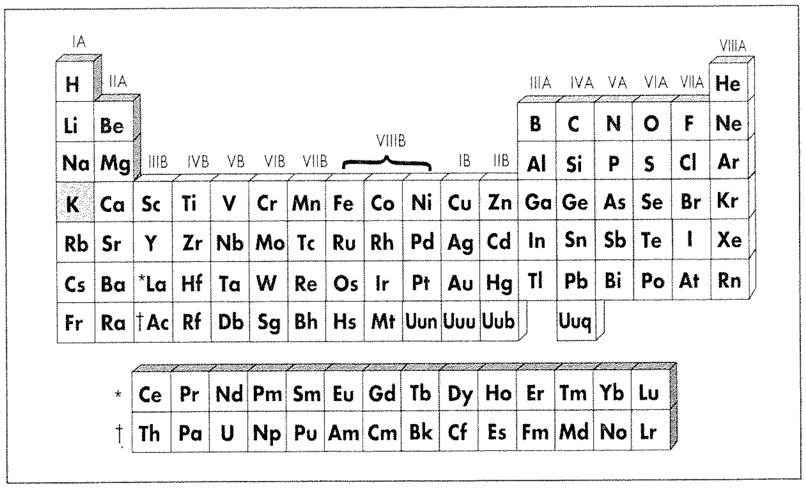
POTASSIUM



K

Potassium is a silvery-white metal with a putty- or wax-like consistency that is so soft it can easily be cut with a knife. It is a member of the alkali metals, the group that contains such elements as lithium and sodium. Like them, it is extremely reactive, and so is never found in the free state in nature.

Potassium occupies the position just below sodium in the periodic table. It is therefore not surprising that sodium and potassium are chemically rather similar and about equally abundant in nature. Both of these elements occur in silicate minerals and in seawater. Interestingly, the oceans contain much more sodium than potassium. Potassium is essential for plant growth, while sodium is not, so that plants take up much of the potassium in minerals as it filters, dissolved in water, through soils before entering streams and rivers on its way to the sea.

Potassium was first isolated by Sir Humphry Davy in 1807. As in so many of his previous discoveries, Davy used electrolysis as a means of separating elements from their compounds.

Almost all of the potassium chloride that is mined is used as plant fertilizer. In fact, plants and trees themselves were an early source of potassium for human use. Wood and other plant materials were burned in pots to give an ash, called potash (potassium-rich ash), which consists primarily of potassium carbonate. The name *potassium* has its origin in the word *potash* from this early source of the element.

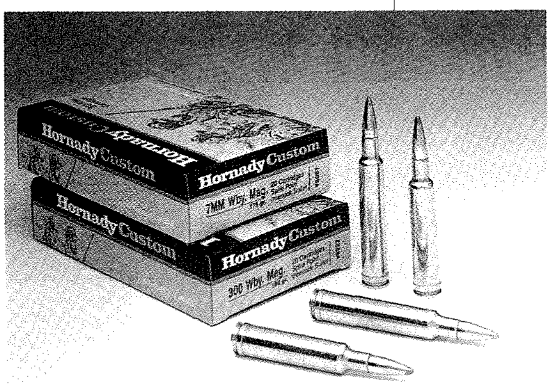
Like all of the alkali metals, potassium reacts violently with water to produce hydrogen. This reaction generates so much heat that it can ignite the hydrogen that bubbles off, causing flames to be produced. To prevent this from happening, it is usually stored immersed in a liquid such as kerosene or naphtha.

Atomic Number **19**

Chemical Symbol **K**

Group **IA—The Alkali Metals**

Potassium burns in air to produce potassium superoxide, whose chemical formula is KO_2. This is an interesting compound that reacts with both water and carbon dioxide to produce oxygen. These properties of potassium superoxide are utilized in self-contained breathing devices. They permit a diver to breathe naturally, using the oxygen generated internally by the superoxide from exhaled carbon dioxide, without any exposure to outside fumes.



Modern high-powered rifle bullets no longer use black gunpowder made with potassium, which produces a great deal of smoke, leaves a heavy residue, and requires frequent cleaning of the rifle bore. Gun cartridges use "smokeless" powder today, which consists basically of nitrocellulose.

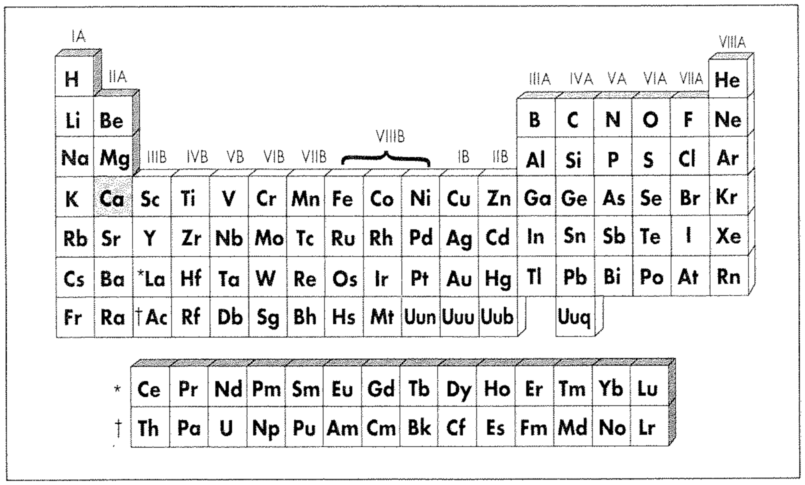
Several compounds of potassium are of commercial interest. Potassium hydroxide, KOH, is an extremely strong base that is very soluble in water. It is used chiefly as an electrolyte in certain types of storage batteries and in the manufacture of liquid soap.

Potassium nitrate, KNO_3, is an important compound that has been known for centuries. It is better known as saltpeter, which really means "rocksalt." The name derives from the Greek word *petra,* for rock. It resembles ordinary table salt in appearance. When saltpeter is dissolved in water, it has a slightly salty taste, which explains its name. It is used as a preservative and as an important component of potassium-containing fertilizers. Perhaps its most spectacular use is as an explosive. Potassium nitrate decomposes when heated, releasing large quantities of nitrogen gas. Gunpowder consists of potassium nitrate, wood charcoal, and sulfur. When gunpowder is heated, large volumes of carbon dioxide, and nitrogen gas are released. The sudden expansion of these hot gases causes an explosion.

A naturally occurring isotope of potassium is the radioactive isotope potassium-40. It occurs naturally in many rocks and has an unusually long half-life of 1.25 billion years. Potassium-40 is used extensively to date rocks. This technique depends on the fact that when potassium-40 decays, it transforms itself into the noble gas argon. Consequently, to determine the age of a rock, one need only determine how much argon is present in the rock. The oldest rocks on Earth have been dated by this method as being 3.8 billion years old.

Potassium-40 is also an important source of normal background radiation. Each human body contains about 140 grams of potassium distributed throughout the body. Since the natural abundance of potassium-40 is about 0.012 percent, we are all partially made up of this radioactive isotope. There is no escaping its radiation, and it is a major contributor to our lifetime dose of radiation.

CALCIUM



Ca

Calcium is the fifth most abundant element in the Earth's crust, and it is an especially important nutrient for a wide range of living organisms. Human teeth and bones contain calcium, and marine organisms build their shells of calcium carbonate ($CaCO_3$), which also makes up the hardened portion of the coral reefs of the Bahamas and the Florida Keys. When these coral organisms die, the sediments of their shells form the large deposits of limestone found distributed throughout the Earth. Limestone is chiefly calcium carbonate and is a rich source of marine fossils.

Calcium is far too active an element to be found as a pure metal in nature. It reacts with moisture to form calcium hydroxide ($Ca(OH)_2$) and with the oxygen in air to form calcium oxide (CaO). Pure calcium metal is fairly hard and has the characteristic silvery-white color of all the alkaline-earth metals.

As far back as the 1st century, the Romans used a compound of calcium known today as lime. They called it *calx*, the Latin name for lime, from which the modern name for calcium is derived. The metal was first isolated and identified as an element by Sir Humphry Davy in 1808. Pure calcium metal has rather limited commercial use and is produced in small quantities by heating calcium oxide with aluminum.

Many water supplies contain dissolved calcium in the form of calcium ions (Ca^{2+}). The calcium ion has lost two of the valence electrons of the calcium atom and so is positively charged. In this form it can easily react with other chemical groups. The calcium ion is known as one of the "hardness ions" because its presence produces hard water. Water is said to be hard when an ion such as calcium combines with soap to form an insoluble scumlike pre-

Atomic Number **20**

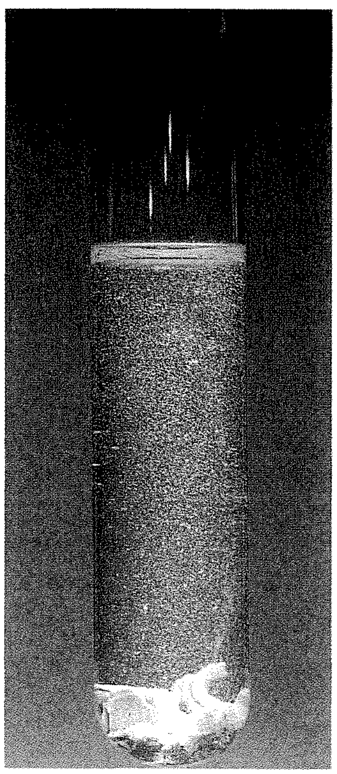
Chemical Symbol **Ca**

Group **IIA—The Alkaline-Earth Metals**

cipitate. The result is to decrease the ability of soap to remove dirt and grease.

Another problem arises in regions where hard water also contains bicarbonate ions $(HCO_3)^-$. When such water is heated, the dissolved bicarbonate ions undergo a chemical reaction that forms carbon dioxide gas (CO_2) and carbonate ions $(CO_3)^=$. Because gases become less soluble in water as the temperature is raised, the heat drives the gaseous carbon dioxide out of solution, causing more bicarbonate to break down into carbon dioxide and carbonate. In the presence of calcium ions, insoluble calcium carbonate $(CaCO_3)$ is formed in the water. This insoluble substance, or precipitate, sticks to the walls of boilers and hot water pipes, narrowing them and restricting the flow of water. In boilers, the precipitate is known as "boiler scale" and is a very serious problem because the scale interferes with the conduction of heat through the walls of the boiler.

Some compounds of calcium are better known by their popular names than by their chemical formulas. Limestone, for example, is calcium carbonate; quicklime, or simply lime, is calcium oxide; and slaked lime is calcium hydroxide. Many compounds of calcium are extremely important commercially. Calcium carbonate is used as an antacid. Mortar is made by mixing slaked lime with sand and water. As the mixture dries, the calcium hydroxide crystallizes and the mortar hardens. Eventually, the mortar reacts with the carbon dioxide in the air to form an extremely hard matrix of limestone and sand. It is used for bricklaying. The ancient Romans used mortar to construct buildings and roads.

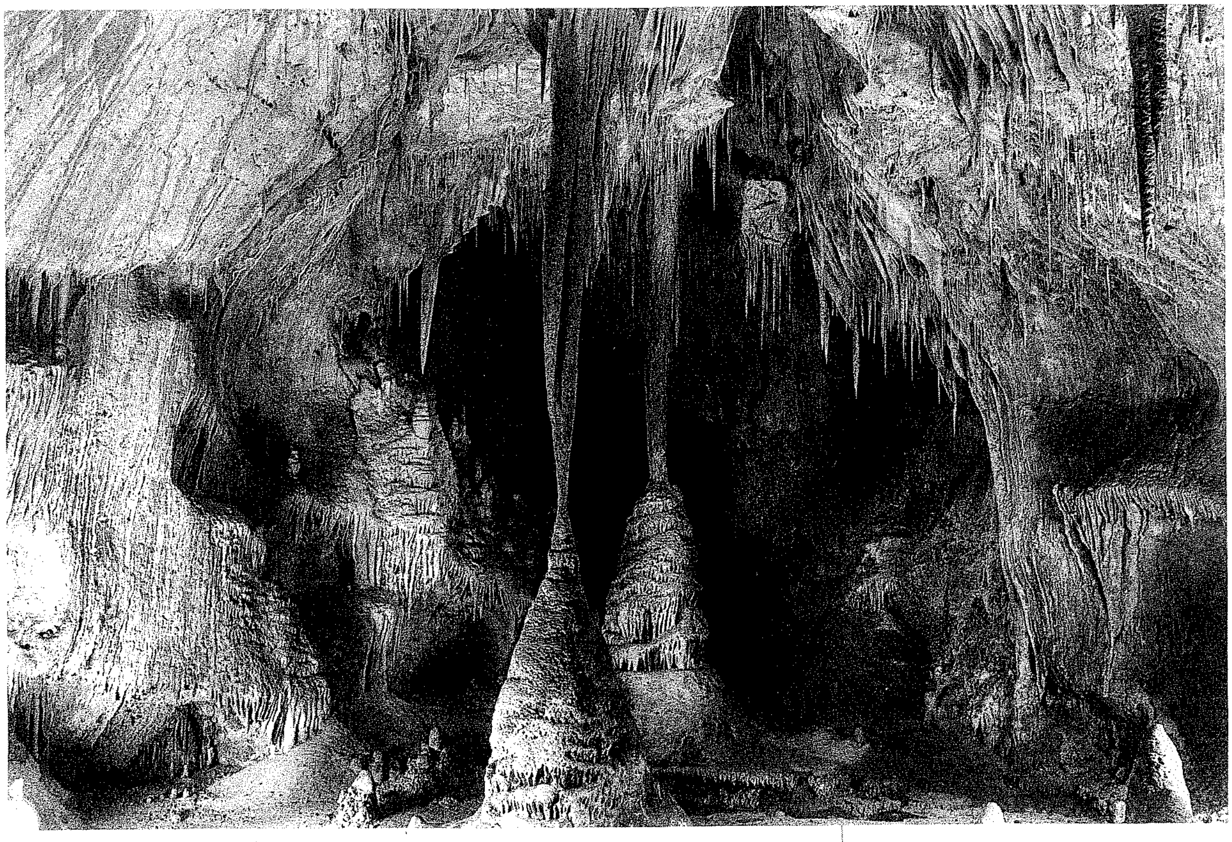


Calcium is a fairly reactive metal. Here it is shown reacting with water to produce hydrogen gas.

Another ancient building material is concrete. It has its origins in Egypt and has been in constant use during the past 5,000 years. Most concretes used today are based on Portland cement. Discovered by an English bricklayer in 1824, Portland cement owes its name to its resemblance to the natural limestone found on the Isle of Portland in England. The cement is made from a mixture of limestone, sand, clay, and gypsum. When it is mixed with sand and water, it hardens into the familiar material we see in so many of the structures of our daily life.

Lime (calcium oxide) is an extremely important industrial chemical. It is easily made by heating limestone. One of the early uses of lime was in theatrical lighting. When lime is heated to a high temperature it gives off an intense, bluish-white light. Such light was used in the early 19th century to illuminate actors, giving rise to the phrase "in the limelight."

Probably the most important modern use of lime is in the production of iron from its ores. The process of making iron



A limestone cave at Carlsbad Caverns National Park in New Mexico.

usually begins with the addition of a mixture of iron ore and lime to a blast furnace. As the mixture is heated, the lime combines with impurities in the iron ore to form a glassy material called slag. The molten slag then flows to the bottom of the furnace and is separately removed as the molten iron pours from the furnace.

Limestone caves are among the most impressive naturally occurring structures. These caves are formed slowly over thousands of years when slightly acidic groundwater, formed by the presence of carbon dioxide in the water, seeps through cracks in the rocks and dissolves enough limestone to hollow out a large opening. The limestone often reprecipitates to form the icicle-like formations known as stalactites and stalagmites. Stalactites grow downward from a cave's ceiling and stalagmites grow upward from a cave's floor (an easy way to remember this is to associate the *c* in stalactite with "ceiling" and the *g* in stalagmite with "ground").

Marble is composed of calcium carbonate and is very sensitive to acid rain. Many marble structures, such as statues, columns, and the facades of public buildings, have been badly damaged by acid rain. Governments dedicated to preserving structures that are of historic interest or that have some artistic merit have been working very hard to control the emissions that produce acid rain.

Gypsum, the popular name for calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), is an important mineral derived from the sea. The

Calcium is an especially important nutrient for a wide range of living organisms. Human teeth and bones contain calcium, and marine organisms build their shells of calcium carbonate.

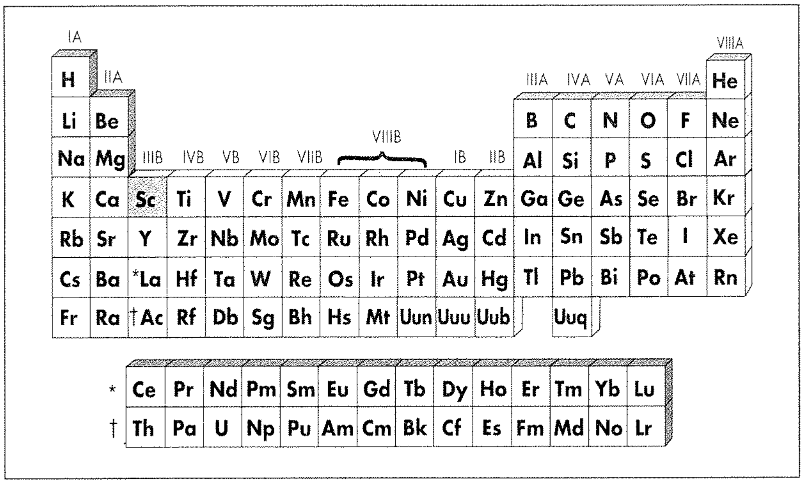
word *dihydrate* refers here to the two water molecules attached to every molecule of calcium sulfate in gypsum. A familiar white chalky material, gypsum was formed when the great inland seas and lakes that once dotted the Earth dried up eons ago. It is widely distributed in nature, constituting most of the White Sands National Monument in New Mexico, for example. It is also a highly important building material and is used to make a variety of products that everyone has seen or used. It forms the plaster used to coat the walls and ceilings of houses as well as the plaster casts used to set broken bones and the plaster molds for artists' sculptures.

The versatility of gypsum is based on the loss of some of its water molecules when it is heated, giving rise to a new material called plaster of paris. When water is added to the powdered plaster of paris, it re-creates small crystals of gypsum, which join with one another to form a hard mass of gypsum. This reaction happens very rapidly and produces a great deal of heat.

Gypsum also exists in the crystalline form known as alabaster. This material is very soft and easy to carve, making it a favorite material of many sculptors. When polished, alabaster becomes translucent, which adds greatly to its beauty.

Calcium chloride ($CaCl_2$) is a compound of calcium that has a strong affinity for water and can actually absorb water from the air, often absorbing enough to dissolve itself. Compounds of this kind are called deliquescent. Many commercial products contain calcium chloride because of its ability to remove moisture from damp places such as basements.

SCANDIUM



Sc

Scandium heads a list of 10 metals called the first-row transition elements, which occupy the center of the periodic table. As the number of protons in the transition elements increases across the row of these elements, electrons are added to an incompletely filled inner shell rather than to the outer, valence shell. Consequently, the number of valence electrons is virtually the same for all of these elements. This similarity in valence electron configuration causes the transition elements to resemble each other in their chemical behavior. All of them, for example, are fairly unreactive metals, and many of their compounds are colored. Care must be taken in dealing with these elements and their compounds because many of them are extremely hazardous. Elements such as chromium, nickel, cobalt, zinc, and titanium, for example, are known to cause cancer.

Scandium is a scarce element that makes up approximately 0.0025 percent of the Earth's crust. Interestingly, it is found in greater concentrations in the sun and certain other stars. It was one of the elements that Mendeleyev, in 1871, theoretically predicted would fill one of the vacant gaps in his periodic table. The element was discovered eight years later, in 1879, by Lars Fredrik Nilson, who named it after his homeland, Scandinavia. The discovery of scandium led to widespread acceptance of the predictive power of the periodic table.

Scandium is a very lightweight metal with a fairly high melting point and good resistance to corrosion. These properties have made it of great interest to the aerospace industry for the construction of aircraft. The pure metal was not available until 1937, and some of the first samples of the silvery-white metal

Atomic Number **21**

Chemical Symbol **Sc**

Group **IIIB—First-Row Transition Element**

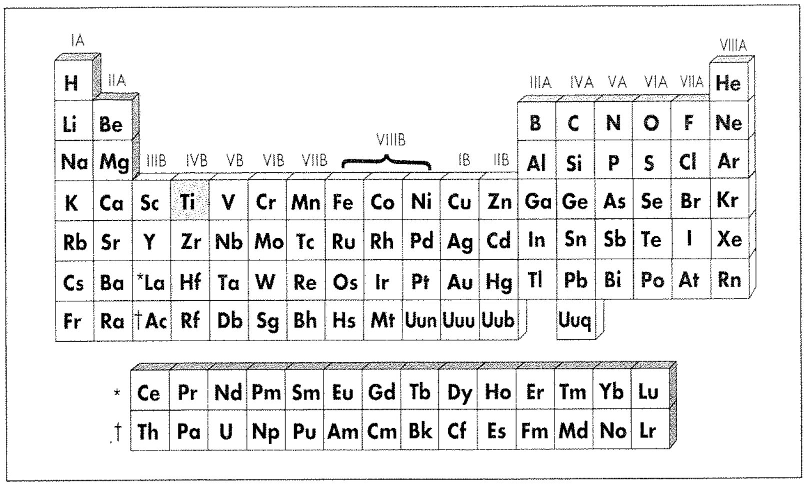
The discovery of scandium in 1879 led to widespread acceptance of the predictive power of the periodic table.

were produced for the U.S. Air Force. Pure scandium is usually prepared by the electrolysis of scandium chloride ($ScCl_2$). It has a tendency to develop a yellowish color when exposed to air.

Scandium forms very few useful compounds. The metal itself has found some use in electronic devices, such as high-intensity lamps that produce light with a color value close to that of natural sunlight. Lamps of this kind are often used to illuminate baseball and football stadiums.

One of the isotopes of scandium, known as scandium-46, has found some use as a tracer in the refining of petroleum. Scandium-46 is radioactive, with a half-life of 83.8 days. When added during the crude-oil refining process, it can keep track of, or trace, by means of its radioactivity, certain desirable components. This greatly increases the efficiency of separating the crude oil into useful components.

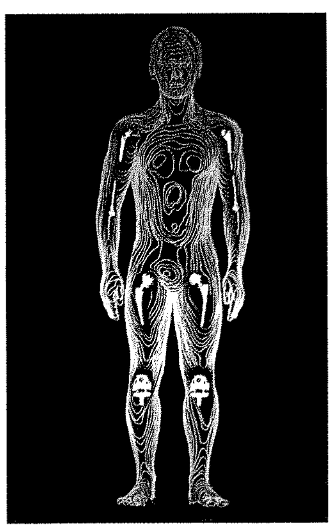
TITANIUM



Ti

Titanium is the ninth most abundant element in the Earth's crust, making up some 0.6 percent of its mass. In its pure state it is a shiny, white metal that is easy to work and quite ductile, or capable of being drawn into wire. Discovered in 1791 by an amateur English mineralogist, the Reverend William Gregor, titanium is named for the Titans of Greek mythology. The minerals rutile and ilemnite are its usual sources. The most common technique at the present time of winning the metal from its ore is by chemical reduction. This is a difficult and expensive process because titanium reacts readily with oxygen and carbon at high temperatures. In September 2000, however, a group of metallurgists, headed by George Chen of Cambridge University, reported an ingenious new way to extract titanium from its ore by electrolysis. If this technique can be scaled up to produce industrial amounts, it would greatly reduce the cost of the metal.

Titanium has a density approximately 40 percent that of steel. Despite its light weight, it is unusually strong and virtually immune to the usual kinds of metal fatigue. It also has an extraordinary resistance to corrosion, so that it has every property needed to make it an ideal structural material for rockets and jet engines. To take but one example, some 10,000 pounds of titanium and its compounds are used in each engine of a Boeing 747 jet.

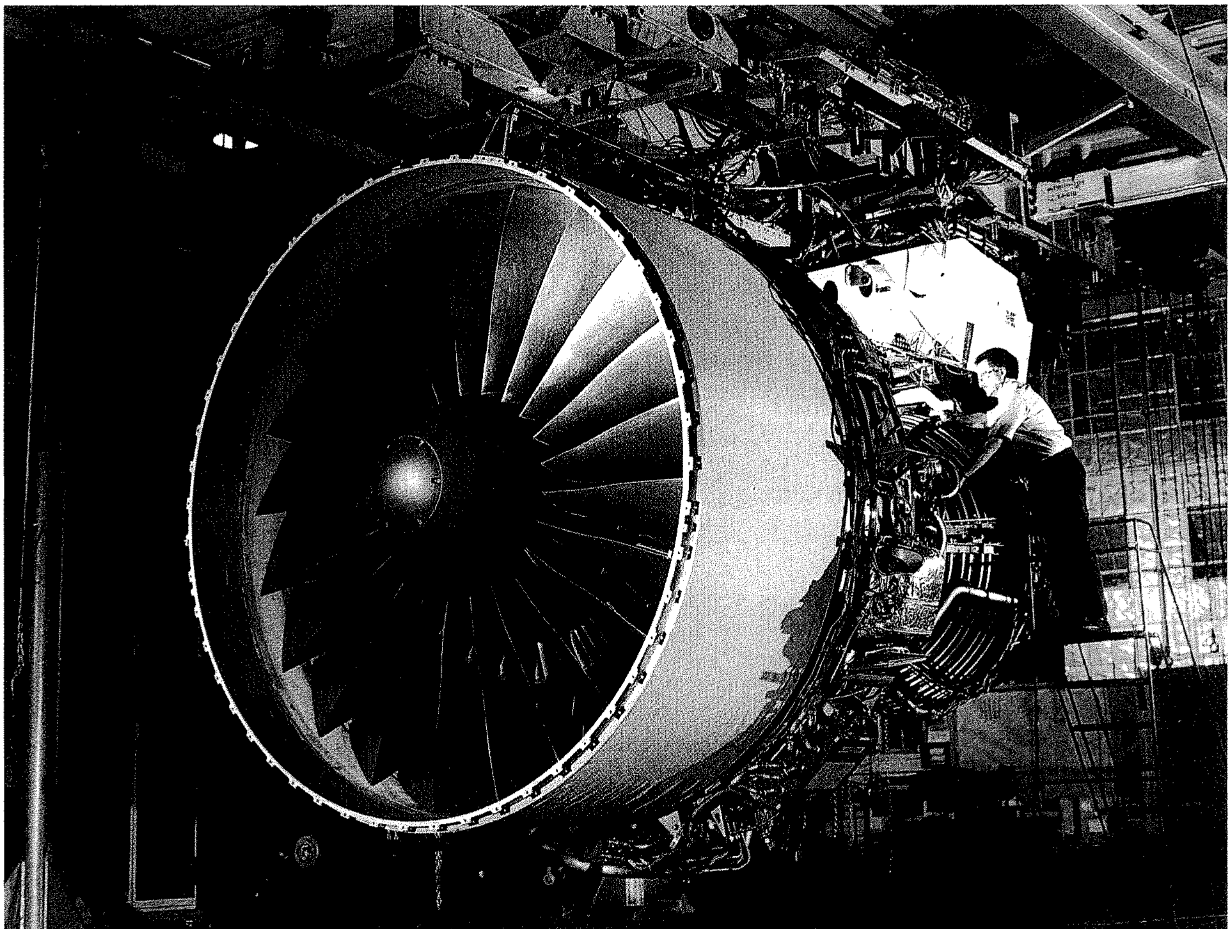


Because titanium does not react with human tissue, titanium pins are often used in surgery.

Atomic Number **22**

Chemical Symbol **Ti**

Group **IVB—First-Row Transition Element**

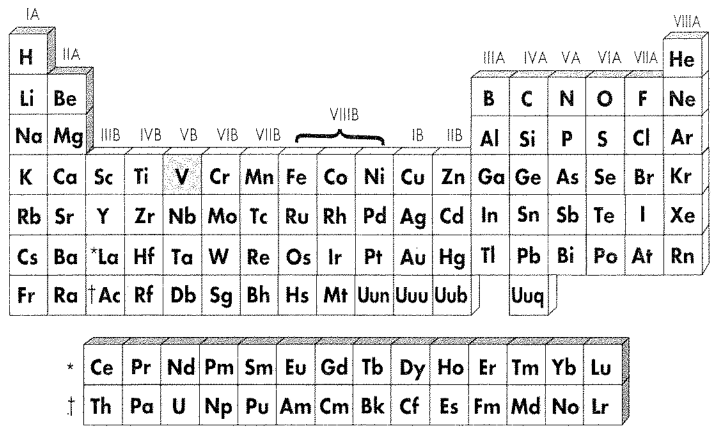


Titanium's strength and light weight make it an ideal component of aircraft engines.

Titanium bicycles have recently taken the sporting world by storm. Many cyclists claim that their combination of light weight and stiffness produces an almost "magic ride." These state-of-the-art bikes are, unfortunately, very expensive. Titanium's resistance to chemical attack has also made it a valuable tool in medicine. Titanium pins, for example, are often used in bone surgery because they do not react with tissue.

The most important compound of titanium is titanium dioxide (TiO_2), a substance with a brilliant, intense white color that is used as a pigment for paints, paper, and plastics. It has also found use as a sunscreen because it can prevent damage to the skin without the use of any other chemical. The annual production of titanium dioxide in the United States is approximately 1 million tons.

Another useful compound of titanium is titanium tetrachloride ($TiCl_4$), a colorless liquid. When exposed to moist air, it forms a dense white cloud of small titanium dioxide particles. The U.S. Navy used titanium tetrachloride during World War II to make smoke screens when it was necessary to block a potential target from view.



VANADIUM

Atomic Number **23**

Chemical Symbol **V**

Group **VB—First-Row Transition Element**

Vanadium is a bright, shiny metal that is fairly soft and extremely resistant to corrosion. It makes up about 0.02 percent of the Earth's crust, and it is found in trace quantities in more than 60 different minerals. As a source of the metal, the most important of these minerals is vanadinite.

A Mexican professor of mineralogy, Andres Manuel del Rio, discovered vanadium in 1801. It was later named for the Scandinavian goddess Vanadis because of its many beautifully colored compounds.

About 80 percent of the vanadium produced in the United States is used as an additive in the making of steel. Its general effect is to make the steel more resistant to wear and stress and also to make the steel perform better at high temperatures. Fortunately, this application does not require very pure vanadium, which is difficult to prepare in quantity because of its reactivity with oxygen and carbon at high temperatures. For this reason, a compound of vanadium known as ferrovanadium, rather than the pure metal, is added to iron to form vanadium steel, a hard steel used for engine parts and cutting tools.

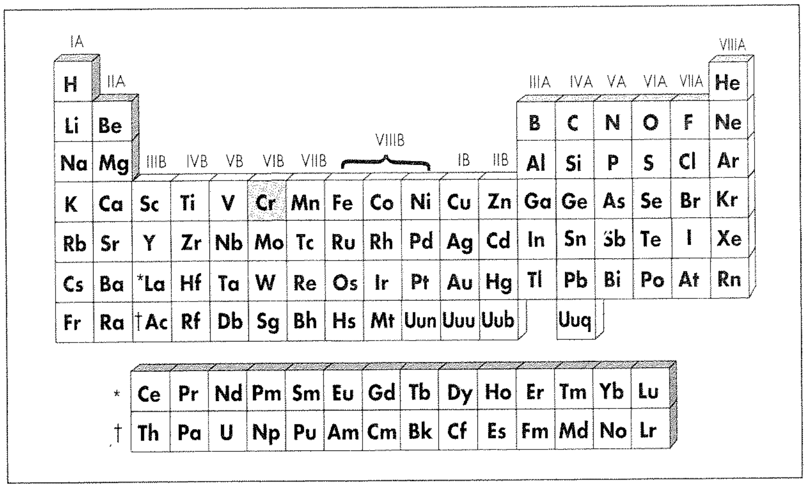
The most important compound of vanadium is its oxide. This yellowish-red crystal is known chemically as vanadium pentoxide (V_2O_5). It is used commercially as a catalyst in the contact process for preparing sulfuric acid. In the contact process, large amounts of sulfur trioxide (SO_3), an important intermediate compound in the manufacture of sulfuric acid, are produced. The sulfur trioxide is usually made by exposing sulfur dioxide (SO_2) to oxygen. But under ordinary conditions, this reaction proceeds very slowly. If these materials are combined while in

A Mexican professor of mineralogy, Andres Manuel del Rio, discovered vanadium in 1801.

contact with solid vanadium oxide, however, the sulfur trioxide is produced very rapidly. The vanadium oxide acts as a catalyst; it does not enter into the chemical reaction but simply speeds it up.

Vanadium is often used as an alloying material in the steels that make up the structural parts of nuclear reactors. Ordinary steel has a tendency to "creep," that is, become distorted and stretched, when it is subjected to high temperatures or weights over a long period of time. In a reactor, for example, this could cause the rods containing the fuel elements to rupture. Vanadium steels are much more resistant to creep. Another advantage is that vanadium does not readily absorb neutrons. Neutrons are the nuclear particles that fission the uranium in a reactor and perpetuate the chain reaction. The presence of vanadium, then, has very little effect on the nuclear processes occurring in the reactor.

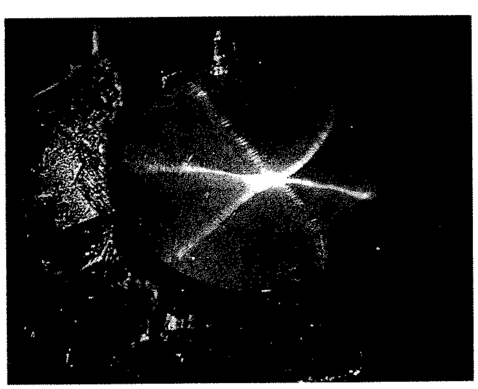
CHROMIUM



Cr

Chromium was discovered by French chemist Louis-Nicolas Vauquelin in 1797 and named from the Greek word *chroma,* meaning "color." This was an appropriate choice because all of the compounds of chromium are colored. The pure metal, however, has a silver-white color. Although brittle, it is quite hard.

Chromium metal is usually extracted from chromite, an oxide of chromium that is its most important ore. Chromium oxide (Cr_2O_3) is among the 10 most abundant compounds in the Earth's crust. When exposed to air, chromium forms an invisible oxide that makes the metal extremely resistant to corrosion and very useful as both a decorative and a protective coating over other metals such as brass, bronze, and steel. Almost everyone is familiar with the chrome plate that is deposited electrostatically on automobile parts such as bumpers. Chromium is also used in large amounts to produce stainless steel, a steel alloy that is resistant to corrosion. A typical stainless steel object can contain as much as 18 percent chromium.



The brilliant red color of rubies can be traced to the presence of small amounts of chromium in the mineral corundum.

One of the principal uses of chromium compounds is in the manufacture of pigments. Chromium oxide (Cr_2O_3), for example, is the most stable green pigment known and is used for coloring paints,

Atomic Number **24**

Chemical Symbol **Cr**

Group **VIB—First-Row Transition Element** cements, and plaster. Another chromium-containing pigment is the yellow pigment known as lead chromate yellow. Pigments account for about 35 percent of the chromium-containing chemicals produced each year.

The beautiful color of many precious gems is also due to the presence of trace amounts of chromium. The red color of rubies, for example, is caused by small amounts of chromium present in the mineral corundum. The characteristic green color of emeralds is due to trace amounts of chromium in the mineral beryl. One of the most interesting precious stones is alexandrite, which contains a small amount of chromium in its basic mineral, chrysoberyl. Alexandrite has the property of changing color in different light sources. When viewed in the light coming from a fire, for example, it is a deep red color, while in daylight it is a beautiful blue.

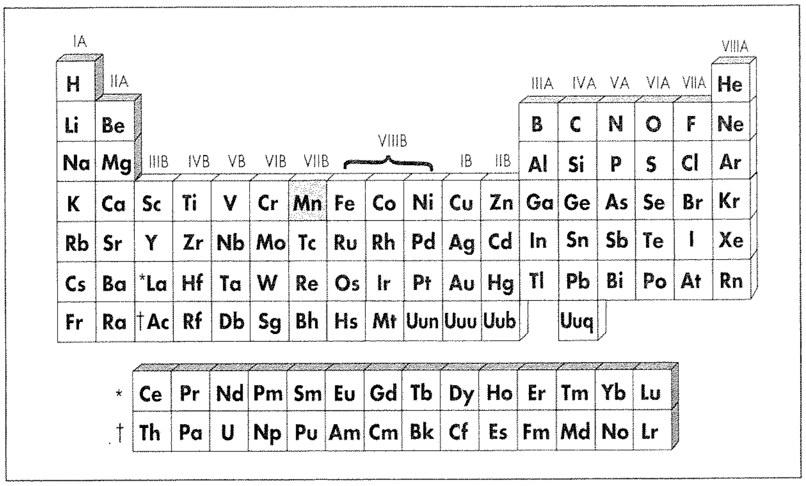
Chromium was discovered by a French chemist in 1797 and named from the Greek word chroma, *meaning "color."*

In addition to their use for treating the surfaces of metals so as to render them resistant to corrosion, chromium compounds are used for tanning leathers and for producing high-quality recording tapes. Electrical engineers have found that the electrical and magnetic properties of chromium oxide produce a superior sound, and it is the active material coated onto these tapes.

In 1960, the first laser, a ruby laser, was constructed by the American physicist Theodore H. Maiman. The ruby laser consists of a ruby crystal, essentially aluminum oxide (Al_2O_3) that contains a small amount of chromium atoms as an impurity in the crystal. The action of a laser is described in the section on helium. In the ruby laser, it is the chromium that stores the energy and is responsible for the laser action. The ruby crystal is usually in the shape of a cylindrical rod with partially mirrored ends, surrounded by a tube containing xenon gas. When the xenon tube flashes and gives off light, the light stimulates the chromium atoms to release their energy. The mirrors reflect some of the radiation back into the tube, which has the effect of further stimulating the release of energy by the chromium atoms.

Chromium compounds should be handled with care because many of them are toxic.

MANGANESE



Mn

Manganese is a hard, gray-white metal that has many properties similar to those of iron, its neighbor in the periodic table. It not only looks like iron, but like iron it corrodes in moist air. Manganese metal does not exist in its free state in nature and is most commonly found combined with oxygen in pyrolusite, a mineral that consists chiefly of manganese dioxide (MnO_2). Manganese was discovered by Carl Wilhelm Scheele in 1774 and named from the Latin word *magnes,* meaning "magnet," referring to the fact that pyrolusite has magnetic properties.

The United States has virtually no sources of manganese, but rich ores containing as much as 40 percent manganese are mined in such areas as South Africa and India. An unusual source of manganese is the so-called manganese nodules scattered on the bottom of the sea. These nodules, roughly spherical in shape and containing chiefly manganese and iron oxides, are thought to have been produced by microorganisms that have the ability to extract manganese from seawater.

When manganese is added to steel, it forms an unusually hard steel that is very resistant to shock. This makes such steel ideal for use in rifle barrels, bank vaults, railroad tracks, and earth-moving equipment. Manganese also adds hardness, strength, and corrosion resistance to alloys of aluminum and magnesium.

One of the most common compounds of manganese in chemical laboratories around the world is potassium permanganate ($KMnO_4$), which is used as an indicator for acid solutions. When dissolved in water, it forms a deep-purple solution. If an acid is then added to the solution, its color quickly turns from

Atomic Number **25**

Chemical Symbol **Mn**

Group **VIIB—First-Row Transition Element**

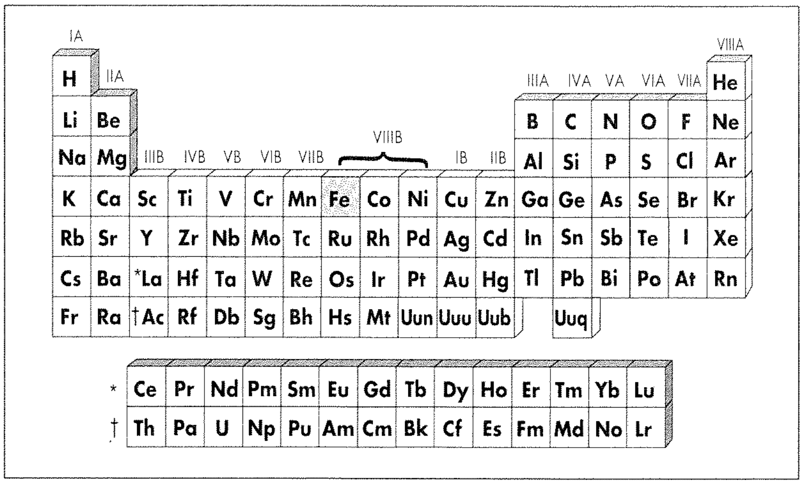
Manganese was discovered by Carl Wilhelm Scheele in 1774 and named from the Latin word magnes, *meaning "magnet."*

purple to a very pale pink. This ability to change color is thus used to "indicate" a change to an acidic state. Potassium permanganate is also used to purify public water supplies and to absorb toxic gases.

The purplish color of permanganate is sometimes seen in antique glass. In the early nineteenth century, glassmakers added manganese oxides to their glass to eliminate the yellow tinge produced by iron impurities that were present. With age and long exposure to the sun, the manganese became converted into a permanganate, giving the glass a faint purplish gleam. This coloring, present in old windows, is now highly prized by owners of early American homes throughout New England. Although glass manufacturers no longer add manganese, its ability to color objects is still used to brighten ceramics and pottery.

Manganese dioxide is a compound commonly used in the dry-cell batteries found in most inexpensive flashlights. The technical name for these batteries is zinc-carbon dry cells. The anode, or positive terminal of the battery, which is the little button on top, is connected to a carbon electrode surrounded by a moist paste that contains manganese, among other compounds. The complex chemical reactions that occur in this paste are essential for the operation of the battery.

The manganese essentially removes hydrogen gas that forms around the carbon electrode as the battery is being discharged. The hydrogen is a product of the chemical reactions that produce the electricity. This production of hydrogen gas is known as polarization, and if the hydrogen were not removed, the battery would soon cease to function. Since a gas is a poor conductor of electricity, the hydrogen build-up is disruptive because it prevents the proper transfer of electrons to the electrode. The common alkaline battery also uses manganese dioxide as one of its reactants.



IRON

Atomic Number **26**

Chemical Symbol **Fe**

Group **VIIIB—First-Row Transition Element**

Fe

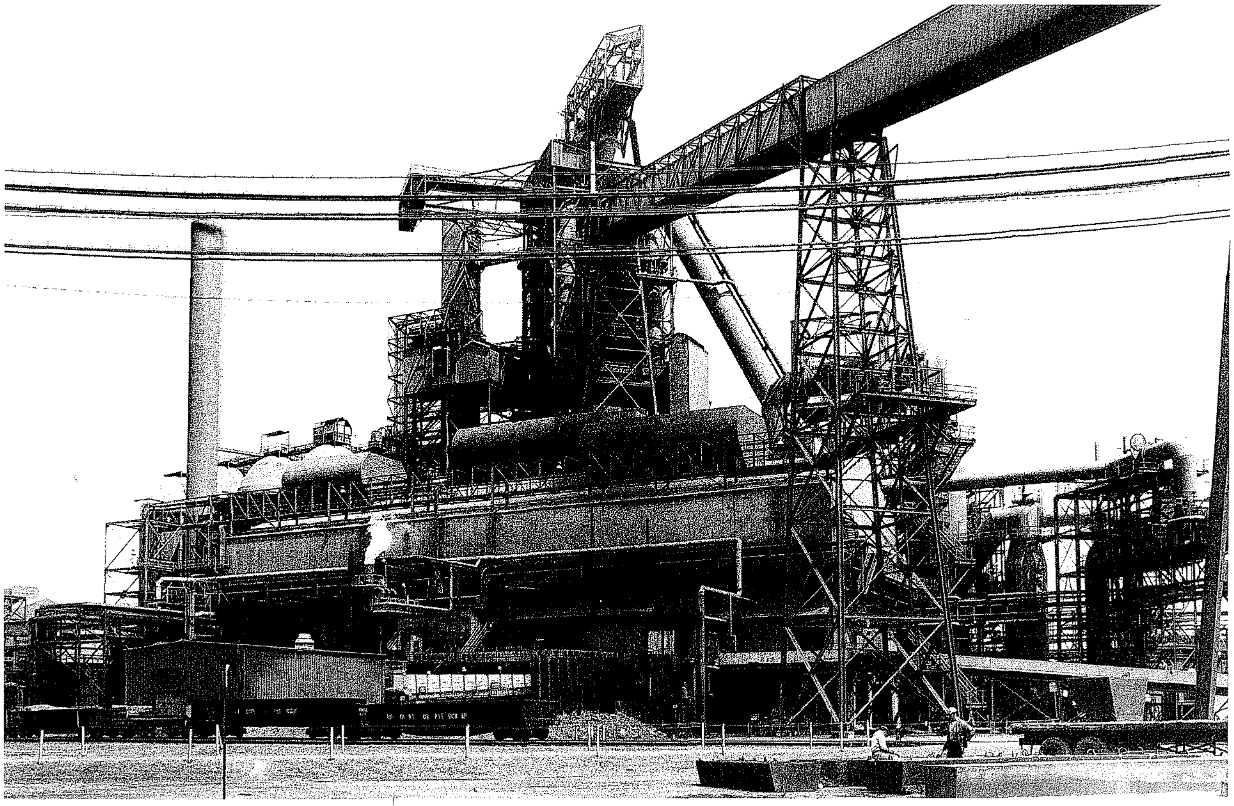
Iron is probably the most common metal in human society. It plays a major role in almost every aspect of everyday life. Whether we are using a screwdriver or a washing machine, or riding in an automobile or train, the importance and usefulness of iron as a structural material is apparent.

Iron is the fourth most abundant element in the Earth's crust and, next to aluminum, the second most abundant metal. The interior of the Earth, known as the core, is thought to be made chiefly of molten iron.

Iron is never found in its pure state in nature. Most iron-bearing ores contain iron combined with oxygen in the form of oxides. Two of the most important iron-containing minerals are hematite and magnetite.

In its pure state, iron is a somewhat lustrous, silver-white metal. Unfortunately, the pure metal quickly corrodes. It reacts with water and air to form rust. Rust is a hydrated oxide of iron ($Fe_2O_3 \cdot xH_2O$), which means that the iron oxide molecule has some water molecules attached to it (the *x* in the formula indicates a variable or unknown number of molecules of water hydration). Rust is a porous, reddish material that adheres very poorly to the surface of iron and usually crumbles off. Unfortunately, the ease with which it does this constantly exposes fresh iron to oxidation, so that many iron artifacts quickly disintegrate if not protected.

Iron was discovered thousands of years ago. The ability to refine the metal from the reddish ores in which it is found served as a major milestone in human development, known as the Iron Age (about 1100 B.C.). The discovery of iron led to tools and weapons that were harder and more durable than those known



This blast furnace in Sparrows Point, Maryland, is capable of making 8,000 tons of iron per day.

during the previous Bronze Age (about 3000 B.C.). Today more than 90 percent of all metal refined in the world is iron.

The production of iron usually takes place in a blast furnace. There, iron ore and carbon in the form of coke are heated to convert iron oxide in the ore into molten iron. This molten iron, known as "pig iron," contains many impurities such as carbon, manganese, and silicon, and it is usually too brittle for most applications. Removing most of the carbon by further heating with large blasts of oxygen converts the pig iron to the much harder form of iron known as steel.

There are many kinds of steel. Each kind is made by adding a small amount of some specific impurity that gives the steel a desired property. The steel is usually named for this impurity. Nickel steel, for example, which contains a small amount of added nickel, is very resistant to tensile, or pulling, stresses. It is used for building bridges, power-transmission towers, and ordinary bicycle chains. Tungsten and vanadium steels are particularly useful for tools that must maintain their cutting edges at high temperatures. Manganese steel can withstand high-energy impacts very well and is therefore used to manufacture rifle barrels and power shovels for moving earth. Stainless steels are made by adding chromium and nickel to iron, often in concentrations as high as 12 to 18 percent.

Iron plays a crucial part in the transport of oxygen throughout the body. The role played by hemoglobin, the molecule in red blood cells that carries oxygen from the lungs to all the tissues of the body, has been discussed in the section on oxygen. It is the four iron atoms that each hemoglobin molecule contains, however, that are central to its structure and function. The oxygen molecules actually bond to the iron atoms, and are then transported by the blood to cells in need of oxygen. It is worth noting that carbon monoxide, a common gas produced in combustion, is bound 200 times more strongly than oxygen to the iron atoms. This means that in an environment of high carbon monoxide concentration, asphyxiation (carbon monoxide poisoning) can occur, since the hemoglobin will become saturated with carbon monoxide and little hemoglobin will be available for oxygen transport.

An important property associated with iron is its magnetism. Iron is attracted to magnets, and magnetite, a compound of iron, is itself strongly magnetic. This property is due to the structure of the iron atom. The electrons orbiting the nucleus of the iron atom make each such atom a tiny magnet.

The fact that an electric current will produce a magnetic field is well known. It is this effect, for example, that is at the heart of an electric motor. But an electric current is really the drift of electrons through a wire. The electrons orbiting the nucleus of an iron atom resemble an electric current, and this motion therefore makes each atom a tiny magnet. In addition, the electrons are spinning on their own axes, very much like the way the Earth spins on its axis. This motion also enhances the magnetic properties of the atom.

In the metal itself, the spacing of the atoms is just right to cause their individual magnetic forces to enhance each other and produce a strong magnetic effect. Heating or melting can destroy this spacing and cause the loss of magnetism.

Besides its presence on Earth, iron is the heaviest element that can be made in the interior of stars through the ordinary process of fusion. In a star, hydrogen nuclei can be compressed together to form all of the elements up to and including iron, but the formation of iron absorbs more energy than it releases, and the fusion process stops. Elements more complex than iron are formed during the extraordinary explosions of dying stars known as supernovas.

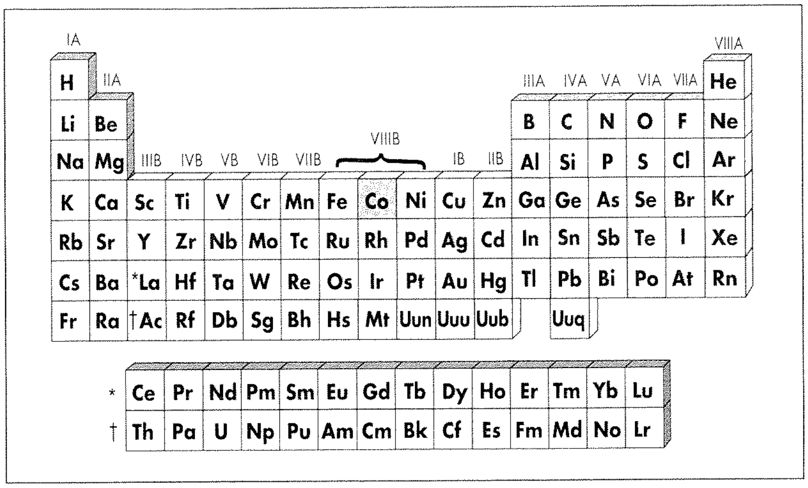
Today more than 90 percent of all metal refined in the world is iron.

COBALT

Atomic Number **27**

Chemical Symbol **Co**

Group **VIIIB—First-Row Transition Element**



Co

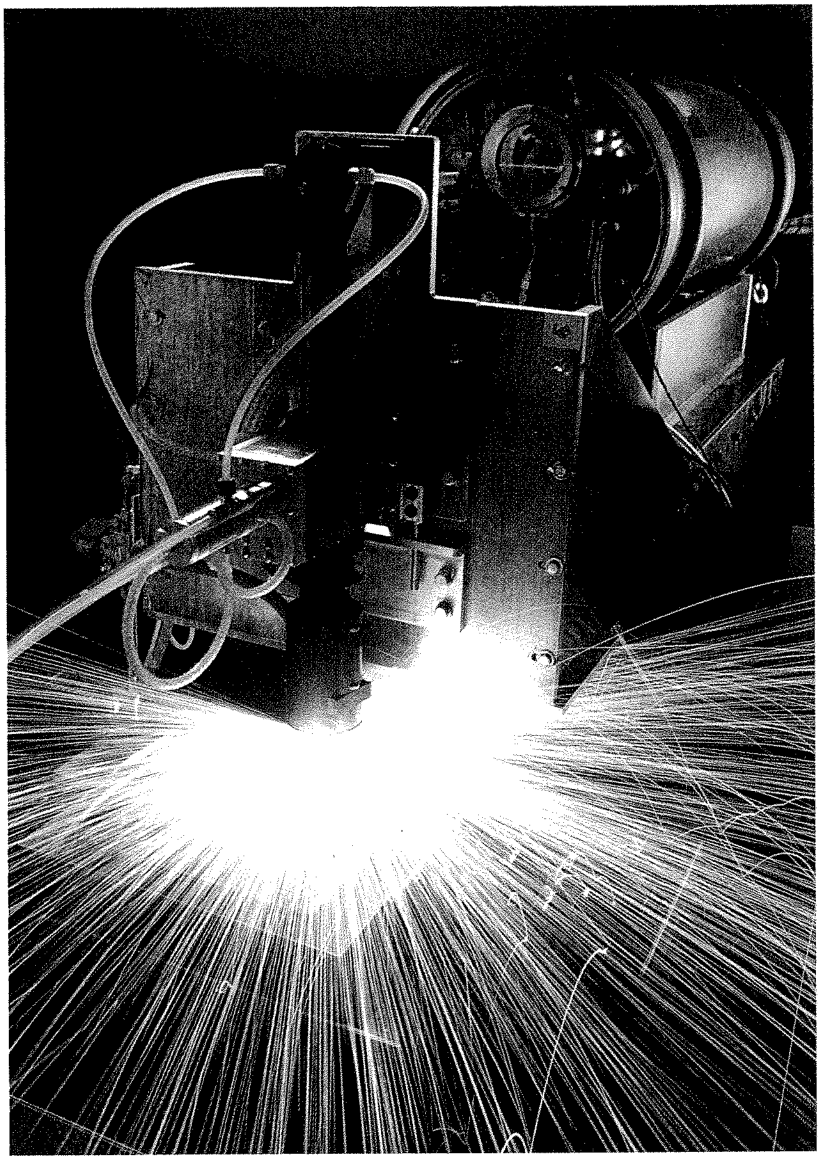
Cobalt is a rather rare element, making up only 0.003 percent of the Earth's crust. One of its major ores is called cobaltite, a compound of cobalt, arsenic, and sulfur. The pure metal, with its characteristic bright bluish-white color, is obtained by roasting this ore in air. Cobalt metal was first isolated by the Swedish chemist Georg Brandt in 1739.

The fact that glass made with trace amounts of cobalt minerals is blue was known to the ancient Egyptians thousands of years ago. The name *cobalt* derives from the German word *kobold,* which refers to an evil gnome or spirit. Miners often said problems or accidents occurring in the mines were caused by "kobald." The mining of cobalt ores was apparently no exception, and the name *cobalt* became the accepted one for the mineral in the 18th century.

Cobalt is often added to steel to improve its resistance to corrosion. When cobalt is mixed with tungsten and copper, it forms an alloy called stellite, a metal that retains its hardness even at high temperatures. This makes it ideal for high-speed drills and cutting instruments.

Like iron, elemental cobalt is known for its magnetic properties. It is easily magnetized and retains its magnetism at temperatures far higher than those for iron. Some 25 percent of all the cobalt produced in the world is used to make a powerfully magnetic substance called alnico. Alnico is an alloy of aluminum, nickel, and cobalt and is used for making industrial magnets. Its name consists of the first two letters of each of its component elements.

When naturally occurring cobalt is placed in a nuclear reactor and exposed to large numbers of neutrons, it can be transformed into a highly radioactive isotope known as cobalt-60.



When cobalt is mixed with tungsten and copper, it forms an alloy called stellite, a metal that remains hard even at high temperatures, making it ideal for use in high-speed cutting instruments.

This isotope emits powerful gamma rays that are similar to X rays. The gamma rays are used for treating certain types of cancer and for sterilizing food.

Cobalt-60 has a half-life of 5.2 years, so that once formed, it will be radioactive for a relatively long time. Unlike a massive and complicated X-ray machine with its cumbersome power source, the isotope, when properly shielded, is easy to transport from one location to another. This makes it particularly useful for field applications, such as using its gamma rays to look for cracks in the hulls of ships.

Cobalt is known to be one of the trace elements essential to human nutrition. It is present in meat and dairy products and in vitamin B-12, an important substance that prevents the disease known as pernicious anemia, in which the blood is depleted of adequate numbers of its oxygen-carrying red cells.

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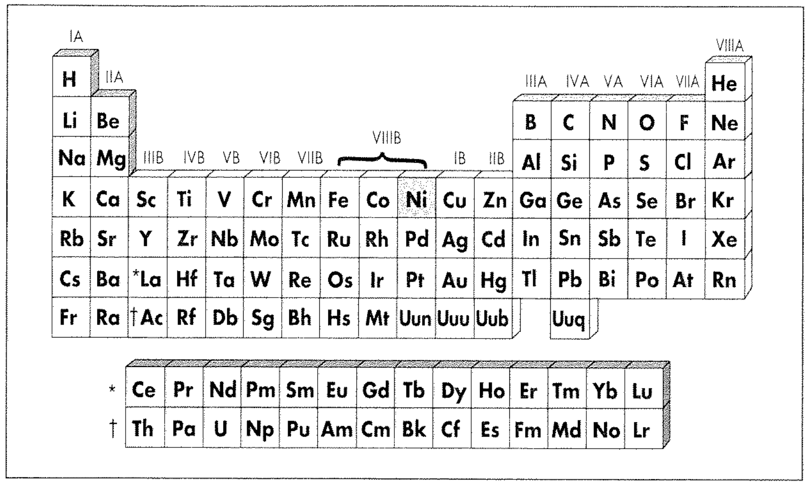
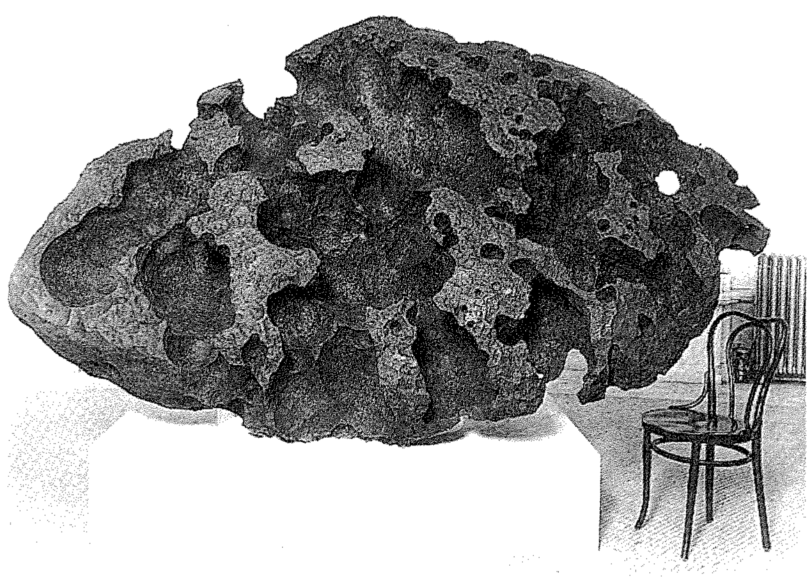
NICKEL



Ni

Nickel is a silvery metal found chiefly in the ore called millerite, a compound of nickel and sulfur. It is considered a rare element because only one one-hundredth of 1 percent of the earth's crust is nickel. Although nickel is scarce on the surface of the Earth, many scientists believe that large deposits of this metal exist deep within its interior. In fact, the molten core of the Earth is thought to be composed chiefly of iron and nickel. This may explain why nickel is often found in meteorites, since these extra-terrestrial rock fragments are thought to have been formed at about the same time as the Earth.



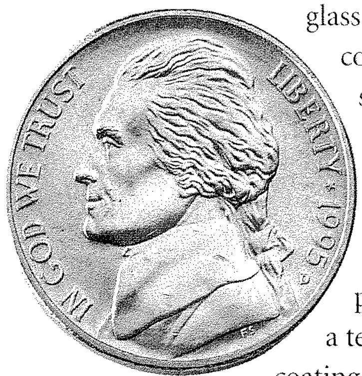
Meteorites, such as this one found in Arizona, often contain nickel.

Atomic Number **28**

Chemical Symbol **Ni**

Group **VIIIB—First-Row Transition Element**

Although nickel compounds have been known since ancient times, the pure metal was first isolated by a Swedish chemist named Axel Fredrik Cronstedt in 1751. *Nickel* is a German word for Satan, and the element is thought to have been named for the German *Kupfernickel*, or Satan's copper. Like cobalt, nickel compounds were known to the ancient world as a way of coloring glass. The characteristic color that nickel compounds add to glass and other substances is green.



The U.S. five-cent coin, called the nickel, is actually made primarily of copper. Only 25 percent of the alloy is nickel.

Nickel is extremely resistant to corrosion and is frequently added to other metals to form alloys resistant to oxidation. Nickel plating, often called electroplating, is a technique that adds a protective coating of nickel to the surface of a metal, such as iron or steel, that is known to corrode fairly easily.

Stainless steel, which typically contains about 18 percent chromium and 8 percent nickel, provides another example of the use of nickel to prevent corrosion. An alloy known as monel is a mixture of nickel and copper whose hardness and resistance to corrosion make it the metal of choice for such applications as the propeller shafts of boats.

Nichrome, the familiar metal used to make the heating elements in toasters and electric ovens, is an alloy of chromium and nickel. The high electrical resistance of nichrome, combined with its high melting point, make it a very efficient material for converting electrical energy into heat energy.

Perhaps the most obvious use of nickel is in the U.S. five-cent coin, which is called the nickel. The coin is actually made of copper and nickel, with nickel making up approximately 25 percent of the alloy. Like iron and cobalt, nickel can be made magnetic. The alloy named alnico, formed with aluminum, nickel, and cobalt, is used to create some of the most powerful magnets known.

An important modern use of nickel is the nickel-cadmium battery. One of the electrodes in this battery is a form of nickel oxide. This battery is rechargeable, which makes it particularly useful in calculators, computers, and cordless electric shavers, for example. The nickel-cadmium battery can also be sealed to prevent leakage, which is of great importance in electronic equipment. It produces a power output of 1.4 volts, or only slightly less than the 1.5 volts produced by an ordinary dry cell.

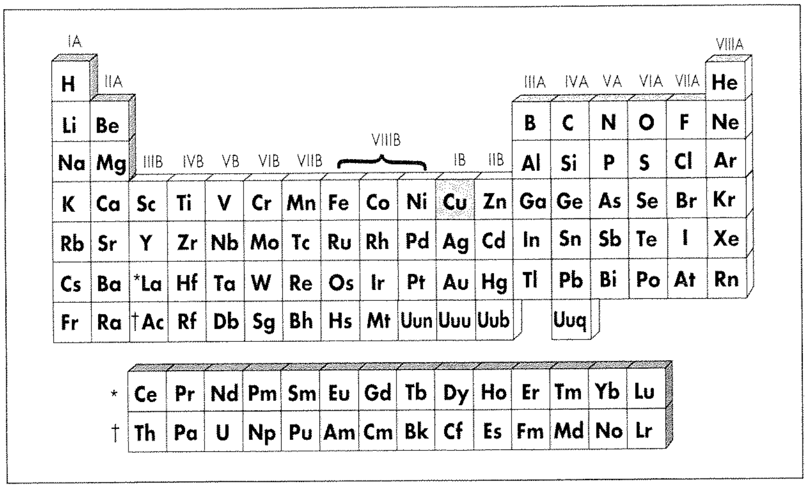
Nickel *is a German word for Satan, and the element is thought to have been named for the German* Kupfernickel, *or Satan's copper.*

COPPER

Atomic Number **29**

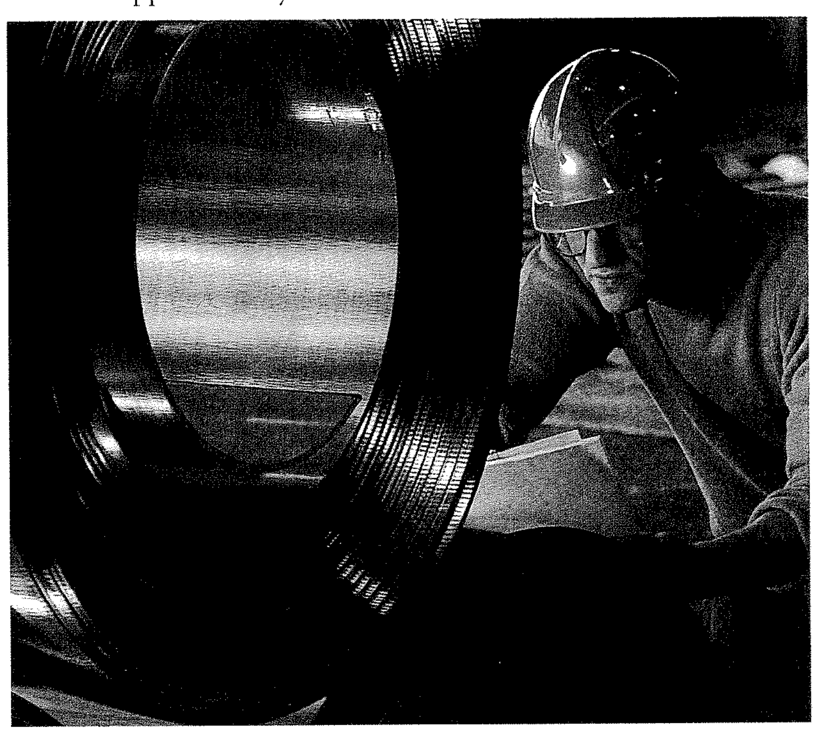
Chemical symbol **Cu**

Group **IB—First-Row Transition Element (Coinage Metal)**



Cu

Copper is one of the most familiar metals of everyday life. Look at the plumbing in your home and you are likely to see copper pipes carrying water to your kitchen and bathroom. Because copper is one of the best conductors of electricity, copper wires are widely used to transmit electrical energy from power stations to homes, offices, factories, and other buildings and from wall outlets to electrical appliances. The concentration of electrical wires under a major city such as New York rivals the mass of copper in many mines.



Brass, an alloy of copper and zinc, has a wide variety of uses, from hardware to ammunition.

Its mechanical properties also make copper almost ideal for electrical transmission. A soft metal, it is extremely ductile, which means that it has the ability to be drawn into wire. Commercial copper wire is made by drawing the metal through a series of dies of decreasing diameter so that the wire becomes thinner with each die.

Another common object, the "copper" penny used in the United States, is unfortunately no longer made of pure copper. Since 1981, the penny has been treated with copper plating to give the coin its characteristic reddish-brown color. Copper is used as a coinage metal because it is relatively unreactive with air and water. It was also once used to make buttons for uniform jackets worn by policemen, and the common slang expression "copper" refers to this practice.

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We may commonly think of corrosion as a process producing rust on objects made of iron. However, copper, although relatively unreactive, also corrodes slowly in the atmosphere by forming a layer either of copper carbonate ($CuCO_3$) or copper sulfate ($CuSO_4$). These green substances are said to form a "patina" that protects the copper metal underneath them from further corrosion. A dramatic example of the formation of patina was the Statue of Liberty, made in France of copper plates. Before being cleaned for its centennial, it was almost entirely green. Many people consider the patina that covers old church steeples or ancient monuments quite beautiful and have resisted attempts to remove it. When modern architects choose copper plates for the roofs and facades of buildings, it is with the expectation that the copper will corrode and produce a beautiful green color.

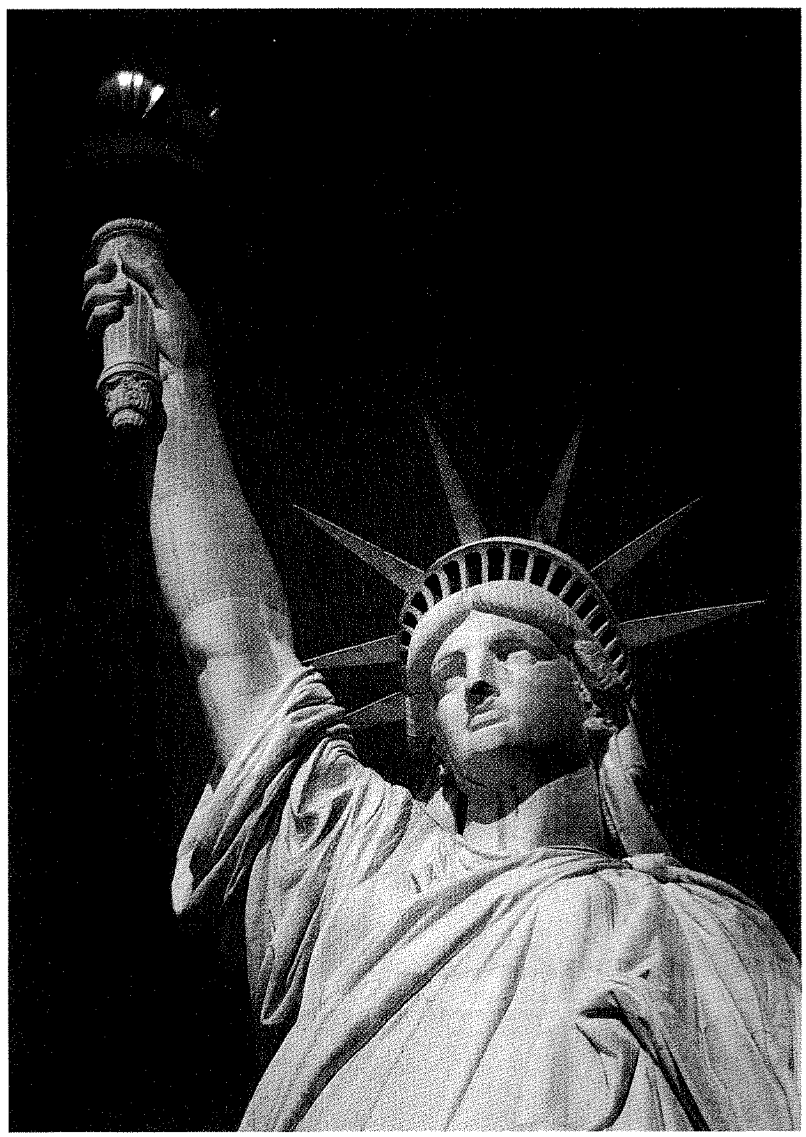
Despite the common use of copper, it is a rather rare element, making up only 0.007 percent of the Earth's crust. When found in its pure metallic state in nature, it is often called "native" copper. More common sources of copper are ores such as chalcopyrite, in which the element is combined with sulfur and iron. Most copper is currently obtained by the open-pit mining of low-grade ores containing only a small percentage of copper. The pure metal is obtained either by roasting the ore, in which it is heated in air, or by electrolysis.

Copper derives its name from the Latin word *cuprum*, which means "from Cyprus," an obvious reference to the island that served as a source of the metal for the Romans. It is easy to refine copper from its ore, and it was therefore known to many ancient civilizations. Copper jewelry dating back to 9000 B.C. has been found in Iraq. Because it is a relatively soft metal, copper never found widespread use as a weapon or tool.

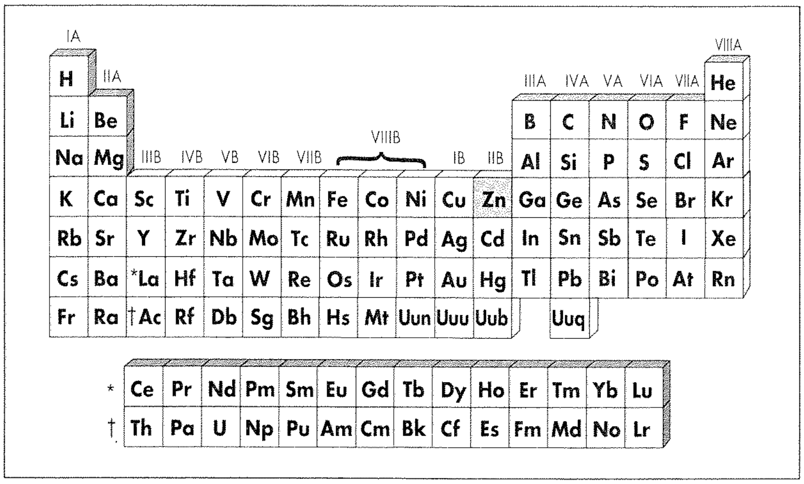
Copper's name comes from the Latin word cuprum, *which means "from Cyprus," a reference to the island that served as a source of the metal for the Romans.*

When copper is combined with other metals to form alloys, the result is often a new metal that is harder and tougher than any of the original metals used in the alloy. Brass is essentially an alloy of copper and zinc, while bronze is an alloy of copper and tin. Bronze tools and weapons served human beings before they learned to smelt iron. When nickel is combined with copper, it produces a hard and strong alloy called monel that resists corrosion.

Copper in large amounts is quite toxic, and copper compounds are used to kill various forms of fungi and bacteria. Paints used for ships' hulls, for example, contain copper to prevent the excessive growth of marine organisms on the surface of the hull. This growth is called fouling and develops slowly on any surface exposed to seawater.



The greenish tint on the Statue of Liberty is a result of the corrosion of its copper plates.



ZINC

Atomic Number **30**

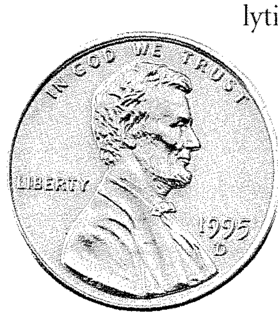
Chemical Symbol **Zn**

Group **IIB—First-Row Transition Element**

Zn

Zinc is not a very abundant element, making up about 0.007 percent of the Earth's crust. It is found chiefly in the mineral zinc sulfide, also known as sphalerite or zincblende. Commercial use of zinc dates back to the 15th century, although there is no record of when the metal was discovered.

Although zinc is fairly reactive in its pure state, in which it is a hard, brittle, silvery metal, it is relatively resistant to corrosion and quickly forms a hard oxide coating that prevents it from reacting further with the air. In the process known as galvanization, a layer of zinc is coated over steel to protect it from corrosion. Galvanized steel is commonly used for a variety of household objects such as metal garbage pails and chain-link fences. The zinc is applied either by dipping a steel object into some molten zinc or by using an electrolytic process to deposit the zinc on the steel. The zinc coating prevents air and moisture from coming into contact with the steel; even if the zinc coating is scratched or broken, the steel is still protected by a phenomenon called galvanic protection, in which the zinc acts as a sacrificial metal. This is because zinc is more easily oxidized than iron, and if corrosion occurs, the zinc rather than the iron reacts. If a zinc disc is attached to the iron rudder of a ship, for example, the zinc will gradually corrode and disappear, but the iron rudder will remain unattacked.

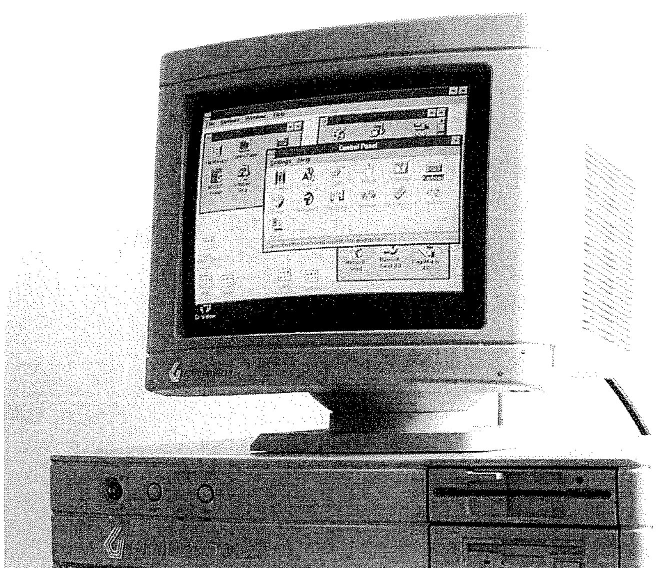


Although the U.S. penny is coated with a thin sheet of copper to retain its original color, since 1981 it has been made primarily of zinc.

Although some 90 percent of the zinc produced in the United States is used for galvanizing steel, the metal has many other uses. One of the most important is in the common dry-cell battery. This source of energy for flashlights, portable radios, and radio-controlled toys was invented more than 100 years ago by the French chemist George Leclanche. The battery consists of a zinc inner case, just beneath an outer protective metal shell that serves as one electrode (the anode), and a carbon rod that serves as the other electrode (the cathode). It generates an electrical force of about 1.5 volts.

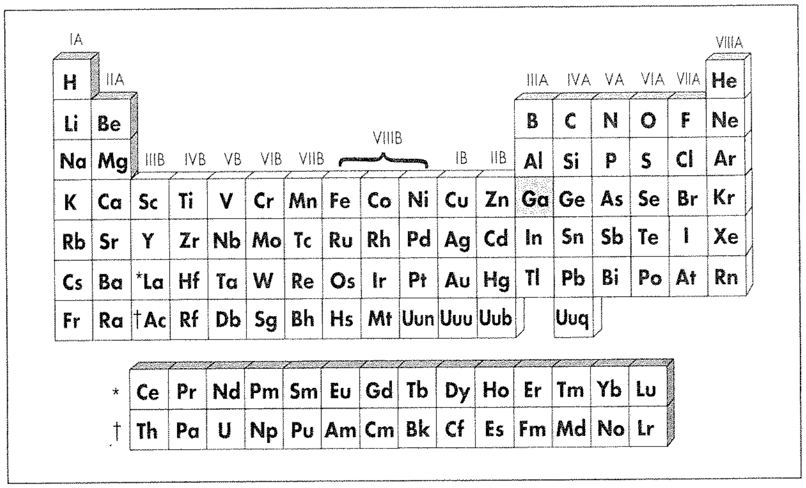
Since 1981, zinc has also served as the chief metal in the U.S. penny, although this coin is still covered with a thin sheet of copper to retain its original "copper" color. Zinc is also combined with copper to form the hard and durable alloy called brass.

Some other useful zinc compounds include zinc oxide, a white powder that is made by burning zinc vapor in air. One of the many uses of zinc oxide is as a pigment in making white paints. In the form of an ointment, zinc oxide has become a popular sunscreen, blocking the sun's ultraviolet light and preventing it from damaging the skin. Zinc oxide is also photoconductive. This means that it conducts electricity when exposed to light. In a photocopier, a zinc oxide plate is electrically charged and exposed to a printed document. When a light is then passed through the document and onto the plate, the parts of the plate that are lighted will carry the electrical charge away from the plate, while the dark parts, corresponding to the ink on the document, remain charged. When a black powder called a toner is then distributed over the surface, it sticks to the electrically charged parts of the plate, reproducing the image of the document. This image is then transferred to paper by heating.



Zinc sulfide gives off light when struck by electrons and is used to coat the inner surfaces of the cathode-ray tubes used in computer monitors.

Another compound of zinc, zinc sulfide, is used in many electronic devices as a phosphor. Phosphors have the important property of giving off light when struck by electrons. Among other uses, zinc sulfide is used to coat the inner surfaces of television tubes and of the cathode-ray tubes used as monitors in computers. When a beam of electrons generated in the tube strikes the sulfide coating, it produces the picture or text you see on these screens.



GALLIUM

Atomic Number **31**

Chemical Symbol **Ga**

Group **IIIA—Post-Transition Metal**

Ga

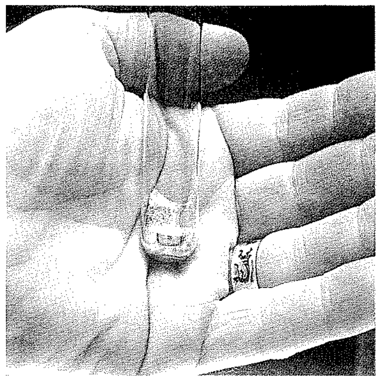
Gallium belongs to the same group of elements as aluminum and shares many chemical properties with that element. It is an extremely soft metal that can be cut with a knife. It also has an extremely low melting point of 29.8°C. Since the temperature of the human body is 37°C, gallium will melt when held in the palm of the hand. However, since it also has the extremely high boiling point of 2,403°C, the range of temperatures within which gallium is liquid is the largest of any known metal. This makes gallium useful for special high-temperature thermometers. Like water, it also has the unusual ability to expand when it freezes.

Commercially, gallium is ordinarily generated as a by-product in the refining of other metals. Chief among these is aluminum, with which it is present in the mineral bauxite. The history of gallium is of interest because it is one of the elements that Mendeleyev theoretically predicted in 1871. Using this prediction, the French chemist Paul-Émile Lecoq de Boisbaudran found and identified the element in 1875. He named it for his native France, using the Latin name, Gallia, for that country.

Light-emitting diodes (LEDs), made of gallium arsenide, are found in a wide range of electronic products.

Until quite recently gallium was a rather exotic element with few practical applications. This changed very rapidly with the discovery that

A French chemist found and identified gallium in 1875. He named it for his native country using the Latin name for France, Gallia.



Due to gallium's extremely low melting point, when a test tube filled with gallium is placed in the palm of a person's hand, the metal will start to melt.

gallium arsenide (GaAs), a compound of gallium and arsenic, could function as a "laser diode" and convert electricity directly into a beam of laser light. It is used in preparing lasers for compact disc players. Light-emitting diodes, or LEDs, made of gallium arsenide are used in a variety of electronic displays, watches, and autodisc players.

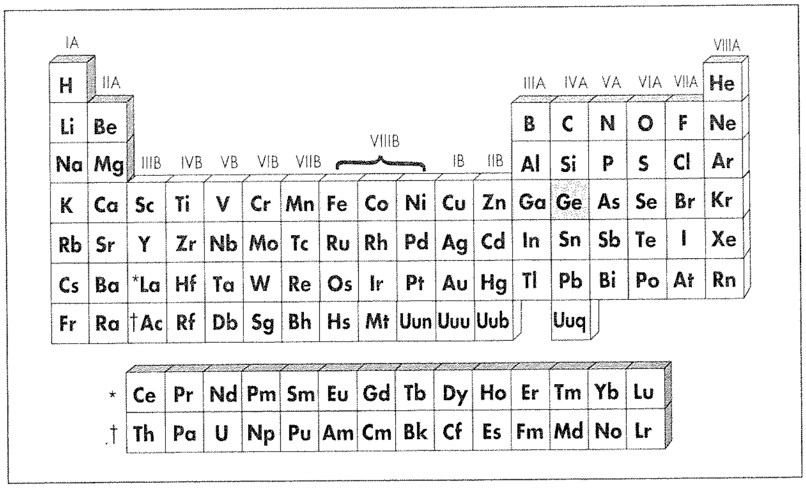
Besides converting electricity to light, gallium arsenide is a semiconductor. It generates less heat than the customary silicon transistor chips used in computers, and GaAs chips are replacing silicon in many supercomputers that require higher power.

Gallium-67 was one of the first artificially produced radioactive isotopes to be used in medicine. Because it has a half-life of only 78 hours, it rapidly loses its radioactivity and ability to harm the body. The isotope has a tendency to concentrate in the tissues of certain cancers, such as melanoma, and can therefore be used to treat the disease without doing too much damage to surrounding tissue.

Gallium is also at the heart of two of the world's major neutrino detectors engaged in efforts to detect neutrinos reaching Earth from the Sun. Neutrinos are subatomic particles that are extremely elusive and difficult to detect. They can pass through miles of solid rock without interacting. The usefulness of gallium is based on the fact that the collision of a neutrino with a gallium nucleus can often convert the gallium into the radioactive isotope germanium-71, which is easy to detect and identify.

One of the detectors is buried deep underground in the Gran Sasso tunnel in Italy. The other, known as SAGE, is also underground, and is found in the small town of Baksan in the Caucasus Mountains in Russia. SAGE is an acronym for Soviet-American Gallium Experiment and contains approximately 250,000 pounds of gallium, which at its present selling price of $390 a pound represents a major resource for the current Russian government. Its value has threatened to undermine the research efforts of the facility. Not only has the government threatened to seize the gallium, but there have also been several attempts by armed bands of thieves to steal the valuable metal from the underground laboratory.

GERMANIUM



Ge

The predictive power of Mendeleyev's periodic table was dramatically demonstrated in 1871 when he predicted the existence of a new element whose chemical properties were similar to those of silicon. He called this new element eka-silicon. The German chemist Clemens Winkler discovered this element in 1886 and named it germanium, from the Latin Germania, the name for Germany. Its physical and chemical properties did indeed very closely resemble those of silicon.

Germanium is a dark gray solid with a metallic shine or luster. It is a relatively rare element. It is never found as a pure metal in nature but generally as a mineral combined with oxygen. Its position in the periodic table is halfway between the metals and nonmetals, and it belongs to the class of compounds called metalloids.

Although germanium has metal-like properties, it is a relatively poor conductor of electricity and is therefore called a semiconductor. The addition of small amounts of certain impurities, such as arsenic, gallium, or antimony, to germanium greatly increases its ability to conduct electricity. This process is known as "doping," and the doped germanium is used to make transistors that are at the heart of the solid-state electronics industry. With doping, tens of thousands of transistors can now be formed on a small germanium chip, which in effect becomes a small computer. Materials such as germanium have made possible the revolution in electronic miniaturization.

Atomic Number **32**

Chemical Symbol **Ge**

Group **IVA—Metalloid**