Contemporary Chemistry

A Practical Approach

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How Are Metals Obtained?

Instructional Objectives

After completing this chapter, you will be able to:

1. Define activity (of metals), alumina, blister copper, bronze, calcine, case hardening, cast iron, charge, copper matte, cryolite, flotation, flux, gangue, ore, pig iron, quenching, reduction, reverberatory (furnace), roasting, slag, steel, and tempering.
2. Explain the difference between first-rate and second-rate ores.
3. List one ore for each of the following metals: iron, copper, and aluminum.
4. Explain how iron, lead, copper, aluminum, and titanium are extracted from their ores.
5. Compare three types of steel.
6. Outline the steps of a generalized metallurgical process, and specific steps for iron, copper, aluminum, and titanium.
7. Compare the handling of oxide, sulfide, and carbonate ores.
8. Compare steel with pig iron.
9. Recognize that titanium is a modern material developed for the jet/space age.

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How Are Metals Obtained?

Part I

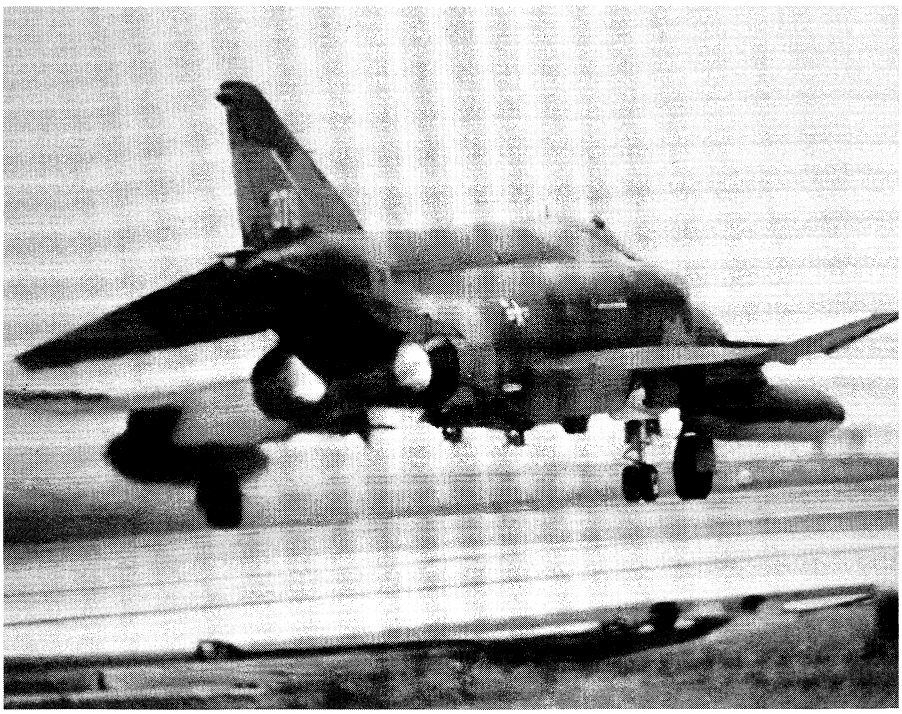


FIGURE 9-1 Courtesy: U.S. Dept. of Defense

Titanium alloys were developed by metallurgical engineers for use in jet engines. They can withstand the intense heat and extreme forces that these engines produce. This is the rear view of a U.S. Air Force F-4 Phantom jet taking off with its after-burners glowing.

Introduction

In 1978, doctors substituted steel rods for shattered bones and hips. After seven years, the metal developed cracks and failed. Since then, alloys have been developed that outlast human bones. Buses, automobiles, and airplanes have also experienced metal failure. The titanium alloy linings of a rocket or jet engine were developed after many years of intensive research. They must withstand severe forces and high temperatures. Why do some metals succeed where others fail? How do we get metals? What is the job of the metallurgical engineer?

FIGURE 9-2 Courtesy: New York City Transit Authority

The N.Y.C. Transit Authority removed new buses from the streets after five months of service because metal parts broke due to metal failure.

9-1 Where Are Metals Found?

About 80% of the elements are metals. They are found as parts of natural chemical compounds, or **minerals** (see section 8–1). The rocks of the earth are mixtures of minerals.

The first metals used by humans were probably gold, silver, and copper. These metals can be found free in nature. Iron, lead, and other metals required energy and technology to be liberated from their compounds. The Iron Age came about many years after the Copper Age (also called the Bronze Age). The ancient techniques for the production of iron, copper, tin, and lead have changed very little. Aluminum and titanium were not discovered until modern times. These metals require special technologies that were not available to early civilizations.

9-2 Why Can't All Metals Be Found Free in Nature?

In Chapter 4, we saw that atoms of metals give away their valence electrons. Some metals lose their electrons more easily than others. The ease with which a metal releases its valence electrons is called its **activity**.

Table 9-1

Ore/Mineral	Formula	
Iron Ores		
magnetite	Fe_3O_4	
hematite	Fe_2O_3	
limonite	mixture FeO + Fe_2O_3	
taconite	contains hematite and magnetite	
Copper Ores		
native copper	Cu	
chalcocite	Cu_2S	
malachite	$CuCO_3$	
azurite	$CuCO_3$	
cuprite	Cu_2O	
Other Ores		
uraninite	UO_2	
carnotite	mixture of uranium and vanadium	
aluminum ore	bauxite	Al_2O_3
lead ore	galena	PbS
titanium ore	ilmenite	$FeTiO_3$
zinc ore	sphalerite	Zns

Table 9-2

Activity of Metals

(In water at 25°C and 1 atm)

The metals are listed in their decreasing order of activity. The most active metal is listed first and the least active metal is last on the list.

Metal	Ionization Equation	* Volts
lithium	$Li - e \longrightarrow Li^{+}$	+ 3.04
rubidium	$Rb - e \longrightarrow Rb^{+}$	+ 2.98
potassium	$K - e \longrightarrow K^{+}$	+ 2.93
cesium	$Cs - e \longrightarrow Cs^{+}$	+ 2.92
barium	$Ba - 2e \longrightarrow Ba^{2+}$	+ 2.91
strontium	$Sr - 2e \longrightarrow Sr^{2+}$	+ 2.89
calcium	$Ca - 2e \longrightarrow Ca^{2+}$	+ 2.87
sodium	$Na - e \longrightarrow Na^{+}$	+ 2.71
magnesium	$Mg - 2e \longrightarrow Mg^{2+}$	+ 2.37
aluminum	$Al - 3e \longrightarrow Al^{3+}$	+ 1.60
manganese	$Mn - 2e \longrightarrow Mn^{2+}$	+ 1.18
zinc	$Zn - 2e \longrightarrow Zn^{2+}$	+ 0.76
iron	$Fe - 2e \longrightarrow Fe^{2+}$	+ 0.44
cobalt	$Co - 2e \longrightarrow Co^{2+}$	+ 0.28
nickel	$Ni - 2e \longrightarrow Ni^{2+}$	+ 0.25
tin	$Sn - 2e \longrightarrow Sn^{2+}$	+ 0.14
lead	$Pb - 2e \longrightarrow Pb^{2+}$	+ 0.13
hydrogen	$H - e \longrightarrow H^{+}$	0.00
copper(ic)	$Cu - 2e \longrightarrow Cu^{2+}$	- 0.34
copper(ous)	$Cu - e \longrightarrow Cu^{+}$	- 0.52
mercury(ic)	$Hg - 2e \longrightarrow Hg^{+}$	- 0.78
mercury(ous)	$Hg - e \longrightarrow Hg^{+}$	- 0.79
silver	$Ag - e \longrightarrow Ag^{+}$	- 0.80
gold	$Au - 3e \longrightarrow Au^{+3}$	- 1.50

*Volts can be thought of as a measure of metallic activity.

More active metals replace less active metals in compounds. The atoms of zinc lose their electrons more easily than atoms of copper. When zinc atoms contact copper ions (Cu^{+2}), the zinc atoms force their electrons onto the copper ions. The result is that the zinc ionizes and the copper ion is restored to the free (uncombined) metal.

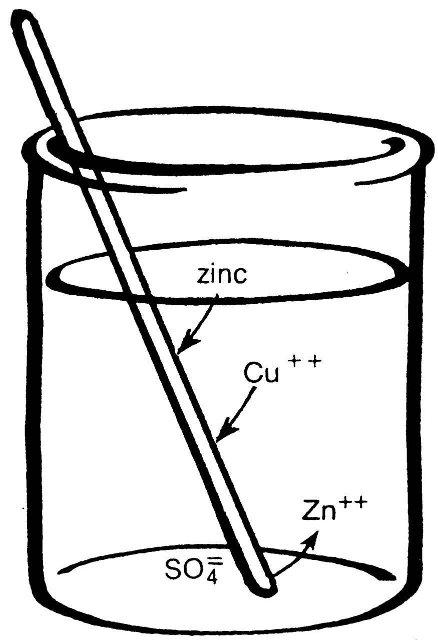


FIGURE 9-3

$Zn^0 + CuSO_4 \quad ZnSO_4 + Cu^0$

More active metals replace less active metals from their compounds. In this beaker, the zinc strip dissolves, and the copper ions deposit on the strip as free metallic copper.

Table 9-3

$$Zn^0 - 2e \longrightarrow Zn^{2+}$$

$$Cu^{2+} + 2e \longrightarrow Cu^0$$

A free metal is shown with a zero charge. Metallic ions are positively charged due to the loss of valence electrons. Nonmetallic ions are negatively charged due to the gain of electrons.

The activity table of metals shows that gold, silver, and copper are all less active than hydrogen. Since they cannot replace the hydrogen in water or any acid, they may possibly be found free in nature. The metals listed above hydrogen, in the activity series, are all more active than hydrogen and capable of replacing the hydrogen in water and acids. They are almost never found free in nature.

9-3 How Are Metals Extracted from Their Ores?

Metallurgy deals with the freeing of metals from their **ores**. An ore is a mineral-bearing rock. The mineral is a compound of the desired metal. The nonmineral part of the ore is called the **gangue** or waste.

MINERAL + GANGUE = ORE

In general, to separate a metal from its ore, we must complete the following steps.

1. Mine the ore.
2. Separate the mineral from the gangue.
3. Change the mineral into the oxide of the metal.
4. Remove the oxygen from the metallic oxide (reduction).
5. Refine the metal (remove the impurities).

9-4 How Is Iron Extracted from the Earth?

The best ores of iron are magnetite and hematite. These ores are considered best because they are richer in minerals and contain less gangue. Unfortunately, the world supply of these excellent ores is about exhausted. In the United States, iron is extracted from second-rate iron ores, such as **taconite** (named after the Taconic Indians). This ore is mined in the Mesabi Range near Duluth, Minnesota. The ore is first concentrated using the **flotation process**. This process was discovered by a washwoman. She noticed that as she laundered the miners' ore- and grease-stained pants, the mineral particles would stick to the oily and soapy bubbles. The pebbles sank to the bottom of the tub. Mining engineers separate the gangue from the mineral by first pulverizing (grinding into a powder) the ore. The powdered ore is then put into an oil-water bath and vigorously frothed up with air. The mineral sticks to the oily bubbles and the froth is skimmed off the surface. The gangue settles to the bottom and is discarded. The mineral consists of iron oxide: Fe_2O_3. This mineral is then mixed with coal and limestone and made into a **charge**. The charge is the mixture put into the blast furnace, to be converted into an impure form of iron called **pig iron** or **cast iron**.

Courtesy: Union Carbide Co.

FIGURE 9-4a

Flotation cell, a standard tool in mining for 50 years, here carries copper and molybdenum ore particles in an oil bubble froth, while unwanted rock particles sink to cell bottom. Ore is crushed before flotation can take place.

Courtesy of Umetco Minerals Corp.

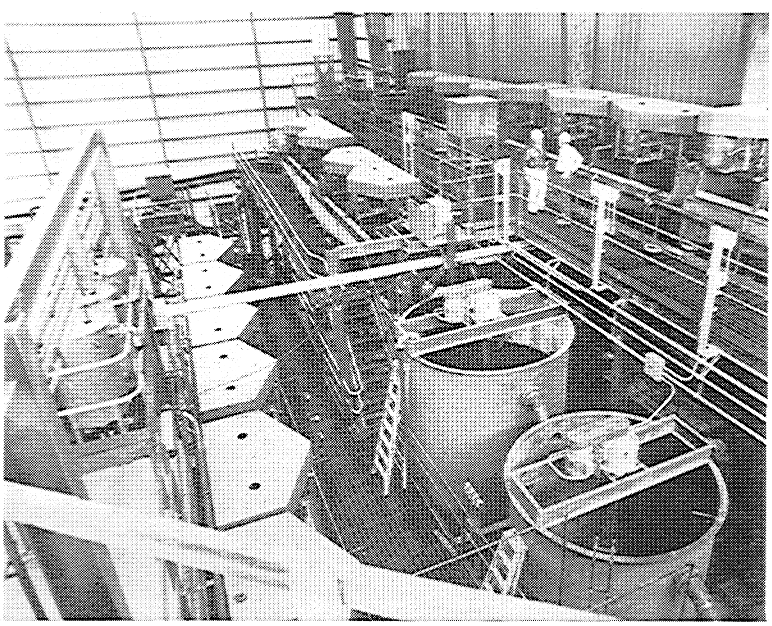
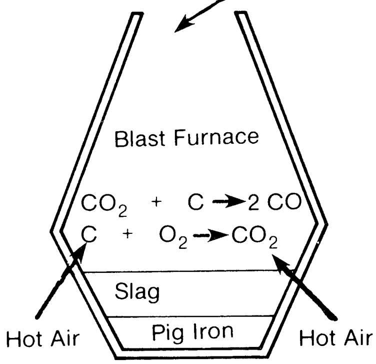


FIGURE 9-4b

Tungsten ore is separated from its waste rock by flotation. Flotation is a physical-chemical method of removing the ore by bubbling air through the slurry. The chemicals allow the tungsten-ore particles to attach themselves to the air bubbles, which carry them to the top of the slurry to form a mineral-rich froth which is skimmed off. The waste rock sinks to the bottom of the flotation cell and is carried away to the tailings pond.

FIGURE 9-5a



SiO_2 (sand)
Fe_2O_3
C (coal)
$CaCO_3$ (limestone)

} Charge

Reactions in the Blast Furnace

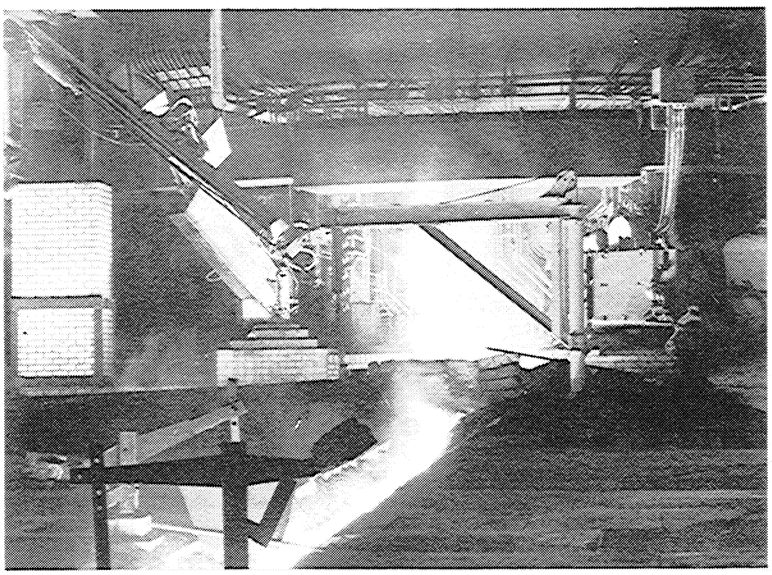
$Fe_2O_3 + 3\,C \longrightarrow 2\,Fe + 3\,CO\uparrow$

$CaCO_3 \xrightarrow{\text{(heat)}} CaO + CO_2\uparrow$

$CaO + SiO_2 \longrightarrow CaSiO_3$ ← {slag or calcium silicate

$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$

The slag is used to make cement (see section 8-2). Pig iron is impure.



Courtesy: U.S. Steel Corp.

FIGURE 9-5b

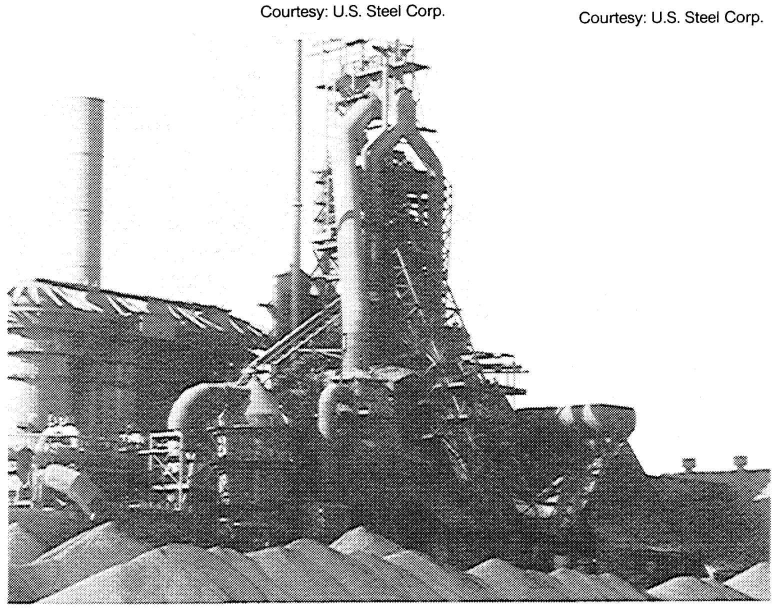
Molten pig iron flowing from a blast furnace.

Courtesy: U.S. Steel Corp.

FIGURE 9-5c

BLAST FURNACE

The carbon in the coal removes the oxygen from the iron oxide. Carbon monoxide also reduces the iron oxide.



The flotation of the ore does not produce a complete separation of the mineral from the gangue. The charge put into the blast furnace still contains much gangue. A **flux** must be added to the charge, in order to eliminate the gangue. If the ore is mined in a sandy area, the gangue will be sand, and the flux will be limestone. When the gangue is limestone, sand is used as the flux to eliminate the gangue as slag.

Table 9-4

$$\text{gangue} + \text{flux} \longrightarrow \text{slag}$$

$$\text{sand} + \text{limestone} \longrightarrow \text{slag}$$

$$SiO_2 + CaCO_3 \longrightarrow CaSiO_3 + CO_2 \uparrow$$

$$2\,CO + O_2 \longrightarrow 2\,CO_2 + \text{heat}$$

Note: Carbon monoxide forms in the blast furnace. It is used as a fuel to heat the incoming air.

Blast furnaces never shut down. They run steadily for 24 hours every day. As the charge is added at the top of the furnace, the molten slag and cast iron are drained off at the bottom.

9-5 Why Is Steel Preferable to Iron?

Cast iron contains many impurities such as carbon, silicon, sulfur, phosphorous, and slag. These impurities make the cast iron very hard, brittle, heavy, and vulnerable to rust. Cast iron cannot be welded. It is not **ductile**. Ductility is a metal's ability to be drawn into a wire. Cast iron is not **malleable**. Malleability is a metal's ability to be rolled or hammered into sheets or plates. This iron can only be cast into molds. It is used to make water mains, automobile engine blocks, and heavy cooking pots and pans. The cast iron from the blast furnace is immediately cast into molds shaped like the trough used by farmers for feeding their pigs—hence the other name, "pig iron." Steel is needed because it does not have the limitations of cast iron. Steel can be welded. It is ductile and malleable. It is lighter in weight than cast iron. It can hold a sharp cutting edge on a knife blade. It is more resistant to rusting. Steel is tougher than cast iron (less brittle).