rich in each of the minerals.
- Describe factors that can decrease or increase the ability of the small intestine to absorb minerals into the blood

From the beginning of this text we discussed the six classes of essential nutrients: Carbohydrates, Lipids, Proteins, Vitamins, Minerals and Water. You will recall that these nutrients can not be made by the human body, or can not be made in sufficient amounts, therefore we must take them in from the outside world. In this portion of Chapter 8 we will discuss the category of essential nutrients called Minerals, also known as **Dietary elements** or **mineral nutrients**. **Minerals** are naturally occurring chemical elements required by living organisms for survival. Many of the minerals we need are plentiful in a typical scoop of dirt! If fact, there is an illness called Pica, in which the affected individual has insatiable cravings to eat dirt. There is evidence that in at least some cases of Pica, the individual is low in minerals (like Iron) and somehow their body knows that they can get those minerals from soil! Of course there are dangers to eating dirt which might be contaminated with substances that are NOT edible. Because minerals are present in the Earth's crust, plants, which grow in the soil are often a good source of minerals though animals, who eat the mineral filled plants, can be good sources as well.

There are two categories of minerals: **Major minerals** and **Trace minerals**. These two terms refer to how much of the mineral is needed in the diet and also by how much is present in the human body. Major minerals are needed in amounts greater than 100 mg per day; whereas Trace minerals are needed in amounts less than 100 mg per day. Alternatively, Major minerals are present in the body in amounts greater than 5 grams and Trace minerals are present in...
the body in amounts less than 5 grams. The major minerals are: calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium. Important trace minerals include: iron, cobalt, copper, zinc, manganese, molybdenum, iodine, bromine, and selenium. These are also called minor minerals, with "minor" referring to their amount, as opposed to their importance.

Over twenty dietary elements are necessary for mammals, and several more for various other types of life. The total number of chemical elements that are absolutely needed is not known for any organism. Ultratrace amounts of some elements (e.g., boron, chromium) are known to clearly have a role but the exact biochemical nature is unknown, and others (e.g. arsenic, silicon) are suspected to have a role in health, but without proof.

Major and trace minerals have a variety of life sustaining roles in the human body. Some, like Calcium and Phosphorus, make up structures like bones and teeth. Others, like Sodium and Potassium regulate our fluid balance and blood pressure. Still others, like Magnesium, Zinc and Copper function as cofactors, which are minerals that must bind to specific enzymes in order for those enzymes to do their job. Many minerals have more than one function and families of minerals often work together doing related jobs in the body. As you read about each mineral below, try to figure out some of the primary functions of the mineral, what happens if you get too little of the mineral in your diet for too long (deficiency) and what happens if you get too much of the mineral in your diet for too long (toxicity).

Bacteria play an essential role in the altering of primary elements that results in the release of nutrients for their own nutrition and for the nutrition of others in the ecological food chain. One mineral, cobalt, is available for use by animals only after having been processed into complicated molecules (e.g., vitamin B12) by bacteria. Scientists are only recently starting to appreciate the magnitude and role that microorganisms have in the global cycling and formation of biominerals.

**Essential chemical elements for mammals**

At least twenty chemical elements are known to be required to support human biochemical processes by serving structural and functional roles as well as electrolytes. Most of the known and suggested dietary elements are of relatively low atomic weight, and are reasonably common on land, or at least, common in the ocean (iodine, sodium). Here is an image of the Periodic Table of The Elements showing Sodium (Na), Iron (Fe), Calcium (Ca) and the other minerals. Please note that Minerals are inorganic, meaning that they are not structures made with Carbon like the vitamins were. Think of an Iron rod, it is not made of Carbon, Hydrogen and Oxygen, it is only made of elemental Iron! Students often get confused about this point so re-read that a few times if it did not make sense.

Nutritional elements in the periodic table:

![Periodic Table of Elements](https://med.libretexts.org/Courses/Folsom_Lake_College/FLC%3A_Nutri_300_(Miller)/Chapters/08%3A_Water_and_Minerals…)
The four organic basic elements

Major Minerals

Essential trace elements

Suggested function from deprivation effects or active metabolic handling, but no clearly-identified biochemical function in humans

The following play important roles in biological processes:

<table>
<thead>
<tr>
<th>Dietary element</th>
<th>RDA/AI (mg/day)</th>
<th>Function(s)</th>
<th>Food sources</th>
<th>Insufficiency</th>
<th>Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td></td>
<td>Relatively large quantities of sulfur are required, but there is no RDA,[3] as the sulfur is obtained from and used for amino acids, and therefore should be adequate in any diet containing enough protein.</td>
<td>A component of organic compounds such as some amino acids and some vitamins.</td>
<td>High Protein foods like: beans, nuts, meat, eggs (some of the amino acids that make up protein contain sulfur)</td>
<td>none reported</td>
</tr>
<tr>
<td>Potassium</td>
<td>4700 mg/day</td>
<td>A systemic electrolyte and is essential in coregulating ATP with sodium.</td>
<td>Legumes, potato skin, tomatoes, bananas, papayas, lentils, dry</td>
<td>hypokalemia</td>
<td>hyperkalemia</td>
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<table>
<thead>
<tr>
<th>Dietary element</th>
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<tbody>
<tr>
<td>Chlorine</td>
<td>2300 mg/day</td>
<td>Needed for production of hydrochloric acid in the stomach and in cellular pump functions.</td>
<td>Table salt (sodium chloride) is the main dietary source.</td>
<td>hypochloremia</td>
<td>hyperchloremia</td>
</tr>
<tr>
<td>Sodium</td>
<td>1500 mg/day</td>
<td>A systemic electrolyte and is essential in coregulating ATP with potassium.</td>
<td>Sea vegetables, milk, and spinach.</td>
<td>hyponatremia</td>
<td>hypernatremia</td>
</tr>
<tr>
<td>Calcium</td>
<td>1300 mg/day</td>
<td>Needed for muscle, heart and digestive system health, builds bone, supports synthesis and function of blood cells.</td>
<td>Dairy products, eggs, canned fish with bones (salmon, sardines), green leafy vegetables, nuts, seeds, tofu, thyme, oregano, dill, cinnamon.[4]</td>
<td>hypocalcaemia</td>
<td>hypercalcaemia</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>700 mg/day</td>
<td>A component of bones (see apatite), cells, in energy processing, in DNA and ATP (as phosphate) and many other functions.</td>
<td>Red meat, dairy foods, fish, poultry, bread, rice, oats.[6][7] in biological contexts, usually seen as phosphate.[8]</td>
<td>hypophosphatemia</td>
<td>hyperphosphatemia</td>
</tr>
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<tr>
<td>Magnesium</td>
<td>420 mg/day</td>
<td>Required for processing ATP and for bones.</td>
<td>Raw nuts, soybeans, cocoa mass, spinach, chard, sea vegetables, tomatoes, halibut, beans, ginger, cumin, cloves.[9]</td>
<td>hypomagnesemia, magnesium deficiency</td>
<td>hypermagnesemia</td>
</tr>
<tr>
<td>Zinc</td>
<td>11 mg/day</td>
<td>Pervasive and required for several enzymes such as carboxypeptidase, liver alcohol dehydrogenase, and carbonic anhydrase.</td>
<td>Calf liver, eggs, dry beans, mushrooms, spinach, asparagus, scallops, red meat, green peas, yogurt, oats, seeds, miso.[4][10]</td>
<td>zinc deficiency</td>
<td>zinc toxicity</td>
</tr>
<tr>
<td>Iron</td>
<td>18 mg/day</td>
<td>Required for many proteins and enzymes, notably hemoglobin to prevent anemia.</td>
<td>Red meat, fish (tuna, salmon), grains, dry beans, eggs, spinach, chard, turmeric, cumin, parsley, lentils, tofu, asparagus, leafy green vegetables, soybeans, shrimp, beans, tomatoes, olives, and dried fruit.[4][11]</td>
<td>anemia</td>
<td>iron overload disorder</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.3 mg/day</td>
<td>A cofactor in enzyme functions.</td>
<td>Spelt grain, brown rice, beans, spinach, pineapple, tempeh, rye, soybeans, thyme,</td>
<td>manganese deficiency</td>
<td>manganism</td>
</tr>
<tr>
<td>Dietary element</td>
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<tr>
<td>Copper</td>
<td>0.900 mg/day</td>
<td>Required component of many redox enzymes, including cytochrome c oxidase.</td>
<td>Mushrooms, spinach, greens, seeds, raw cashews, raw walnuts, tempeh, barley.[13]</td>
<td>copper deficiency</td>
<td>copper toxicity</td>
</tr>
<tr>
<td>Iodine</td>
<td>0.150 mg/day</td>
<td>Required not only for the synthesis of thyroid hormones, thyroxine and triiodothyronine and to prevent goiter, but also, probably as an antioxidant, for extrathyroidal organs as mammary and salivary glands and for gastric mucosa and immune system (thymus):</td>
<td>Sea vegetables, iodized salt, eggs. Alternate but inconsistent sources of iodine: strawberries, mozzarella cheese, yogurt, milk, fish, shellfish,[14]</td>
<td>iodine deficiency</td>
<td>iodism</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.055 mg/day</td>
<td>Essential to activity of antioxidant enzymes like glutathione peroxidase.</td>
<td>Brazil nuts, cold water wild fish (cod, halibut, salmon), tuna, lamb, turkey,</td>
<td>selenium deficiency</td>
<td>selenosis</td>
</tr>
<tr>
<td>Dietary element</td>
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<tr>
<td>Molybdenum</td>
<td>0.045 mg/day</td>
<td>The oxidases</td>
<td>Tomatoes, onions, carrots,[17] molybdenum deficiency molybdenum toxicity[18]</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>xanthine oxidase, aldehyde oxidase, and sulfite oxidase.[16]</td>
<td>calf liver, mustard, mushrooms, barley, cheese, garlic, tofu, seeds.[15]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Blood concentrations of dietary elements**

Dietary elements are present in a healthy human being's blood at certain mass and molar concentrations. The figure below presents the concentrations of each of the dietary elements discussed in this article, from center-right to the right. Depending on the concentrations, some are in upper part of the picture, while others are in the lower part. The figure includes the relative values of other constituents of blood such as hormones. In the figure, dietary elements are color highlighted in purple.

Reference ranges for blood tests, sorted logarithmically by mass above the scale and by molarity below.
Dietary nutrition

Dietitians recommend that dietary elements are best supplied by ingesting specific foods rich with the chemical element(s) of interest. The elements may be naturally present in the food (e.g., calcium in dairy milk) or added to the food (e.g., orange juice fortified with calcium; iodized salt, salt fortified with iodine). Dietary supplements can be formulated to contain several different chemical elements (as compounds), a combination of vitamins and/or other chemical compounds, or a single element (as a compound or mixture of compounds), such as calcium (as calcium carbonate, calcium citrate, etc.) or magnesium (as magnesium oxide, etc.), chromium (usually as chromium(III) picolinate), or iron (as iron bis-glycinate).

The dietary focus on chemical elements derives from an interest in supporting the biochemical reactions of metabolism with the required elemental components.[20] Appropriate intake levels of certain chemical elements have been demonstrated to be required to maintain optimal health. Diet can meet all the body's chemical element requirements, although supplements can be used when some requirements (e.g., calcium, which is found mainly in dairy products) are not adequately met by the diet, or when chronic or acute deficiencies arise from pathology, injury, etc. Research has supported that altering inorganic mineral compounds (carbonates, oxides, etc.) by reacting them with organic ligands ( amino acids, organic acids, etc.) improves the bioavailability of the supplemented mineral.[21]

Other elements

Many elements have been suggested as essential, but such claims have usually not been confirmed. Definitive evidence for efficacy comes from the characterization of a biomolecule containing the element with an identifiable and testable function. One problem with identifying efficacy is that some elements are innocuous at low concentrations and are pervasive (examples: silicon and nickel in solid and dust), so proof of efficacy is lacking because deficiencies are difficult to reproduce.[20]

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Excess</th>
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</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>Essential in rat, hamster, goat and chicken models, but no biochemical mechanism known in humans.[23]</td>
<td>arsenic poisoning</td>
</tr>
<tr>
<td>Nickel</td>
<td>There have been occasional studies asserting the essentiality of nickel,[24] but it currently has no RDA.</td>
<td>Nickel toxicity</td>
</tr>
<tr>
<td>Chromium</td>
<td>Chromium has been described as nonessential to mammals.[25][26] Some role in sugar metabolism in humans has been invoked, but evidence is lacking,[27][28] despite a market for the supplement chromium picolinate.</td>
<td>Chromium toxicity</td>
</tr>
<tr>
<td>Fluorine</td>
<td>Fluorine (as fluoride) is not generally considered an essential element because humans do not require it for growth or to sustain life. However, if one considers the prevention of dental cavities an important criterion in determining essentiality, then fluoride might well be considered an essential trace element. However, recent research indicates that the primary action of fluoride occurs topically (at the surface).[29][30]</td>
<td>Fluoride poisoning</td>
</tr>
</tbody>
</table>
### Boron

Boron is an essential plant nutrient, required primarily for maintaining the integrity of cell walls.\(^{[31][32][33]}\) In animals, supplemental boron has been shown to reduce calcium excretion and activate vitamin D.\(^{[34]}\) However, whether these effects were conventionally nutritional, or medicinal, could not be determined.\(^{[35]}\)

### Lithium

It is not known whether lithium has a physiological role in any species,\(^{[36]}\) but nutritional studies in mammals have indicated its importance to health, leading to a suggestion that it be classed as an essential trace element with an RDA of 1 mg/day.\(^{[37]}\)

Observational studies in Japan, reported in 2011, suggested that naturally occurring lithium in drinking water may increase human lifespan.\(^{[38]}\)

### Strontium

Strontium has been found to be involved in the utilization of calcium in the body. It has promoting action on calcium uptake into bone at moderate dietary strontium levels, but a rachitogenic (rickets-producing) action at higher dietary levels.\(^{[39]}\)

### Other

Silicon and vanadium have established, albeit specialized, biochemical roles as structural or functional cofactors in other organisms, and are possibly, even probably, used by mammals (including humans). By contrast, tungsten and cadmium have specialized biochemical uses in certain lower organisms, but these elements appear not to be utilized by humans.\(^{[2]}\)

### Mineral ecology

Recent studies have shown a tight linkage between living organisms and chemical elements on this planet. This led to the redefinition of minerals as "an element or compound, amorphous or crystalline, formed through 'biogeochemical' processes. The addition of 'bio' reflects a greater appreciation, although an incomplete understanding, of the processes of mineral formation by living forms." Biologists and geologists have only recently started to appreciate the magnitude of mineral biogeoengineering. Bacteria have contributed to the formation of minerals for billions of years and critically define the biogeochemical mineral cycles on this planet. Microorganisms can precipitate metals from solution contributing to the formation of ore deposits in addition to their ability to catalyze mineral dissolution, to respire, precipitate, and form minerals.

Most minerals are inorganic in nature. Mineral nutrients refers to the smaller class of minerals that are metabolized for growth, development, and vitality of living organisms. Mineral nutrients are recycled by bacteria that are freely suspended in the vast water columns of the world oceans. They absorb dissolved organic matter containing mineral nutrients as they scavenge through the dying individuals that fall out of large phytoplankton blooms. Flagellates are effective bacteriovores and are also commonly found in the marine water column. The flagellates are preyed upon by zooplankton while the phytoplankton concentrates on the larger particulate matter that is suspended in the water column as they are consumed by larger zooplankton, with fish as the top predator. Mineral nutrients cycle through this marine food chain, from bacteria and phytoplankton to flagellates and zooplankton who are then eaten by fish. The bacteria are important in this chain because only they have the physiological ability to absorb the dissolved mineral nutrients from the sea. These recycling principals from marine environments apply to many soil and freshwater ecosystems as well.

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Bioavailability

The term bioavailability refers to the ability of a body to extract a nutrient out of a food or beverage and effectively move it into the bloodstream for use in the body. Minerals are absorbed through the small intestinal wall like most nutrients and, like other nutrients, there can be factors that either decrease absorption and/or increase absorption of minerals. One example of increasing absorption of a mineral is the consumption of food containing Vitamin C (like citrus dressing) together with a food containing Iron (such as spinach). Combining these two nutrients in a spinach salad with citrus dressing for example, significantly increases the absorption of the iron present in the salad. Absorption can also be hindered by some factors in the diet. One example of decreasing absorption of minerals is the consumption of unleavened (no raising agents used) whole wheat flat-bread. Wheat bran contains compounds called phytates which tend to trap much of the zinc present in the bread. If a raising agent (like yeast) is used, the phytates release the zinc and it is available to be absorbed but if a raising agent is not used, much of the zinc remains trapped and will be excreted rather than being absorbed into the blood. Even the cooking method can impact how much of a mineral is available for us to absorb. If you have ever steamed broccoli, you’ve noticed the darkly colored water that collects beneath. Some of the water soluble minerals (as well as other water soluble nutrients) have been lost in the cooking water when you dump it down your drain. Finally, your own gastrointestinal health can greatly impact bioavailability. From teeth that chew inefficiently, to inadequate digestion, to small-intestinal walls that are inflamed and not very good at catching and absorbing nutrients, your entire GI tract can greatly influence how many of the nutrients from your food can make it into your blood stream. Most of the time the human body does a great job trying to compensate for increased and decreased bioavailability of nutrients but it is important to keep these concepts in mind if someone is eating a healthy diet but still having trouble getting appropriate blood levels of some nutrients.

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