Micronutrients, Food Additives, and Food Safety

In Chapter 5 we saw that foods consist largely of macronutrients: the fats and oils, proteins, and carbohydrates that provide us with the material structures and energy of our bodies. In this chapter we examine the much smaller components of foods that do not provide us directly with bodily substance or energy, but that are nonetheless vital to our well-being (i.e., vitamins and minerals), or that contribute to the taste, texture, or stability of foods (i.e., food additives). Some of these additives occur in **fuctional foods**, substances that may offer additional health benefits.

We also look at the safety of the foods and liquids that we eat and drink. We examine whether poisons exist in our food supply—poisons that can make us sick or even kill us—put there either by nature or by people, individually and commercially, as we prepare, process, cook, store, and modify foods. Produce that is stored for extended periods, for example, can harbor **aflatoxin**, a fungal toxin; the skins of potatoes and the leaves and stems of tomatoes naturally contain the toxin **solanine**; and **thiosulfates**, which are toxic to dogs and cats, are components of onions. We conclude the chapter with the question, "Is our food safe to eat?" and with an examination of what we mean when we use the word "safe."

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CHAPTER OUTLINE

14.1 Micronutrients

LEARNING OBJECTIVES

1. **Define** vitamins and describe their classification and roles in health.
2. **Define** minerals and describe their classification and roles in health.

In Chapter 5 we studied the macronutrients of food: its fat, carbohydrates, and proteins. But food contains small quantities of other essential natural products as well, known as **micronutrients**. Obtaining adequate amounts of these micronutrients, which include vitamins and minerals, is essential for good health. In this section, we explore the chemistry of micronutrients, learn about their dietary sources, and examine the health consequences of micronutrient deficiencies.

micronutrients Dietary substances needed in trace amounts for proper health.

Vitamins

Vitamins are organic compounds that form in small amounts within the plants and animals we eat as food, and that are essential for life and good health. The word "vitamin" came into our language in 1912, devised by the Polish biochemist (later, American citizen) Casimir Funk. He discovered these organic substances and believed that they were all amines (Section 12.2) that are vital to our health, or "vital amines." Hence he named them "vitamines," later shortened to our current "vitamins." We now know that not all vitamins are amines, but we also know that they are, indeed, vital to our health.

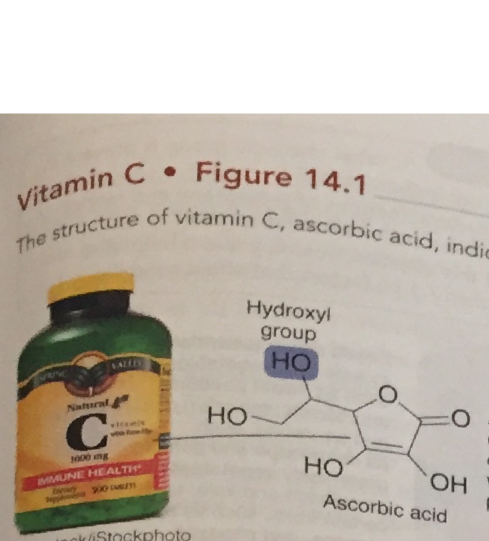
vitamins Organic compounds required in small amounts for proper health.

Vitamins Table 14.1

Chemical Name (and Letter Designation)	Dietary Source	Deficiency Symptoms or Disease
Water-Soluble Vitamins		
Ascorbic acid (vitamin C)	Fruits, especially citrus; many vegetables	Scurvy; degeneration of tissues
Biotin	Various foods	Rare; nausea, loss of appetite
Cobalamin (vitamin B_{12})	All foods of animal origin	Pernicious (fatal) anemia
Folic acid	Meat; green, leafy vegetables	Anemia
Niacin, or its equivalent in tryptophan (vitamin B_4)	Meat; legumes; grains	Pellagra; skin, digestive, and nervous system disorders; depression
Pantothenic acid (vitamin B_3)	Widely distributed; occurs in virtually all foods	Defects in metabolism
Pyridoxine, Pyridoxal, Pyridoxamine (Forms of vitamin B_6)	Various foods; widely distributed	Deficiency is rare; results in defects in amino acid metabolism with various symptoms
Riboflavin (vitamin B_2)	Meat, especially animal organs; milk and dairy products; green vegetables	Skin disorders
Thiamine (vitamin B_1)	Pork; animal organs; whole grains; nuts; legumes	Beriberi; muscular weakness; paralysis
Fat-Soluble Vitamins		
Cholecalciferol (vitamin D_3)	Liver and liver oils; fatty fish (such as salmon); fortified milk	Rickets; malformation of the bones; osteomalacia (adult counterpart of rickets)
Retinol (vitamin A)	Liver and liver oils; carrots and other deeply colored vegetables	Night blindness; degenerative diseases of the eyes leading to total blindness
α-Tocopherol (vitamin E)	Various foods, especially grain oils	Deficiency disease unknown in humans
Vitamin K	Plants and vegetables; produced by intestinal bacteria and absorbed through the intestinal wall	Deficiency disease unknown in adults; needed for blood clotting

Vitamin C • Figure 14.1

The structure of vitamin C, ascorbic acid, indicates that it is water-soluble.



As with any naturally occurring compound, a molecule of naturally occurring ascorbic acid is identical with a molecule of ascorbic acid produced synthetically.

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Think Critically

1. How many hydroxyl groups are present in ascorbic acid?
2. Most acids present in foods are carboxylic acids (Section 8.3). Is ascorbic acid a carboxylic acid? Explain.
3. What structural features of ascorbic acid help make this compound water-soluble? (You may find it helpful to refer to the discussion of solubility in Section 7.1.)

Like all chemicals, each vitamin has a specific chemical name. In addition, many vitamins are associated with a specific capital letter of the alphabet, and some carry a numerical subscript to that letter. Ascorbic acid, for example, a vitamin that protects us from a disease called scurvy, is also known as Vitamin C. Retinol, a vitamin needed for healthy eyes, is referred to as Vitamin A. Among the vitamins that carry subscripts is a large set of the B vitamins, known collectively as the B complex:

Thiamine (B_1), riboflavin (B_2), pantothenic acid (B_3), niacin (B_4), pyridoxine (B_6), and cobalamin (B_{12}).

Vitamins can be divided into two important groups: the **fat-soluble vitamins** and the **water-soluble vitamins**. Fat-soluble vitamins are much more soluble in fats, hydrocarbons, and similar solvents than in water. Water-soluble vitamins exhibit the opposite property. Vitamins A, D, E, and K constitute the fat-soluble class, and the B complex and vitamin C are water-soluble. This classification (fat-soluble vs. water-soluble) doesn't tell us much about what kinds of food contain any particular vitamin. Some fatty foods can be good sources of the water-soluble vitamins, and moist, green, leafy vegetables often provide ample supplies of fat-soluble vitamins. **Table 14.1** presents the best-known vitamins and brief descriptions of their dietary sources and biological properties.

A full description of the chemistry and the nutritional importance of all the vitamins is beyond the scope of this discussion. Instead, we'll look closely at three of the better-known vitamins: the water-soluble vitamin C and the fat-soluble vitamins A and D.

Vitamin C, a water-soluble vitamin Vitamin C, the best known of all the vitamins, is one of the most widely used dietary supplements. Its chemical name, *ascorbic acid* (**Figure 14.1**), represents two properties of the substance, one chemical, the other biological. First, Vitamin C is an acid, although it's not a carboxylic acid. Second, the term **ascorbic** reflects its ability to protect against the disease **scurvy**. (The words **scurvy** and **ascorbic** come from the Latin word for this disease, *scorbutus*.)

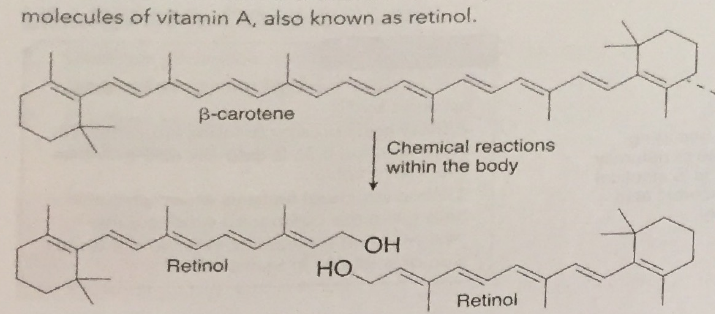
The symptoms of scurvy can develop from a dietary deficiency of vitamin C. Humans require this vitamin for the formation of bonds that hold together strands of the collagen of our connective tissues (Section 5.4). Tough fibers of this protein are important components of our skin, muscles, blood vessels, scar tissue, and similar bodily structures. The gums in particular are rich in blood vessels and are subject to wear and abrasion through eating and the brushing of teeth. Thus, the bleeding of gum tissue, weakened by deterioration of its collagen, can be the first visible symptom of scurvy. As the disease progresses, the gums weaken and decay, the teeth fall out, and the body bruises easily.

Until a few hundred years ago, scurvy was the scourge of sailors, explorers, and those on long military expeditions—people who had to survive for months or years on stored provisions. These provisions lacked the fresh fruits and vegetables that are rich in vitamin C. Although some Dutch and English seamen of the 1500s knew of the value of fresh fruit and lemon juice in preserving sailors' health on long voyages, it wasn't until 1795 that the British navy officially made lemons part of the required stores of its fleet at sea.

Vitamin A, a fat-soluble vitamin Vitamin A maintains the health of eyes, skin, and mucous membranes and is particularly important for good vision in dim light. A deficiency can produce "night blindness," an inability to see in the dark. More severe deficiencies can cause eventual blindness.

Formation of vitamin A • Figure 14.2

Human metabolism converts one molecule of β-carotene into two molecules of vitamin A, also known as retinol.



Think Critically 1. What chemical group is present in retinol but not in β-carotene?
2. What structural features of β-carotene and retinol help make these compounds fat-soluble?
(To answer this question, you may find it helpful to review Section 7.1 on factors that affect solubility.)

Foods rich in β-carotene include root vegetables, such as sweet potatoes and carrots; melons and squashes, such as cantaloupe and pumpkin; green leafy vegetables, such as spinach and kale; and certain fruits, such as apricots, mangos, and papayas.

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As one of the fat-soluble vitamins, vitamin A accumulates in the body's fat cells, particularly in the liver. A moderate excess of vitamin A in our bodies normally does no harm. We simply store it, largely in our livers, for use later, when it might be in short supply. A large excess, though, can overwhelm the body's storage capacity and can generate toxic symptoms, including nausea, blurred vision, loss of hair, and worse, including death. Moreover, even though vitamin A is required for the normal development of an embryo, excesses taken in early stages of pregnancy–and even shortly before conception, since the vitamin can be stored–can produce serious birth defects.

Toxic doses of the vitamin can result from overzealous use of vitamin supplements and from eating certain rare and bizarre foods that are particularly rich in vitamin A. Polar bear livers, for example, contain unusually large quantities of the substance; a 3-oz portion of polar bear liver provides about 200 times the currently recommended daily intake for an adult. There have been reports of extreme toxicity and death among early Arctic explorers who ate large quantities of these livers.

Although animal livers can store very large concentrations of vitamin A, plants don't contain any. Carrots, which are supposed to be a very good source of the nutrient (and indeed are), have none whatever. This strange-sounding contradiction makes more sense when we examine the chemistry of the vitamin.

Our bodies can use vitamin A (known chemically as *retinol*) itself, or we can easily convert several chemical structures closely related to retinol into the vitamin, or even use these closely related compounds directly as retinol's equivalents. For this reason, vitamin levels in foods or supplements are sometimes stated in Retinol Equivalents (REs) of the vitamin, or in International Units (IUs). REs and IUs represent not only the quantity of the vitamin itself, but the total amount of the vitamin and all its physiological equivalents that can be converted into or used as the vitamin. (One RE of vitamin A is equivalent to 1 μg—one microgram or 10^{-6} g—of retinol. One IU of vitamin A represents 0.3 μg of retinol. A little arithmetic shows that 3.33 IUs of retinol constitute one RE.)

Although carrots contain no retinol, they do provide large amounts of β-carotene, a deeply colored material that we easily convert into vitamin A (**Figure 14.2**). With enough of the vitamin stored in our liver, our body stops converting the β-carotene into retinol. As a result, we can't poison ourselves by overeating carrots and other deeply colored red, orange, and yellow fruits and vegetables, all of which provide plenty of β-carotene.

When we consume more β-carotene than we need, some of it reaches our surface tissues, where it's stored and begins imparting its own color to the skin and eyes. There are reports of people whose skin acquires a yellow–orange tint from consuming enormous quantities of carrots and/or tomato juice (which is also rich in carotenes) over a long period. It's a harmless and reversible condition that disappears when carrots and tomatoes are removed from the diet.

Vitamin D, a fat-soluble vitamin Vitamin D promotes the absorption of food-borne calcium and phosphorus through our intestinal wall and into the bloodstream, thereby providing the raw materials for forming and maintaining healthy bones. Without vitamin D, children's bones develop poorly, resulting in the severely bowed legs and other skeletal deformations that characterize the condition known as rickets. Fortifying milk with added vitamin D makes sense because milk is rich in calcium, and the fat-soluble vitamin dissolves readily in milk's fatty components.

However, there's another side to vitamin D. Both rickets and vitamin D itself may be largely the products of the way civilization has developed in the northern and southern latitudes. For some of us, the chemical may not be a vitamin at all because vitamin D, unlike other vitamins, can form in our own bodies. Under the right conditions, we generate vitamin D in our own skin through the action of the sun's ultraviolet rays.

Furthermore, vitamin D isn't even a single organic compound. The term applies to a set of very closely related molecular structures, differentiated from each other by subscripts. There are vitamins D_1, D_2, D_3, and so on, all with the same physiological function. As ultraviolet radiation strikes our skin, it converts a bodily substance known as *7-dehydrocholesterol* into the form of the vitamin known as vitamin D_3, or *cholecalciferol* (**Figure 14.3**).

With plenty of exposure of our skin to sunshine, lots of cholecalciferol would be in plentiful supply in all our bodies, rickets would be virtually unknown, and vitamin D wouldn't be a vitamin at all. But with the limited sunshine, copious clothing, and indoor living and working conditions of the more extreme latitudes, the chemical becomes scarce. This could be especially dangerous for children, whose bones are still growing. Under these conditions, rickets would be common if it weren't for the addition of vitamin D to children's diets, usually in the form of fortified dairy products.

Minerals

You might think of minerals as hard, sometimes metallic or crystalline substances we obtain from the ground, ranging in value from lead to gold, or to gems such as opals or rubies. Nutritionally, though, the term **minerals** refers to all the nutritionally important chemical elements of our foods, except for the carbon, hydrogen, nitrogen, and oxygen that come to us with the macronutrients. Of all the minerals, calcium is the most abundant in our bodies, ranking fifth among all of our atoms, just behind hydrogen, oxygen, carbon, and nitrogen.

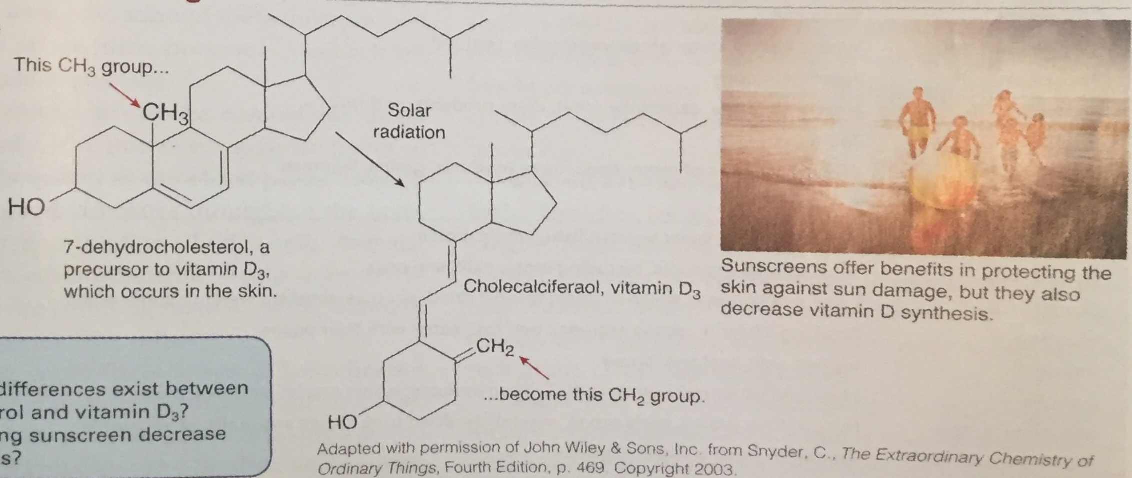
minerals Elements needed by the body in small amounts for proper health.

Two significant features distinguish minerals from vitamins: their structure and their origin. Vitamins are chemical compounds, composed of molecules in which atoms of various elements are held together by covalent bonds. However, all the minerals of food consist of atoms or ions of individual elements. The molecules of vitamins are formed biochemically by the bonding together of various elements within the structures of the plants or animals we use as food; minerals must be absorbed by plants from the soil in which they grow, or ingested by animals as they eat the plants that have absorbed the minerals. In essence, vitamins are synthesized by the living things we eventually eat; minerals can't be created by living things, but (ultimately) must be absorbed from the earth in which they exist.

Major minerals Between 1.5 and 2.0% of your weight comes from calcium—in the form of the Ca^{2+} ion—in your body, and more than 99% of all this calcium lies in your bones and teeth. This means that if you weigh, for example, 70 kg (154 lb), you're carrying around some 1.0–1.5 kg (roughly 2–3 lb) of calcium in your skeleton and in your mouth.

Formation of vitamin D • Figure 14.3

We naturally produce vitamin D when our skin is exposed to the ultraviolet radiation of sunlight.



Sunscreens offer benefits in protecting the skin against sun damage, but they also decrease vitamin D synthesis.

Uwe Krejci/Digital Vision/Getty Images

Ask Yourself

1. What structural differences exist between 7-dehydrocholesterol and vitamin D_3?
2. Why does wearing sunscreen decrease vitamin D synthesis?

> **major minerals**
> Minerals required in the diet in amounts greater than 100 mg per day or present in the body in amounts greater than 0.01% of body mass.

Next in rank of the **major minerals** comes the element phosphorus. Although calcium is the major mineral of our bones and teeth, it takes about half a gram of phosphorus to pack each gram of calcium firmly into the lattices of your bones and teeth and to hold it there. Add to this the smaller amounts of phosphorus in our soft tissues, and a 70-kg person carries around a total of almost a kilogram (about 2 lb) of this element.

We have smaller amounts of potassium, chlorine, sodium, and magnesium inside us, in that order. These elements form the major ions of the fluids in and around cells. (The fluids within the cells are *intracellular*, those outside are *extracellular*.) Potassium ion (K^+), the principal cation inside the cells, governs the activities of the cellular enzymes. Sodium ion (Na^+), which is the dominant cation outside the cells, keeps the water content of the intracellular and extracellular fluids in a healthy balance and thereby helps maintain proper fluid levels in the body. Both sodium and potassium cations regulate the distribution of hydrogen ions throughout the body and thereby keep the acidities of various bodily fluids within their normal ranges. They also play a critical role in the transmission of nerve signals within the body.

Along with these alkali metal cations, chloride anions (Cl^-) also help regulate fluid balances and, in combination with protons, provide the hydrochloric acid in gastric juices. They also serve to balance the electrical charges of the various bodily cations.

Magnesium—in the form of the Mg^{2+} ion within the body—plays several secondary roles. It's second to calcium as the hard mineral of bones and teeth, and second to potassium in regulating biochemical activities within the cells. Magnesium helps control the formation of proteins inside the cells and the transmission of electrical signals from cell to cell.

Another major mineral, sulfur, is a component of the amino acids methionine and cysteine and hence is found within various proteins of the body. Sulfur is also present within other biomolecules, including one essential for the metabolism of all foods and another that helps rid the body of toxins. Sulfur also occurs as part of the sulfate ion (SO_4^{2-}), one of several anions in the blood.

Trace minerals Together, just 11 elements–the carbon, hydrogen, nitrogen, oxygen, and sulfur of the macronutrients and of water, and the calcium, phosphorus, potassium, chlorine, sodium, and magnesium of the micronutrients–compose well over 99% of the mass of all living matter. All the remaining elements necessary for good health constitute the category of **trace minerals**. Generally, we consider trace minerals to be those needed

> **trace minerals**
> Minerals required in the diet in amounts of less than 100 mg per day.

Dietary sources of minerals Table 14.2

Major Minerals	Source
Calcium, Ca	Milk and dairy products such as cheese and ice cream; fish, such as sardines, eaten with their bones; broccoli and other dark green vegetables; legumes
Chlorine, Cl	Table salt
Magnesium, Mg	Whole grains; nuts; green vegetables; seafood
Phosphorus, P	Nearly all foods
Potassium, K	Nearly all foods, especially meat, dairy products, and fruit
Sodium, Na	Table salt
Sulfur, S	Dietary proteins of meat, eggs, dairy products, grains, legumes
Minor Minerals	**Source**
Chromium, Cr	Brewer's yeast; meat (except fish); whole grains
Cobalt, Co	Most animal products, including meta, milk, and eggs
Copper, Cu	Liver and kidneys; shellfish; nuts; raisins; dried legumes; drinking water in some areas
Fluorine, F	Drinking water (in some regions); tea; fish, eaten with their bones
Iodine, I	Iodized salt; seafood; bread
Iron, Fe	Liver and other red meats; raisins; dried apricots; whole grains; legumes; oysters
Manganese, Mn	Nuts; whole grains; leafy green vegetables; dried fruits; roots and stalks of vegetables
Molybdenum, Mo	Animal organs; cereals; legumes
Selenium, Se	Various foods, including Brazil nuts, grains, meat, and seafood
Zinc, Zn	Meat; eggs; seafood (particularly oysters); dairy products; whole grains

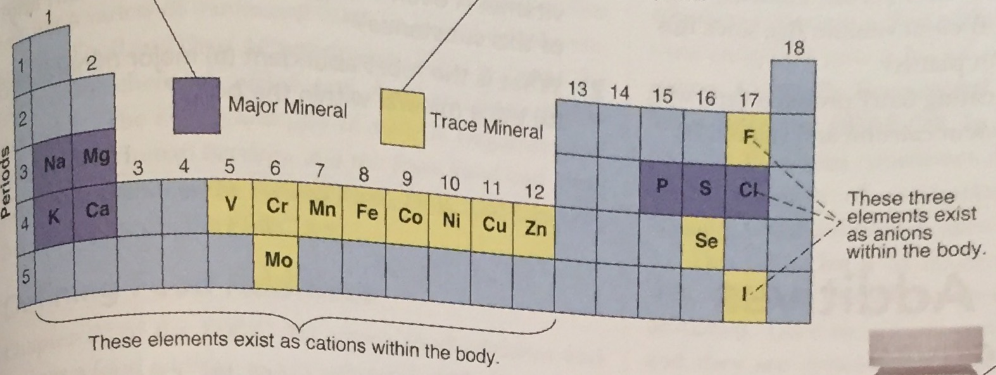
WHAT A CHEMIST SEES

Dietary Minerals and the Periodic Table

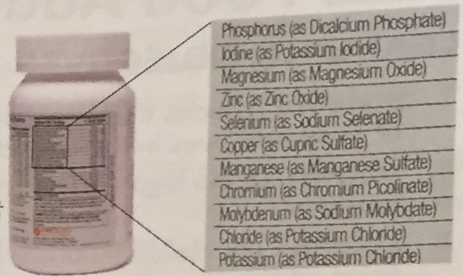
Dietary minerals are atoms or ions of elements that are necessary in small amounts for good health.

Major minerals collectively account for about 3% of the mass of our bodies. These minerals include the Group 1 elements, sodium (Na) and potassium (K); the Group 2 elements, magnesium (Mg) and calcium (Ca); and the nonmetals, phosphorus (P), sulfur (S), and chlorine (Cl). Calcium is the most abundant major mineral, followed by phosphorus.

Trace minerals are present in far lower quantities within the body than the major minerals. These elements include the Period 4 transition metals, vanadium (V) through zinc (Zn); the Period 5 transition metal, molybdenum (Mo); and the nonmetals, selenium (Se), fluorine (F), and iodine (I). Iron is the most abundant trace element within the body, yet constitutes only 0.005% of our body mass.



Since almost all dietary minerals exist as ions, multimineral supplements, such as that shown here, provide these minerals in the form of ionic compounds.



Ken Karp

Ask Yourself

Just four elements—hydrogen, carbon, nitrogen, and oxygen— make up 96% of the mass of our bodies. Where are these elements located in the periodic table?

in our diets at levels of less than a tenth of a gram (less than 100 mg) per day.

Among the more important trace minerals are iron, fluorine, zinc, copper, selenium, manganese, iodine, molybdenum, chromium, and cobalt, arranged here in decreasing order of their presence in an adult body. They function in various ways, with most of them incorporated into the structures of enzymes, hormones, and related biologically important molecules.

Iron forms a critical part of the hemoglobin molecule in red blood cells. The iron of hemoglobin bonds to oxygen molecules acquired as the blood passes through the lungs. As the blood circulates throughout the body, it dispenses this oxygen to all the body's cells. Anemia, a condition characterized by fatigue, results from a deficiency of iron and the resulting inability of the blood to carry sufficient oxygen to the cells.

Fluorine, acting as the fluoride anion, helps harden the enamel of teeth, making them resistant to decay. Many communities add fluoride salts to drinking water to protect the teeth of children. The fluoride anion, often as sodium fluoride, is also an ingredient of most anti-cavity toothpastes.

Other trace minerals include zinc, which promotes growth, the healing of wounds, and the development of male sex glands. Iodine is important to the proper development and operation of the thyroid gland in the neck. A deficiency of iodine can lead to enlargement of the thyroid gland, a condition known as a goiter, and has been implicated in learning deficiencies. A single cobalt atom is incorporated into every molecule of vitamin B_{12}.

Still other trace minerals play various roles in the body. Deficiencies of copper can produce symptoms ranging from changes in hair color to anemia and bone disease, and may impair the immune system. Manganese is essential for healthy bones, a well-functioning nervous system, and reproduction. Chromium plays an important part in the metabolism of glucose.

Table 14.2 summarizes some of the more common dietary sources of minerals. *What a Chemist Sees* summarizes some of the distinctions between the major minerals and the trace minerals, and their locations within the periodic table.

Eating a well-balanced diet and a variety of foods is the best way to ensure that you are obtaining sufficient micronutrients. Generally, healthy adults who maintain a good diet do not need to take vitamin and mineral supplements. Nevertheless, these supplements may be recommended for certain groups of individuals, including:

- those on calorie-restricted diets (<1600 Calories/day)
- vegans (who may lack sufficient vitamin B_{12}, since this vitamin does not occur in plants)
- those who abstain from eating dairy products (and who may therefore lack sufficient calcium and vitamin D)
- women of child-bearing age and pregnant women (who should consume at least 400 mg of folic acid daily), and
- older adults

CONCEPT CHECK STOP

1. **Why** are carrots considered a good source of vitamin A even though they do not contain any of this substance?
2. **What** is the most abundant (a) major mineral and (b) trace mineral within the body?