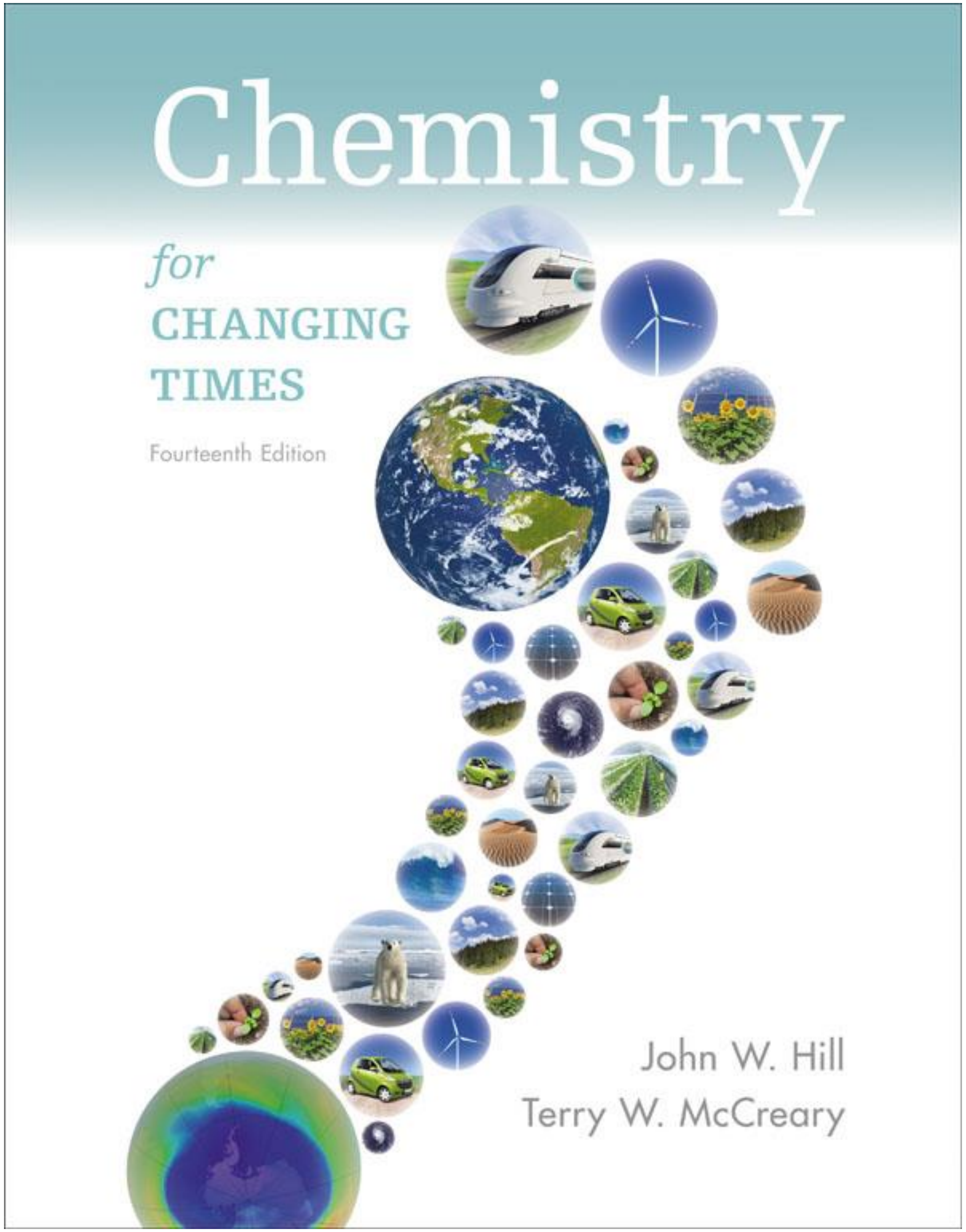

Chemistry for Changing Times,

Fourteenth Edition

Lecture Outlines

Chapter 12
Chemistry of Earth

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Learning Objectives

- Describe the structure of Earth and the regions of Earth’s surface. (12.1)
- List the most abundant elements in Earth’s crust. (12.1)
- Describe the arrangement of silicate tetrahedra in common silicate minerals. (12.2)
- Describe how glass differs in structure from other silicates. (12.2)

Learning Objectives

- List the most important metals with their principal ores, and explain how they are extracted. (12.3)
- Describe some of the environmental costs associated with metal production. (12.3)
- List the main components of solid waste. (12.4)
- Name and describe the three Rs of garbage. (12.4)

Learning Objectives

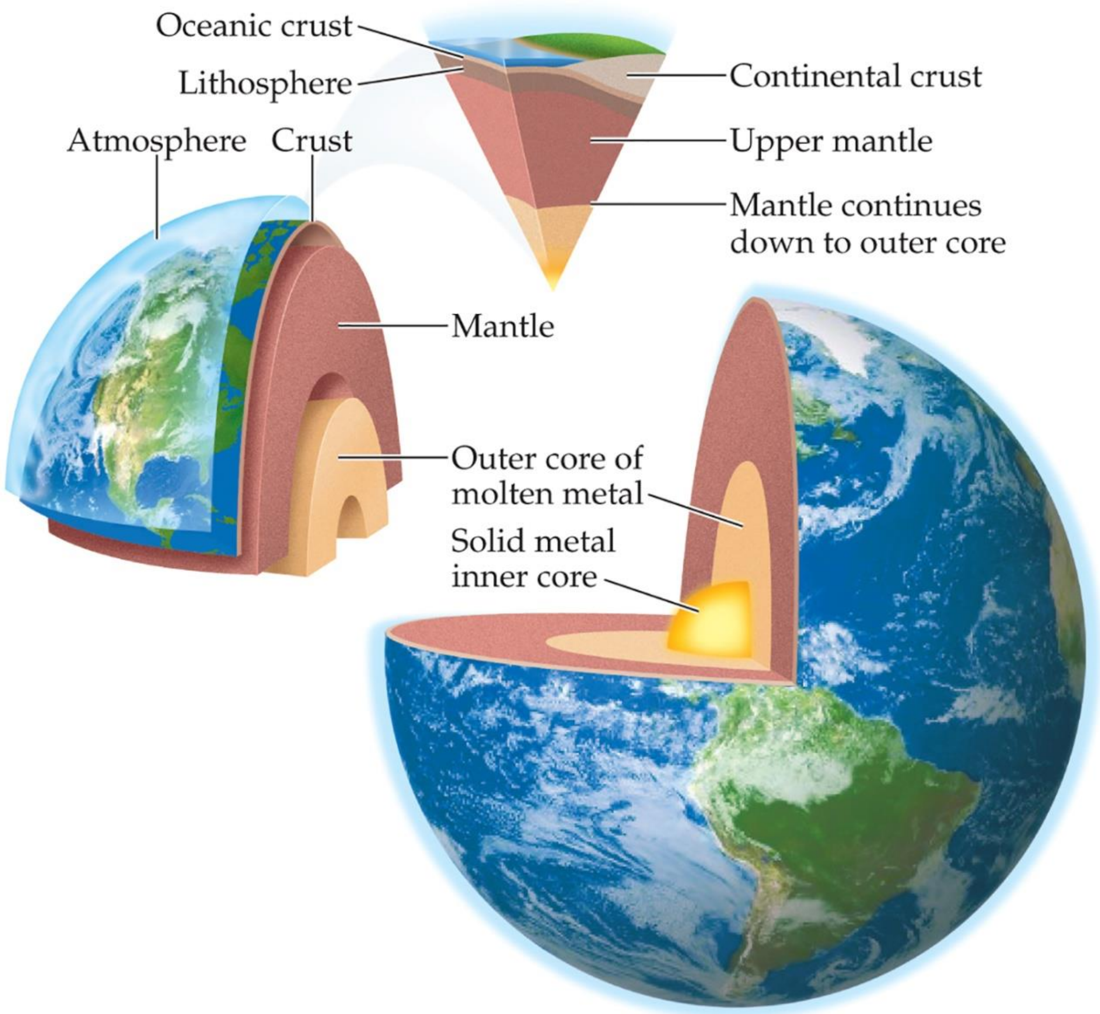
- Identify the green chemistry principles that can guide the determination of which metal, Fe or Al, is greener.
- Describe how recycling supports sustainable use of natural resources.

Spaceship Earth: Materials Manifest

Earth is divided into three main regions:

1. The ***core*** is largely iron and nickel and is not accessible.
2. The ***mantle*** consists of silicates and a variety of metals.
3. The ***crust*** is the outer shell of Earth. The ***lithosphere*** is the land masses, the ***hydrosphere*** makes up the water, and the ***atmosphere*** is the air surrounding Earth.

Spaceship Earth: Materials Manifest



Spaceship Earth: Materials Manifest

Table 12.1 Elemental Composition of the Earth's Surface

Element	Atom Percent	Percent by Mass
Oxygen	53.3	49.5
Silicon	15.9	25.7
Hydrogen	15.1	0.9
Aluminum	4.8	7.5
Sodium	1.8	2.6
Iron	1.5	4.7
Calcium	1.5	3.4
Magnesium	1.4	1.9
Potassium	1.0	2.4
All others	3.7	1.4
Total	100.0	100.0

The Lithosphere: Organic and Inorganic

The inorganic portion of the ***lithosphere*** is composed of rocks and minerals.

Table 12.2 Some Nonsilicate Minerals of Economic Importance

Mineral Type	Name	Chemical Formula	Source and/or Use
Oxide	Hematite	Fe_2O_3	Ore of iron; pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone; abrasive
Sulfide	Galena	PbS	Ore of lead
	Chalcopyrite	$CuFeS_2$	Ore of copper
Carbonate	Calcite	$CaCO_3$	Cement; lime

The Lithosphere: Organic and Inorganic

The ***organic*** portion of the lithosphere includes the living organisms, their waste and decomposition products, and their fossilized remains (including petroleum products). These organic materials contain carbon, as well as elements such as hydrogen, oxygen, and nitrogen.

Meeting Our Needs: From Sticks to Bricks

Throughout human history, our existence has depended on our ability to extract from Earth materials to sustain and enrich our lives. Much of science is devoted to the development of knowledge and technology for extracting and developing materials to enhance our existence.

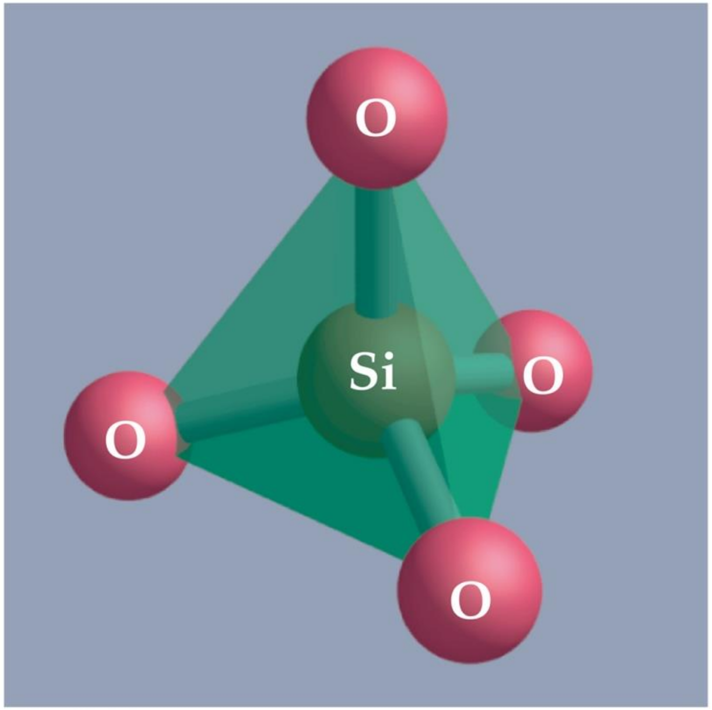
Silicates and the Shapes of Things

Table 12.3 Silicate Tetrahedra in Some Minerals

Mineral(s)	SiO_4 Arrangement	Formula	Uses
Zirconium silicate	Simple anion (SiO_4^{4-})	$ZrSiO_4$	Ceramics; gemstones (zircon)
Spodumene	Long chains	$LiAl(SiO_3)_2$	Source of lithium and its compounds
Chrysotile asbestos	Double chains	$Mg_3(Si_2O_5)(OH)_4$	Fireproofing (now banned)
Muscovite mica	Sheets	$KAl_2(AlSi_3O_{10})(OH)_4$	Insulation; lustrous paints; packing (vermiculite)
Quartz	Three-dimensional array	SiO_2	Making glass (sand); gemstones (amethyst, agate, citrine)

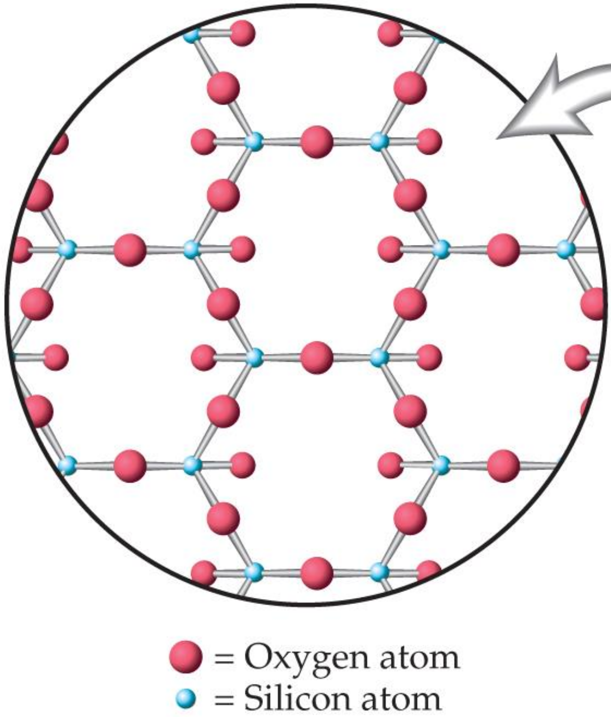
Silicates and the Shapes of Things

Quartz is silicon dioxide (SiO_2). Silicon dioxide is a macromolecular substance composed of oxygen-linked silicon in a tetrahedral array. The ratio of oxygen to silicon is 2:1.



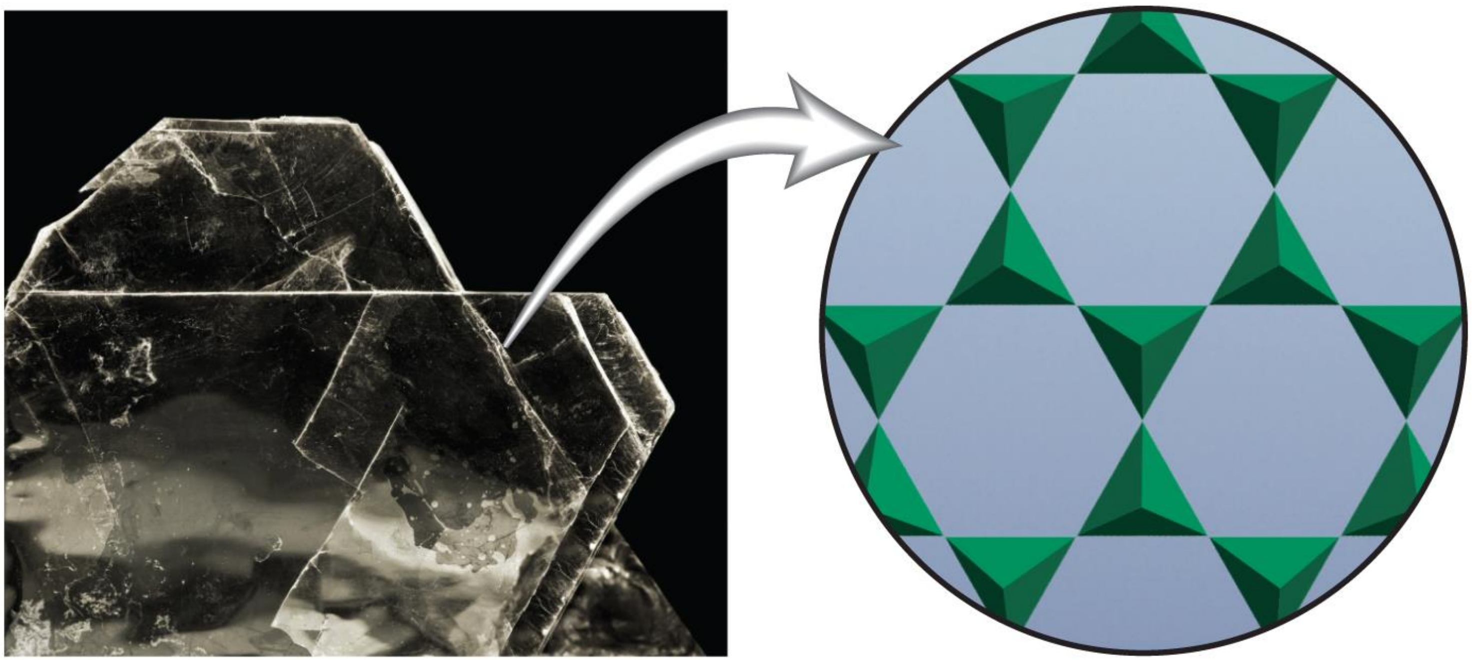
Silicates and the Shapes of Things

Quartz is pure silicon dioxide (SiO_2).



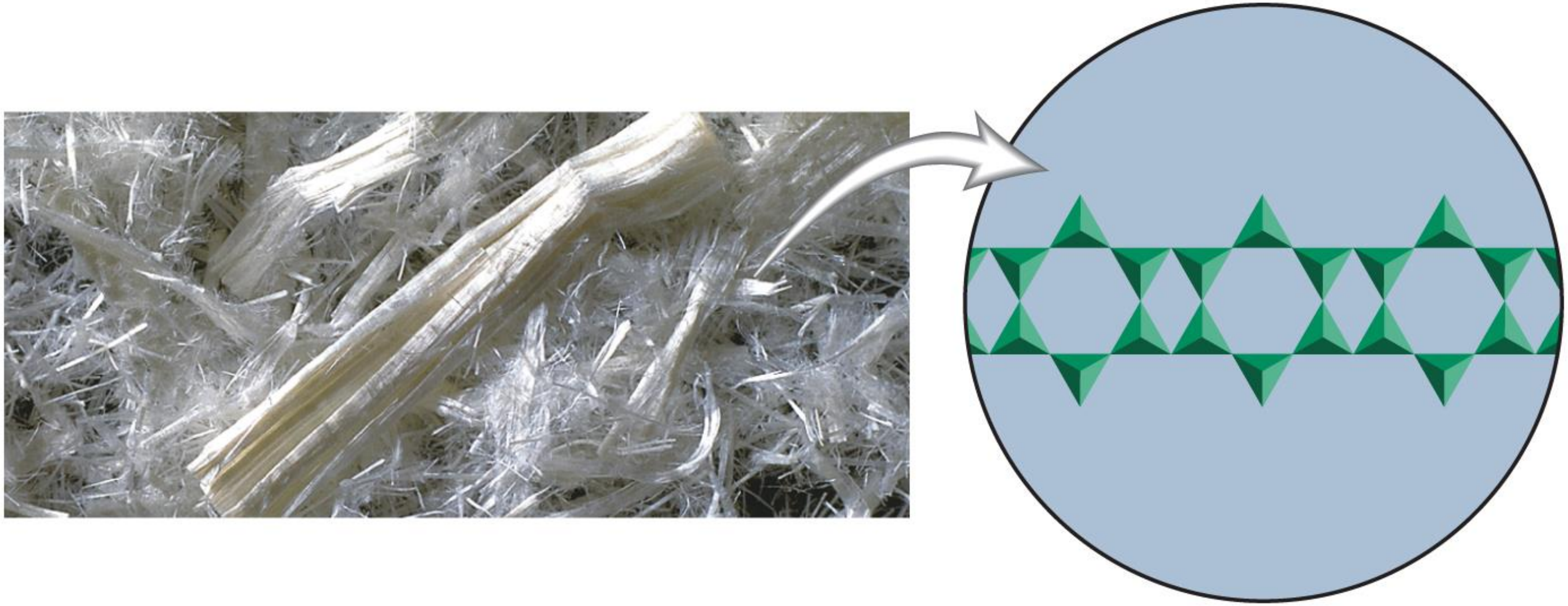
Silicates and the Shapes of Things

Micas are composed of SiO_4 tetrahedra arranged in a two-dimensional, sheetlike array.



Silicates and the Shapes of Things

The term ***asbestos*** applies to a variety of fibrous silicates. The best known is *chrysotile,* which is a magnesium silicate.

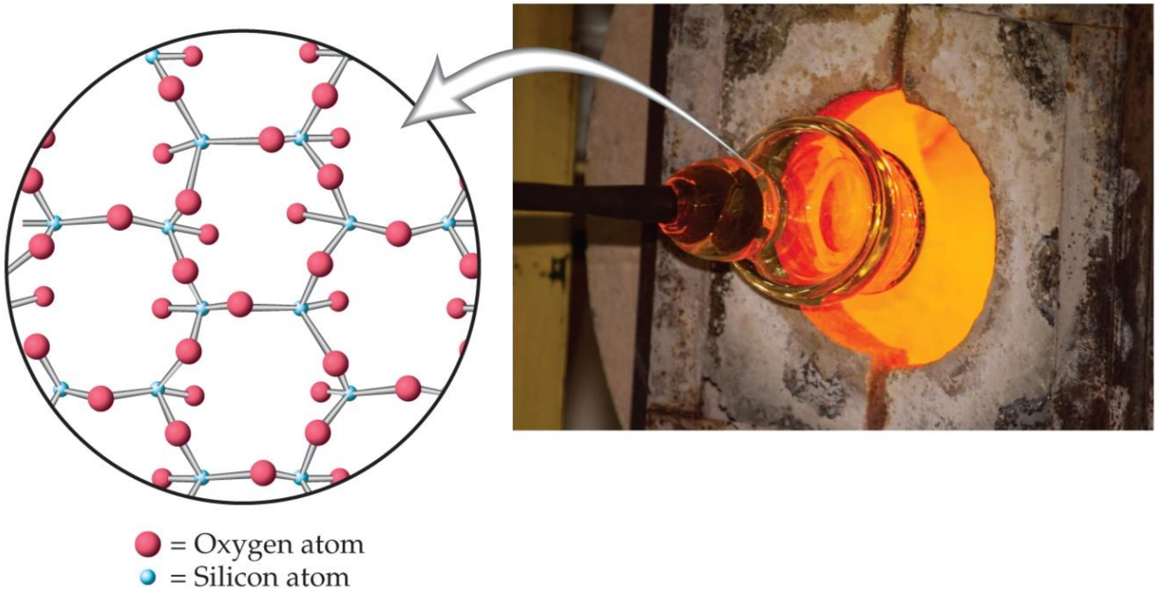


Modified Silicates: Ceramics, Glass, and Cement

Ceramics are clays (aluminum silicates) that have been shaped and fired to a hard, durable material. Ceramic research has led to some amazing new materials.

Modified Silicates: Ceramics, Glass, and Cement

Glass is a noncrystalline solid. It was first made in ancient Egypt by heating sand, sodium carbonate (Na_2CO_3), and limestone ($CaCO_3$).
The properties of glass can be varied by adding or replacing certain components.



Modified Silicates: Ceramics, Glass, and Cement

Table 12.4 Compositions and Properties of Various Glasses

Type	Special Ingredient(s)	Special Properties and/or Uses
Soda–lime glass	Sodium and calcium silicates	Ordinary glass for windows, bottles, other housewares
Borosilicate glass	Boron oxide (instead of lime)	Heat-resistant, for laboratory ware and ovenware
Lead glass	Lead oxide (instead of lime)	Highly refractive (bends light); optical glass, art glass, table crystal
Colored glass	Selenium compounds	Red (ruby glass)
	Cobalt compounds	Blue (cobalt glass)
	Chromium compounds	Green
	Manganese compounds	Violet
	Carbon and iron oxide	Brown (amber glass)
Photochromic glass	Silver chloride or bromide	Darkens when exposed to light, for sunglasses, hospital windows

Modified Silicates: Ceramics, Glass, and Cement

Cement and Concrete

Cement is a complex mixture of calcium and aluminum silicates. Raw materials of limestone ($CaCO_3$) and clay (aluminum silicates) are mixed and heated to high temperature. The resulting material is called ***clinker***. Clinker is ground to a fine powder and mixed with gypsum ($CaSO_4$). The resulting cement is then mixed with aggregate (sand and gravel) and water. When it cures (hardens), it is known as ***concrete***.

Modified Silicates: Ceramics, Glass, and Cement

Cement and Concrete

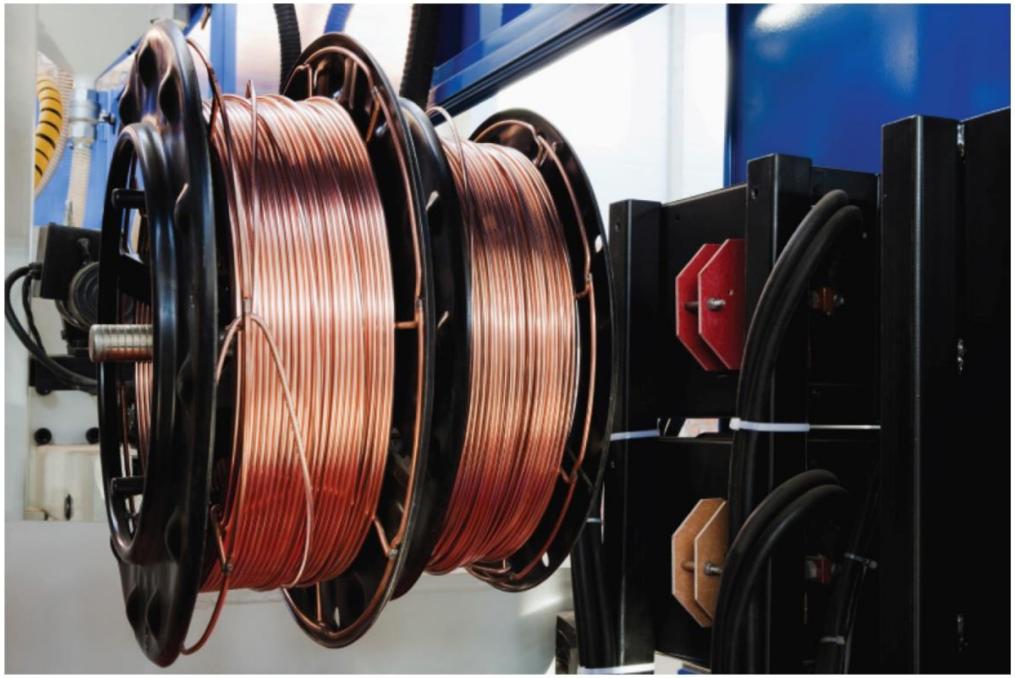
To make Portland cement, the ground limestone and clay are heated in a kiln to about 1500 °C before mixing with sand, gravel, and water to form concrete.

Metals and Ores

Human history is often defined by our ability to extract useful materials and minerals from Earth. For example, we use the terms *Stone Age*, *Bronze Age*, and *Iron Age*. Each of these “ages” has been defined by our ability to develop the technology to extract materials and make useful tools for our lives.

Metals and Ores

Copper is sometimes found in the native (uncombined) state. It was the first metal to be won from its ore by smelting techniques.



Metals and Ores

Bronze is an alloy of copper with about 10% tin. It is harder than copper and could be used for many useful tools.

Metals and Ores

Iron is produced from iron ores using high-temperature furnaces, such as blast furnaces.

In the furnace, coke (C) is converted to carbon monoxide:

$$2\,C(s) + O_2(g) \rightarrow 2\,CO(g)$$

Then the carbon monoxide reduces the iron oxide to molten iron:

$$Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(l) + 3\,CO_2(g)$$

Metals and Ores

Basic Oxygen Furnace

Pure oxygen is blown into a mix of blast furnace iron and scrap iron. Powdered limestone is added to the top of the furnace.

Metals and Ores

Iron and Steel

Limestone is added to the furnace to combine with silicate impurities in the ore to form ***slag***.

The molten iron drawn off the bottom of the furnace is known as ***pig iron***, and when solidified, it is known as ***cast iron***.

Cast iron is brittle and must be alloyed with carbon to form **steel**.

Steel can be alloyed with other metals to achieve desired properties.

Metals and Ores

Iron and Steel

Table 12.5 Some Alloys of Iron

Material	Alloying Elements	Properties
Cast iron (pig iron)	2–4% C	Strong, rigid, brittle
Wrought iron	Very low C	Tough, malleable, ductile, easily welded
Stainless steel	12–30% Cr; some Ni	Corrosion resistance
Manganese steel	13% Mn; some C	Hardness; wear resistance
Nickel steel	0.5–6.0% Ni; some C	Strength
Molybdenum steel	10–15% Mo; some C	Wear resistance
Tungsten steel	1–20% W; some C	Strength at high temperatures

Metals and Ores

Aluminum is the most abundant metal in Earth's crust. Its principal ore is bauxite (impure aluminum oxide). Al_2O_3 is extracted from its impurities with a strong base, and then electricity is passed through the molten oxide to produce molten aluminum metal. Aluminum production is extremely energy intensive.

$$2\ Al_2O_3(l) \rightarrow 4\ Al(l) + 3\ O_2(g)$$

Metals and Ores

Other Important Metals

Table 12.6 Technologically Important Metals

Metal	Source(s)	Typical Use(s)	Annual World Production (t)
Indium	China, Canada	Transparent, conducting coatings on LCD displays and photovoltaic cells	625
Lithium	Chile, Argentina	Batteries for tools, laptops, digital cameras, and cell phones	30,200
Palladium	Russia	Catalytic converters, energy-storing capacitors in electronic devices	225
Platinum	South Africa, Russia	Catalytic converters, computer hard drives, glass for LCD displays, fuel cells	220
Rare earths (lanthanides)	China	Electronics, energy-efficient technologies	117,000
Europium		Red phosphor in CRT displays	
Cerium		Commercial catalysts, glass polishing, self-cleaning ovens	
Neodymium		Ingredient in super magnets and lasers	
Yttrium	China	Fluorescent light bulbs, ceramics, lasers	500
Tantalum	Democratic Republic of the Congo	Electronic capacitors in computers, digital cameras, and cell phones	900

Earth's Dwindling Resources

At one time, many metals were available as native materials or high-grade ores.

High-grade ores are disappearing, and the demand for metals has not diminished.

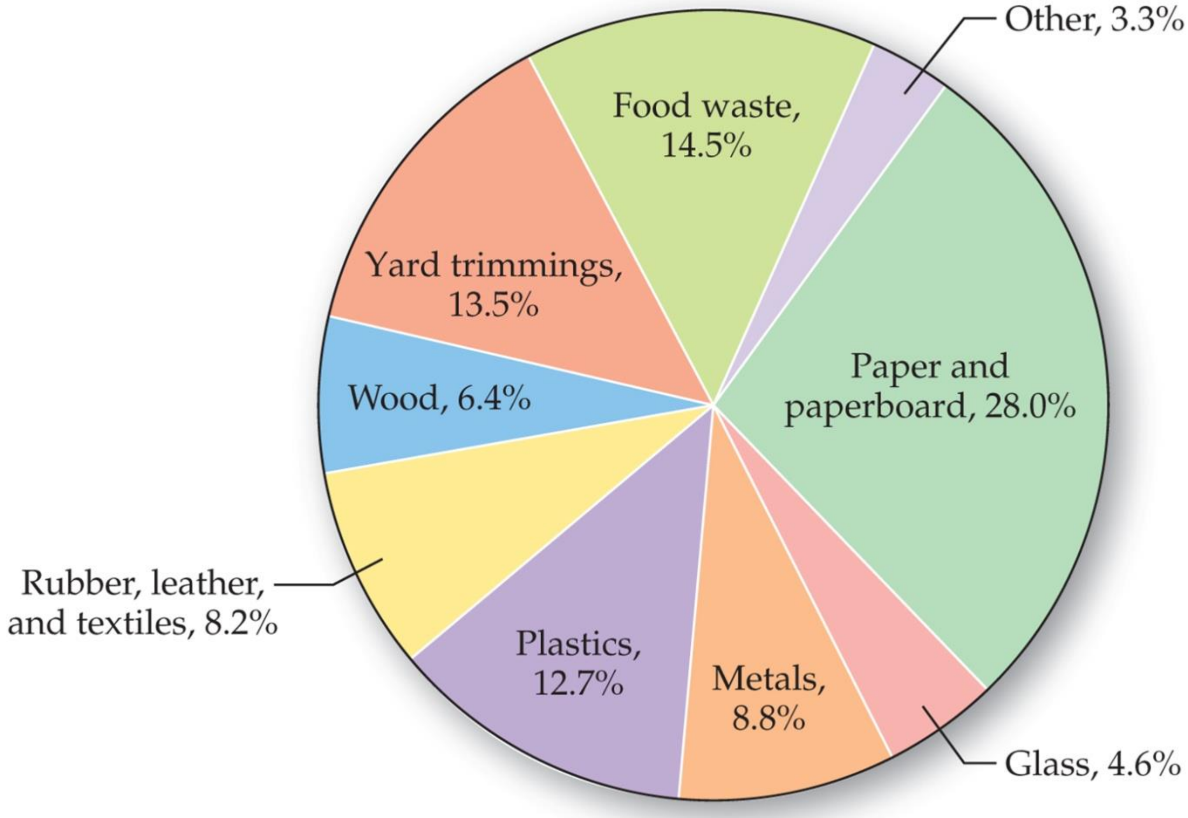
Lower- and low-grade ores are now being mined and smelted at increased economic and environmental cost.

Earth’s Dwindling Resources

The oceans are one possible source of metals in the future.

Land Pollution: Solid Wastes

Municipal solid wastes (MSWs) are the by-products of our modern world.



Land Pollution: Solid Wastes

Currently in the United States 30% of MSWs is recovered and recycled or composted, 14% is incinerated, and 56% is disposed of in sanitary landfills.

The Three Rs of Garbage: Reduce, Reuse, and Recycle

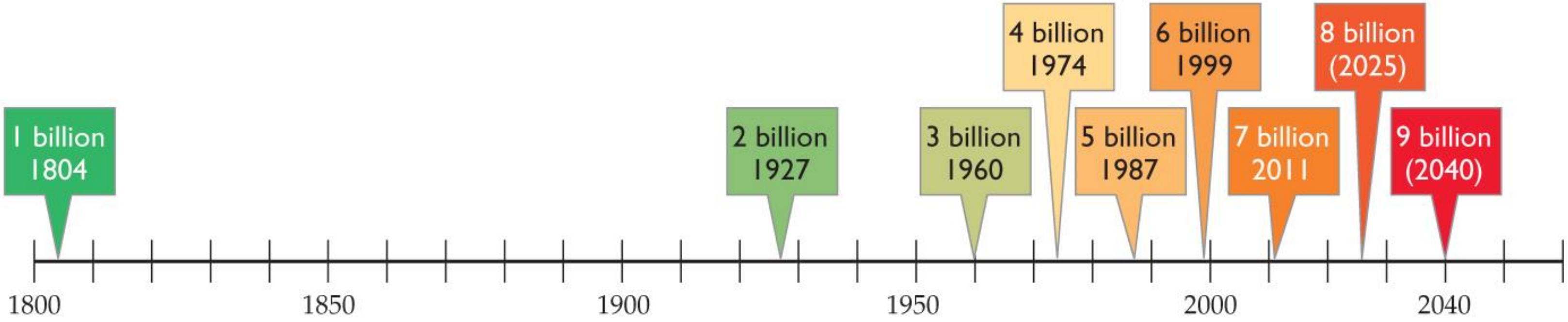
Reducing the amount of disposable materials is the best way of dealing with solid waste.

Reusing materials both saves energy for production of new materials and alleviates disposal concerns.

Recycling reduces waste volume, but there is an energy cost.

How Crowded Is Our Spaceship?

Each day, 200,000 more people are born than die. Scientific advances have reduced the death rate and done little to reduce the birth rate. The United Nations estimates a world population of 9.0 billion people by the middle of the twenty-first century.



Instructor's Resource Materials (Download only) for *Chemistry for Changing Times*, 14/e
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