contain 0.08 of a neutron. This number is derived by averaging the weights of the isotopes of calcium that occur together, some of which have more than 20 neutrons in the nucleus.

The Modern Periodic Table

The modern statement of the periodic law is that the chemical and physical properties of the elements vary in a periodic way with their atomic numbers.

The modern periodic table is arranged very much like Mendeleyev's table. The elements are arranged in rows called periods; in each period the elements are arranged in order of their atomic number. The periods are numbered from 1 to 8 from the top row to the bottom row. Below the main body of the table are two long rows of 14 elements each. One of these long groups follows lanthanum ($Z = 57$) and is known as the lanthanides. The other group follows actinium ($Z = 89$) and is known as the actinides. These elements actually belong in the main body of the table but are too long to fit conveniently into it.

The vertical columns of the periodic table are also called groups. There has been some disagreement about how these should be numbered. In one commonly used system the groups are labeled with Roman numerals and divided into A-groups and B-groups. The International Union of Pure and Applied Chemistry (IUPAC), an international body of scientists responsible for setting standards in chemistry, has officially adopted a system in which the groups are simply numbered in sequence from left to right, using Arabic numerals from 1 to 18. Thus, Group VIIA in the old Roman numeral system is Group 17 in the IUPAC system. The scientific world has still not achieved uniformity in the system used for the periodic table, and most chemists in the United States prefer the more traditional system. We will also use the traditional system in this book, but reference to the periodic table shown on page 6 will quickly translate the heading for a particular column into the IUPAC scheme.

All of the elements within a group have similar chemical properties and are sometimes referred to as families of elements. The elements in the A-groups, or longer groups, are known as representative elements. The elements in the B-groups are called transition elements.

Many of the groups of elements in the periodic table have acquired common names. For example, the elements in group IA, with the exception of hydrogen, are called the alkali metals. The elements in Group IIA are called the alkaline-earth metals, and those in Group VIIA are called the halogens.

What causes this periodic behavior of the elements? Why do the elements within a particular group have similar chemical behavior? The reason is that atoms are attracted to each other by electric forces. The atomic number, the number of positively charged protons in the nucleus, determines how many negatively charged electrons are contained in the atoms of a particular element, and it is the electrons that determine how elements behave and react with one another. The chemical behavior of an element is determined by the way in which the electrons orbiting the nucleus are structured. It was the new quantum physics, developed in the early 20th century by the Danish physicist Niels Bohr, the German physicist Werner Heisenberg, and the Austrian physicist Erwin Schrödinger, that put forward the idea of a complex arrangement of electron orbits or "energy levels" as a way of explaining the bonding properties of elements.

This new quantum physics, based on the idea that matter has properties resembling those of waves, tells us that the electrons in an atom are restricted to certain orbitals. These orbitals, which vaguely resemble the orbits of the planets of our solar system around the sun, are often referred to as shells. The inner shells, closest to the nucleus, are the most stable, and the electrons in these shells are closely held by the attractive force of the nuclear protons. If an electron absorbs energy, it jumps to the next outer orbital. If an electron in an outer orbital gives off energy, it drops to the next inner orbital. Electrons in the outer shells are relatively loosely bound to the nucleus. These electrons may be attracted to other atoms or they may become energetic enough to separate from the atom altogether, leaving behind an atom with a net positive charge that will attract electrons belonging to other atoms.

Strict rules govern how many electrons can occupy any particular shell of an atom. For example, two electrons will fill the first shell closest to the nucleus, whereas eight can occupy the next shell, slightly farther out from the nucleus, and eighteen can occupy the shell beyond this. Because each major shell contains various subshells, the exact electron configuration of an atom can become quite complex. The distribution of the electrons in the outer shell of the atom, the one farthest from the nucleus, is the important one, however, because these are the electrons that are exposed to other atoms when the atoms react.

Atoms with similar outer-shell configurations have similar chemical properties. Chemists call the outer shell the valence shell, and the electrons that occupy it are known as the valence electrons.

The term *valence* is derived from the Latin word *valent,* which means "strength." The valence electrons determine the chemical "strength" of atoms—their reactivity, or how strongly and in what way they will bind with other atoms. Elements in the same group in the periodic table have the same number of electrons in their outer shells and are therefore said to have the same valence electron configuration. As a result, the chemical and physical properties of the elements in this group will be similar. As the inner shells of an atom become filled with electrons, its outer shell takes on a specific valence configuration that is determined by the rules that govern how many electrons can occupy a particular shell. It is this regularity in the number of electrons that occupy the outer shell that accounts for the periodic behavior shown by the elements as the atomic number increases. Other properties, such as the size of an atom, are also determined by the number of shells it contains. For example, the radius of the atoms of the elements in a particular group in the periodic table tends to increase from the top of the group to the bottom.

Elements whose shells are completely full are extremely

HOW ELECTRONS OCCUPY ATOMIC SHELLS

	Scientific name	Permitted subshells	Maximum electrons in subshell	Maximum electrons in shell
shell closest to nucleus	K	1s	2	2
next shell farther out	L	2s	2	8
		2p	6	
next outer shell	M	3s	2	18
		3p	6	
		3d	10	
next outer shell	N	4s	2	32
		4p	6	
		4d	10	
		4f	14	

stable and seem to react with almost nothing else. The elements of Group VIIIA, for example, the so-called noble gases, all have complete shells and are the most chemically inert elements that exist. A complete shell of electrons is so energetically stable that atoms with incomplete shells will tend to react with other atoms in a manner that will complete these shells. In other words, atoms react in order to attain a "noble gas" configuration. In moving from left to right across a horizontal row, or period, within the periodic table, there is a transition from elements that are metals to those that are nonmetals. Metals, which generally have few electrons in their outermost valence shells, tend to lose electrons when they react, so that they reach a state in which they have fewer shells, all of which are completely filled with electrons. Nonmetals, whose valence shells are almost completely filled, tend to accept electrons to fill these shells and stabilize their configuration. In both cases, the tendency is to assume a completely filled valence shell, approximating that of a noble gas.

The periodic table, then, is a map of the way in which electrons arrange themselves in the atoms of a particular element. As you go down a column within a group, all the elements of that group have the same number of valence electrons. As you go across a row, from left to right, electrons are being added to a shell. The ability to predict the chemical behavior of an element, based on the row and column in which it is found, makes the periodic table an indispensable reference tool for scientists. Open a chemistry textbook and the chances are that there will be a periodic table, often in bright colors, printed on the inside cover of the book. Its constant use by chemists emphasizes the central role the periodic table plays in making sense out of what otherwise might be a chaotic jumble of facts about the elements and their many molecular combinations.

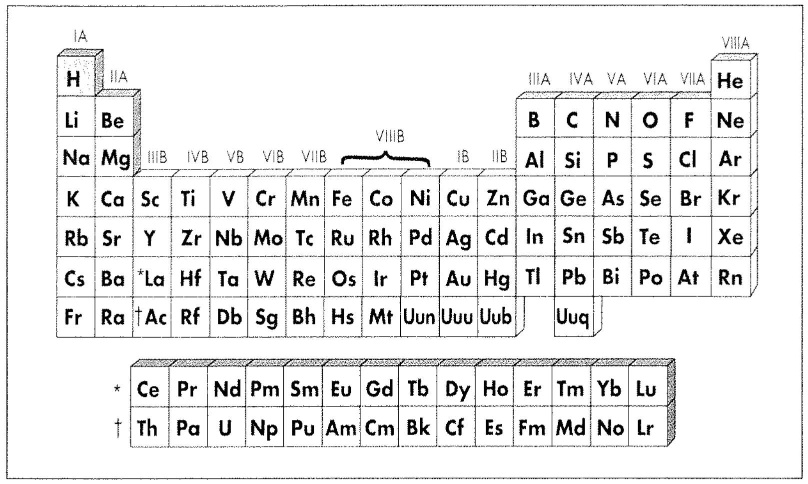
The chemical group of each of the elements described in the sections that follow is listed directly below the chemical symbol of the element. The similarity of chemical properties of elements in the same group should be as apparent to you as it was to Mendeleyev or to any chemist who uses the periodic table for information and research.

HYDROGEN

Atomic Number **1**

Chemical Symbol **H**

Group **IA**



Hydrogen is the simplest of all the atoms. It consists of nothing more than a single proton, which serves as its nucleus, circled by a single electron. Its simplicity helps to explain why it is by far the most abundant element in the universe. Huge quantities exist in interstellar space, and it is the predominant element in stars. It has such a dominant position among the other elements, that it makes up an astonishing 93 percent of all the atoms in the universe.

It is a very ancient element, having been formed shortly after the Big Bang, the moment when the universe is thought to have exploded into existence. All the other elements were made either by nuclear reactions taking place in the core of burning stars, or by the catastrophic explosions called supernovas that are sometimes produced when stars die.

Given the major role played by hydrogen in the universe, it is surprising to learn that there is very little hydrogen gas in the Earth's atmosphere. If you were to take 100 million liters of air, only about 5 liters would be hydrogen. Hydrogen is a very light gas. The gas weighs so little that the gravitational pull of the Earth was not strong enough to have prevented most of the hydrogen that was once present in the air from escaping into outer space. Some of the larger planets, such as Saturn and Jupiter, exert a much greater gravitational attraction and contain considerably more hydrogen gas in their atmospheres.

Much of the hydrogen still found on Earth is bound up in the water molecules that form our great oceans and seas. About three percent of the Earth's crust is made up of hydrogen atoms.

Under normal conditions, hydrogen gas is a diatomic molecule. This means that a hydrogen molecule is made up of two atoms of hydrogen. The chemical symbol of the gas is written as H_2 to show the coupling of the atoms. The gas has no odor or taste and is completely colorless. It is, however, an extremely flammable gas. When hydrogen burns in air, it combines very vigorously with oxygen present in the air to form large amounts of heat. The combination of hydrogen and oxygen also produces water. It is this reaction that gave birth to the name of hydrogen, which is derived from the Greek words *hydro*, or "water," and *genes*, or "creator."

The discovery of hydrogen is usually credited to the English chemist Henry Cavendish (1731–1810), after whom Cambridge University's Cavendish laboratory is named. Cavendish was about as eccentric a scientist as there ever was. The son of English aristocrats, he spent almost none of his huge inheritance and devoted his entire life to science. He worked out a value for G, the gravitational constant, and accurately calculated the mass of the Earth, which confirmed Isaac Newton's theory of universal gravitation. But whenever Cavendish had to talk to anyone, he was shy to the point of stammering, and he never spoke to women. He gave instructions to his female servants by handwritten notes, and he would fire them instantly if they did not stay hidden from his sight when he walked around his house.

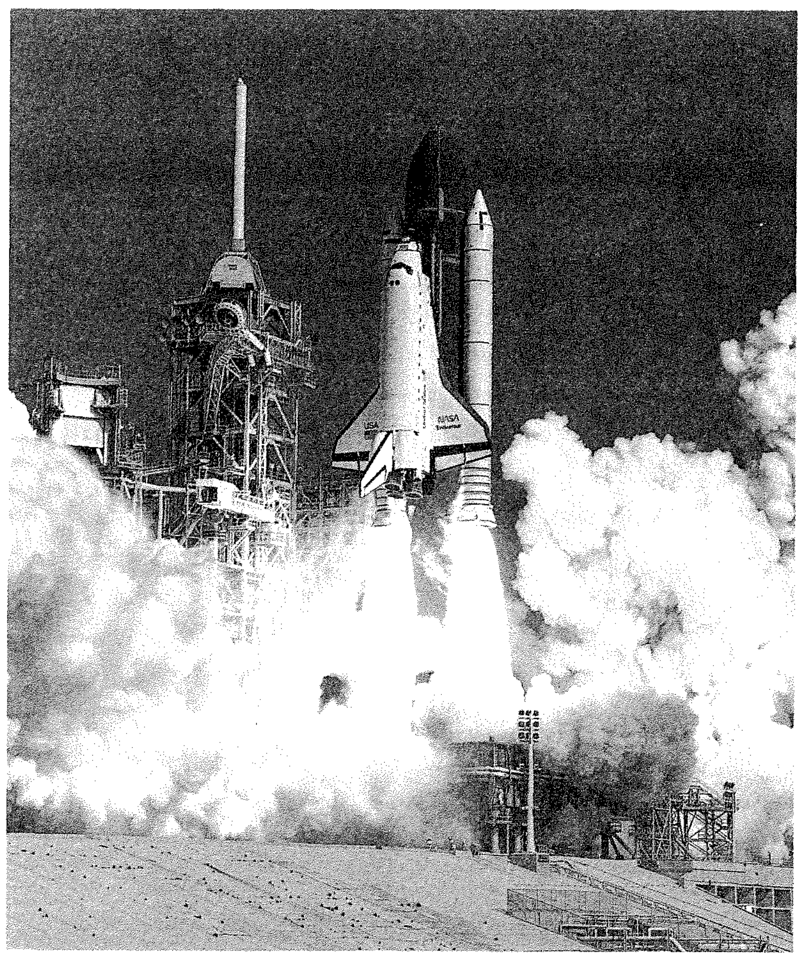
Thanks to a large inheritance from his family, the eccentric English chemist Henry Cavendish was able to devote his entire life to science, experimenting in a wide range of areas. He is best known for his discovery of hydrogen in 1766.

In 1766, Cavendish produced hydrogen gas by adding some zinc metal to an acid. He recognized that the "inflammable air," as it was then called, being given off by the reaction was a distinct substance, and he identified it as an element. This method is still used to produce small quantities of hydrogen gas in laboratories. A few pieces of zinc, or some iron filings, added to a test tube containing some hydrochloric acid will produce bubbles of hydrogen gas. When large amounts of hydrogen are needed, most laboratories and manufacturing plants use cylinders of the compressed gas.

Hydrogen is well known for being a gas that is lighter than air. A balloon filled with hydrogen will immediately start rising when released and float away. Its low density, the smallest of any gas, gives it this great lifting power in air. Hydrogen was once used to keep blimps and manned balloons afloat. After a spark set the German blimp *Hindenburg* aflame in 1937, however, the use of hydrogen for filling airships was abandoned. It has since been replaced by helium, which is slightly denser but far safer because it is nonflammable.

The most common compound of hydrogen is water. In the creation of this compound, two atoms of hydrogen combine with one atom of oxygen to form the familiar water molecule H_2O. But hydrogen is also contained in an almost uncountable number of organic, or carbon containing, compounds, and biological compounds present in living organisms. It is often combined directly with carbon in organic molecules. Among the immense variety of organic molecules in which hydrogen is linked chemically to carbon are hydrocarbons, the long, chainlike molecules found in natural gas and oil that, when broken apart, release the energy we use to run our power plants and automobiles. Another group of organic compounds is the carbohydrates, which consist of molecules of hydrogen, carbon, and oxygen found in sugars and starchy foods that supply humans and plant-eating animals with energy. Hydrogen compounds are also found in perfumes, dyes, pesticides, DNA, and proteins. The list goes on and on.

Hydrogen is usually prepared commercially by decomposing water. In a famous reaction called the "water gas reaction," steam is passed over hot carbon in the form of coke, although methane gas is sometimes substituted for the coke. Methane, whose chemical formula is CH_4, contains four hydrogen atoms per molecule. And if the water used is in the form of superheated steam, the hydrogen from both the methane and the water are freed from their



The space shuttle Endeavour *blasts off in 1992. Large quantities of liquid hydrogen are used to power the shuttle.*

molecules to form hydrogen gas. The steam that reacts with coke produces gaseous carbon monoxide and hydrogen. These two gases can be physically separated, but often the combination of the gases, called "water gas," is used industrially as a fuel.

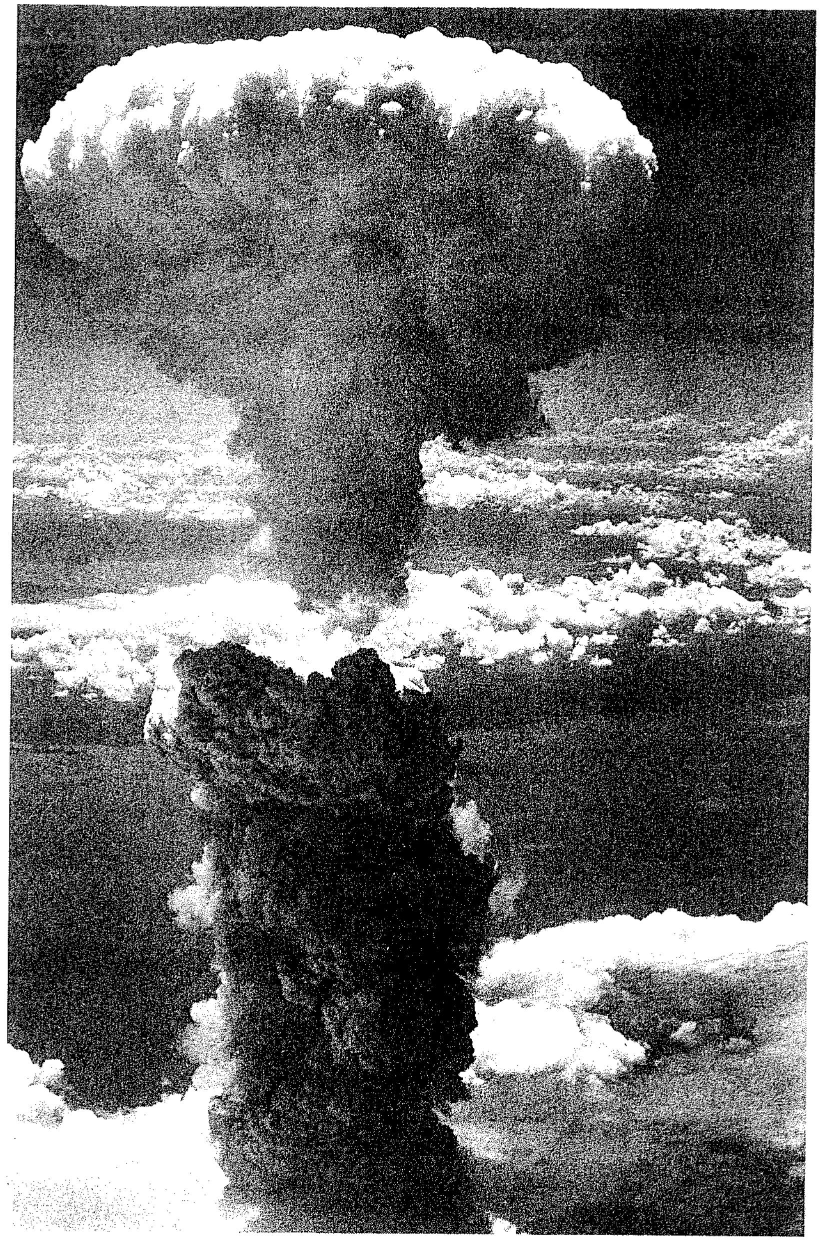
Commercially produced hydrogen gas has many uses in the chemical and food industries. Probably its most important use in the chemical industry is for the manufacture of ammonia, an ingredient of fertilizers. For the preparation of food, large quantities of hydrogen are used in a process called hydrogenation. In this process, hydrogen is added to a liquid vegetable oil, converting it to a solid such as margarine. Because it contains much less cholesterol, a fatty substance that tends to clog blood vessels, margarine is used as a substitute for butter, which is an animal fat. The aerospace industry also requires large quantities of liquid hydrogen for the manufacture of rocket fuels. When mixed with oxygen in a propulsion chamber, the hydrogen burns to produce hot steam that supplies the thrust for rocket propulsion.

Hydrogen has two isotopes of interest. The isotope containing a single neutron in addition to the single proton that normally constitutes the nucleus of hydrogen is known as hydrogen-2, or deuterium (D); the isotope with two extra neutrons is hydrogen-3, or tritium (T). These isotopes have the distinction of being the only isotopes of any element that have individual names.

Deuterium is a stable isotope that is heavier than ordinary hydrogen because of the extra neutron in its nucleus. It is often known as "heavy" hydrogen. Like its lighter cousin, deuterium combines with oxygen to form water, which in this case is known as "heavy" water, or D_2O. The natural abundance of deuterium is only about two hundredths of 1 percent, which means that about 1 out of every 6,000 water molecules found in the oceans and lakes of the Earth is heavy water. Deuterium is usually separated from water by a process known as electrolysis. Here the water is decomposed into hydrogen and oxygen gas by passing an electric current through it. A small amount of the hydrogen will be deuterium, and the two gases are then separated by using the difference in their atomic weights.

Deuterium is unusual in that its chemistry differs somewhat from that of hydrogen. For example, water that contains more than 40 percent D_2O is toxic. This difference in the chemical behavior of the isotopes of hydrogen from the conventional element is caused by the different weights of the atoms and is almost unique among the elements.

Heavy water is chiefly used as a moderator in nuclear reactors. A moderator serves to "moderate," or slow down, the neu-



A hydrogen bomb is based on the same process—nuclear fusion—by which the sun produces the light and heat that sustain life on Earth.

trons released in the reactor during the process of nuclear fission. Surprisingly, uranium atoms will undergo fission more easily if hit by slow-moving neutrons, and heavy water greatly increases the efficiency of the nuclear reactions in which uranium produces energy in a reactor.

Tritium, which contains one more neutron than deuterium, is an even heavier isotope of hydrogen. Its extra neutron is apparently enough to make tritium unstable, so that it is radioactive, with a relatively short half-life of 12.26 years. The half-life of a radioactive substance is the time required for half of its atoms to decay into atoms of lighter elements. Despite its short half-life, tritium is still found on the Earth because it is constantly being produced. High-energy particles, called cosmic rays, are constantly coming in from outer space and bombarding the upper layers of the Earth's atmosphere. This bombardment produces nuclear reactions that create tritium.

Like ordinary hydrogen, tritium reacts with the oxygen in the atmosphere to form T_2O, a radioactive "water" molecule. This radioactive water constantly enters the Earth's seas and lakes in the form of slightly radioactive rain. Fortunately, its half-life is short enough to prevent a hazardous buildup of radioactivity.

Deuterium and tritium have become key fuels in the attempt to create a device that uses nuclear fusion to produce energy. A fusion reaction is a process in which the nuclei of two atoms are brought into sufficiently close proximity for them to fuse together, almost like two water drops, forming a new, larger nucleus and liberating large amounts of energy in the process. The fusion of hydrogen nuclei is the process by which the sun produces the light and heat energy that sustains life on Earth. The hydrogen bomb, which also uses the fusion of hydrogen isotopes, is based on the huge amounts of energy available from such a reaction.

A bomb, however, is a reaction out of control. Scientists today are trying to produce a controlled fusion reaction, and one that will sustain itself. The hope is to create a fusion machine that produces more energy than is required to make the reaction work. The energy yield from such a device, if it could be controlled, would be so great that major research efforts are underway all over the world to overcome the enormous scientific and engineering difficulties facing workers in this field. One of the major problems is that the nuclei of the hydrogen atoms that scientists want to fuse have to be heated to temperatures of hundreds of millions of degrees. These high temperatures are needed to give the hydrogen nuclei enough energy to overcome their natural electrical repulsion from one another, because both nuclei are positively charged, and make them fuse together. The reason that deuterium and tritium are the atoms of choice in creating such a fusion reactor is that the temperature required to overcome their repulsion is lower than that needed for any other feasible fuel. Although the concentration of deuterium in the Earth's oceans is low, the Earth has so much water that the deuterium available for use in a fusion reactor would be almost unlimited.

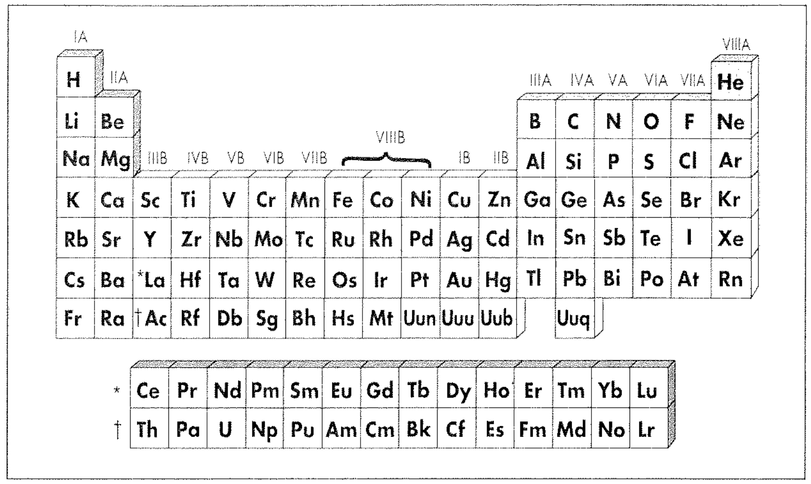
A bomb is a reaction out of control. Scientists today are trying to produce a controlled fusion reaction, and one that will sustain itself.

HELIUM

Atomic Number **2**

Chemical Symbol **He**

Group **VIIIA— The Noble Gases**



He

Add a second proton and two neutrons to the hydrogen nucleus and you have helium. In the periodic table helium heads the column known as the noble gases, so called because they are chemically inert and give the impression of keeping aloof from other elements. Like all the gases in this group, helium is colorless and odorless. It is so inactive that it will not even combine with itself. In fact, the basic unit of helium gas consists of a single atom. Helium's inertness makes it one of those rare elements that always exists in their pure elemental form. No stable compound of helium has ever been made.

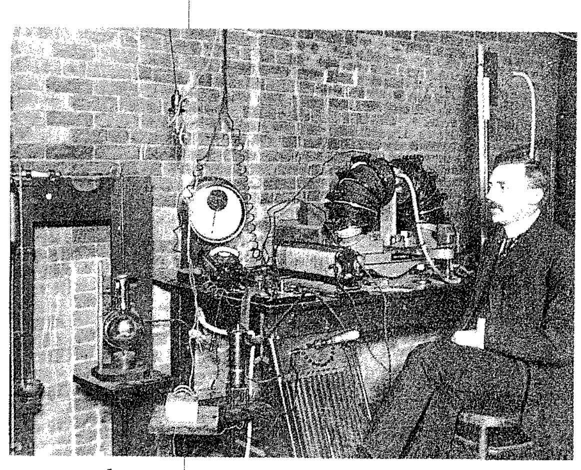
Helium is second only to hydrogen as the most abundant element in the universe. It makes up about seven percent of all the existing atoms. Together, hydrogen and helium form an astonishing 99.9 percent of elements in the universe. Helium, however, is relatively scarce on Earth, and ranks a poor sixth among the gases that make up the air.

Interestingly, helium was discovered on the sun before being identified on Earth. In 1868 the French astronomer Pierre Janssen (1824–1907) happened to notice an unusual and unexpected spectral line during his analysis of the spectral emission of the sun. Spectral emission lines refer to the wavelengths of light given off by each element when it is heated to a fairly high temperature. Every element gives off colors that are unique to it. Scientists use these colors to identify an element in the same way that a police officer uses fingerprints to identify a suspect. The yellow light given off by the sodium vapor in lamps used for highway illumination is an example of the pure light that an element produces.

Janssen correctly reasoned that the strange spectral line he detected in the sun's light must be due to an element that had never before been identified. He named this new element helium, from the Greek *helios,* which means "sun." In 1895, the Scottish chemist William Ramsay discovered helium gas in a sample of uranium ore on Earth.

The helium in the sun is produced by the fusion of hydrogen. Scientists often refer to this process as "hydrogen burning." It is this reaction that supplies the energy that the sun radiates out into space. At the high temperatures and pressures found in the interior of the sun, a number of nuclear reactions are present that have the net effect of fusing protons into a helium nucleus. Temperatures as high as 10 million degrees Celsius and pressures 100 times that of the atmospheric pressure on Earth are required to start these reactions. Luckily, even at these extreme conditions hydrogen burns rather slowly. The sun has been burning hydrogen for some 5 billion years, and is expected to continue doing so for the next 5 billion years.

On Earth, almost all the helium is found in natural gas and results from the decay of such radioactive isotopes as uranium and radon. These radioisotopes spontaneously emit helium nuclei as they decay. The more common name for these helium nuclei is alpha particles, so called by their discoverer, Sir Ernest Rutherford, a professor of physics at the Cavendish Laboratory at Cambridge University in England. Rutherford did not at first realize that alpha particles were helium nuclei and therefore assigned the Greek letter "alpha" to them, in much the same way that unknowns are generally called x in algebra.



Sir Ernest Rutherford in his laboratory at Cambridge University. Rutherford did not realize at first that the mysterious particles released during the decay of such radioactive isotopes as uranium and radon were actually helium nuclei.

Some 3 billion cubic feet of helium is made commercially each year in the United States alone. Although natural gas, an important source of energy, consists primarily of methane, it also contains helium in concentrations as high as 0.3 percent. The helium is separated from the methane and other contaminants by a process known as fractional distillation. Fractional distillation is a technique of separating a mixture of liquids by using the differences in their boiling points. Helium is a difficult gas to liquefy, since its boiling point of -268.9°C is lower than that of any other gas. If natural gas is cooled, all of the other gases in it will liquefy first, leaving only

Because helium is lighter than air, it can be used to make blimps and balloons float. Although hydrogen has more lifting power than helium, its flammability makes it unsafe to use.

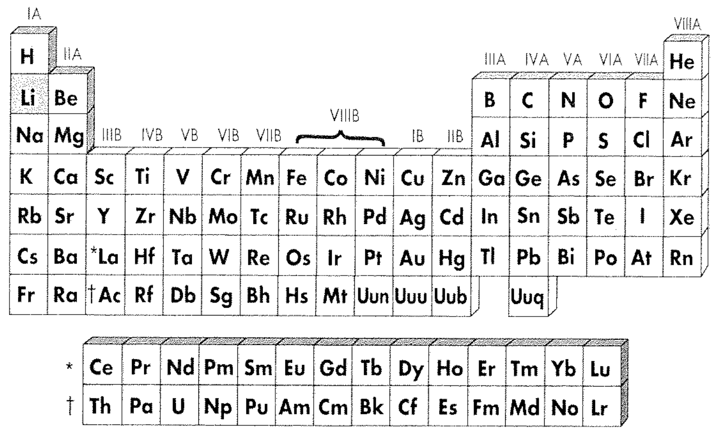
air. Divers working at high pressures underwater usually breathe "air" that is a mixture of oxygen and helium. Helium is substituted for nitrogen in this mixture because it is less soluble than nitrogen and therefore less likely to dissolve in the bloodstream. This offers better protection against one of the major hazards of diving, called the "bends." If a diver returns to the surface too quickly after a dive, the relatively lower pressure at the surface than deep underwater causes dissolved gases to bubble out of solution in the blood. The effect is similar to the frothing in a bottle of soda water when the cap is removed. In the body, the bubbles of the gases released in this way often get trapped in the joints of the body, causing extreme pain and often making it impossible for the diver to straighten up, which is why this condition is aptly named the bends.

An amusing side effect of breathing helium is a change in the pitch and quality of one's voice. Because helium is less dense than air, the vocal cords produce sounds of higher pitch than with air, and make the speaker sound like Donald Duck.

A mixture of helium and neon gas produced the first gas laser ever made. The word *laser* is an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation. Lasers produce intense and very narrow beams of light that are sharply focused on a single color. One of the major applications of the helium-neon laser is in supermarkets, where it is used to read the bar codes of food labels during checkout.

Since World War I the United States has maintained a stockpile of helium. We now store some 32 billion cubic feet of helium gas in natural caverns. Although helium is no longer critical for military purposes, it still has many vital scientific applications. It is used for weather balloons that can also study the upper layers of the atmosphere. Many of the world's large particle accelerators, built to investigate the structure of matter, use liquid helium to cool their superconducting magnets. Astronomers also use liquid helium to cool many of their detectors. This removes the interference called thermal "noise," and makes it easier and more reliable to receive data from distant galaxies.

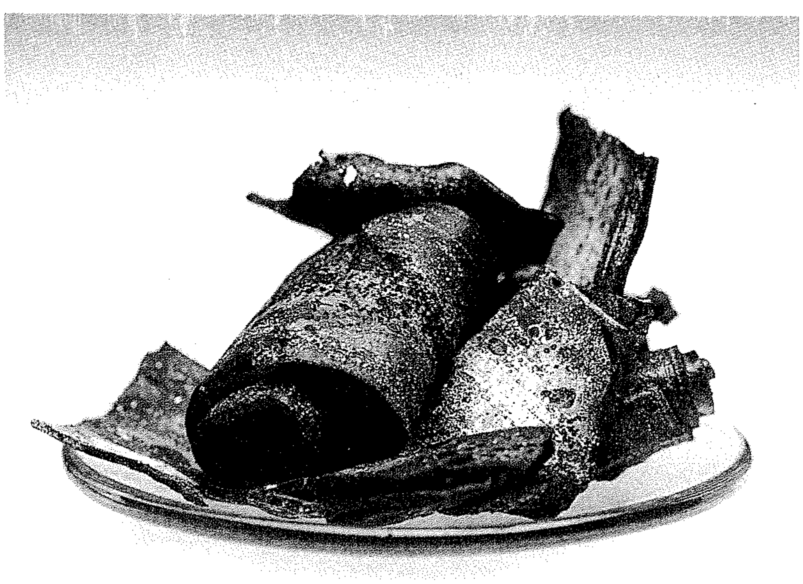
LITHIUM



Li

Lithium is the element that follows helium in the periodic table. The difference in the chemical and physical properties of these two elements could not be more striking. Lithium is a metal, an extremely reactive one. It reacts vigorously with water, for example, to produce hydrogen gas, and with oxygen to form lithium oxide (Li_2O). To prevent these reactions from occurring spontaneously in air, lithium is usually isolated from its environment by storing it immersed in oil or kerosene.

Lithium is the lightest metal of the group known in the periodic table as the alkali metals. Lithium is at the head of this group. All these metals are very reactive. Lithium metal is so soft that it can be cut with a sharp knife. It is never found in its "free," or pure, state in nature, since it reacts so readily with air and water.



Lithium is such a soft metal that it can be cut with a sharp knife.

Atomic Number **3**

Chemical Symbol **Li**

Group **IA—The Alkali Metals**

Lithium was discovered in 1817 by a Swedish chemist during a routine chemical investigation of some minerals from a mine in Sweden.

When purified, it has a beautiful silvery-white color.

It is startling to think of a metal floating on water, but the density of lithium is so low that it actually does float. When carefully placed on the surface of water, a small piece of lithium will whirl about erratically, very much like a small boat out of control.

Lithium was discovered in 1817 by the Swedish chemist Johan August Arfvedson during a routine chemical investigation of some minerals from a mine in Sweden. It was named for the Greek word *lithos,* which means "stone."

All the alkali metals are reactive, but their reactivity increases with their atomic number. This means that these metals become more reactive as you go down their column in the periodic table. This can be explained by noticing that the "valence" electron, the electron occupying the outermost shell of the atom, is further from the nucleus in large atoms. The farther away the electron is from the nucleus, the less tightly it is bound to the atom and the more likely it is to be removed from the atom in a chemical reaction. Thus, for example, when rubidium and cesium—the heaviest of the alkali metals and the two members of this group with the largest atoms—react with water, the reaction proceeds with explosive violence, rather than with a simple bubbling of hydrogen.

The most common commercial source of lithium is the mineral spodumene. A compound called lithium carbonate (Li_2CO_3), obtained from this mineral, is the starting point for obtaining metallic lithium and most of its important compounds. The pure metal itself, for example, is obtained by the electrolysis of lithium chloride (LiCl), which is prepared from lithium carbonate. Electrolysis is a process in which electricity is used to produce a chemical change in a substance. In the electrolysis of lithium chloride, two electrodes, one called an anode and the other a cathode, are placed in a vat of molten lithium chloride. The electrodes are connected to a source of electricity and large electric currents are passed through the molten compound. Lithium metal forms at the cathode and is removed for further processing.

The use of lithium metal has assumed some commercial importance in recent years. It is, for example, combined with aluminum to form a low-density, structurally strong alloy for use in aircraft and spaceships. Lithium metal is also used as the positive terminal, or anode, in the small batteries used in cameras, pacemakers, and calculators. In addition to being lighter than the standard dry cell, these batteries produce a higher voltage (3 volts versus 1.5 volts).

Lithium hydroxide (LiOH) is an important compound of lithium obtained from the carbonate. It is a strong base, which means that when dissolved in water, it produces a high concentration of hydroxide $(OH)^-$ ions. An ion is an atom or molecule that has a net electric charge because it contains fewer or more electrons than protons. If electrons are stripped away from an atom, a positively charged ion is formed. If electrons are gained, a negatively charged ion is formed. Ions are highly reactive because their electric charge attracts other atoms, with which they combine in an effort to lose their electron imbalance and once again become electrically stable. When lithium hydroxide is heated with a fat, it produces a soap called lithium soap. (All soaps are essentially prepared by combining animal fats with a strong base.) Lithium soap has the ability to thicken oils and so is used commercially to manufacture lubricating greases.

Lithium hydroxide is also a very efficient and lightweight purifier of air. In confined areas—aboard spacecraft or submarines, for example—the concentration of carbon dioxide from exhaled air can often approach unhealthy or even toxic levels. Lithium hydroxide absorbs the carbon dioxide from the air by reacting with it to form lithium carbonate.

In its purified form, lithium carbonate has recently been used to treat patients with the severe mental illness known as bipolar disorder. More than 3 million prescriptions for this compound are filled yearly to help patients with this disorder. The role of lithium carbonate in the complex chemical reactions that determine brain dysfunction is not known but it is thought to affect the way in which brain cells respond to certain hormones and to the complex biological molecules known as neurotransmitters, which assist the transmission of messages along nerve networks and can greatly affect moods and behavior.

One of the isotopes of lithium, lithium-6 (so designated because its nucleus contains three neutrons in addition to three protons), played a major role in the production of the hydrogen bomb. The hydrogen bomb makes use of the thermonuclear fusion of deuterium and tritium to produce vast amounts of energy. In order to fuse the nuclei of these isotopes of hydrogen, however, temperatures as high as millions of degrees are required. The problem in creating the hydrogen bomb was to fabricate a device that could produce these high temperatures and supply enough deuterium and tritium to make an effective bomb.

During World War II, the Hungarian-born American physicist Edward Teller saw an ingenious way to construct such a bomb using a compound of lithium-6 and deuterium that is known as

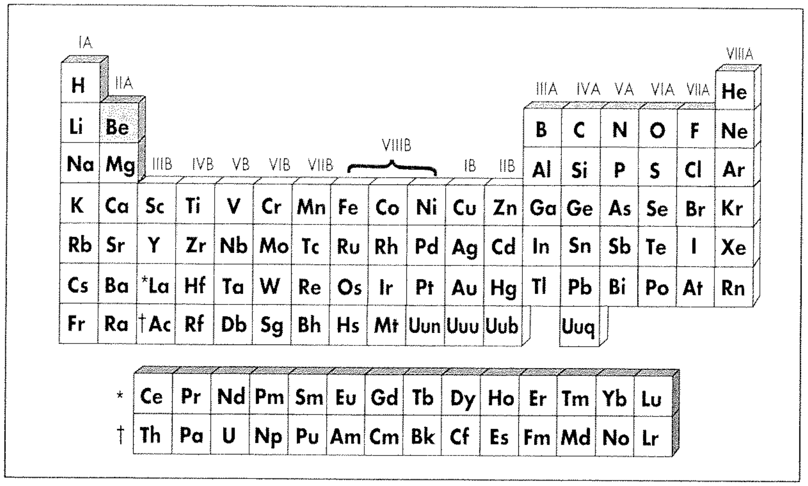
The American physicist Edward Teller used a compound of lithium—lithium deuteride—to help construct a bomb far more powerful than the original atomic bombs exploded over Hiroshima and Nagasaki.

Lithium has the highest heat capacity of any element, more than twice that of water, which means that it can absorb large amounts of heat with only a slight increase in its own temperature.

lithium deuteride. The deuteride is a solid and therefore contains a large amount of deuterium in a small volume. The important feature of this compound, however, is that when lithium-6 is subjected to bombardment by neutrons, it undergoes a nuclear reaction to form tritium. Teller reasoned that if an ordinary uranium fission bomb—the original atomic bomb—was surrounded with a layer of lithium deuteride, the explosion of the uranium bomb would not only supply the neutrons needed to transform lithium-6 into tritium but would also produce the temperatures needed to fuse the tritium with deuterium. The idea worked brilliantly, and, for good or evil, superbombs with megaton capabilities were created.

Lithium plays another role in the world of nuclear energy. It has the highest heat capacity of any element, more than twice that of water, which means that it can absorb large amounts of heat with only a slight increase in its own temperature. This property makes lithium an ideal heat-transfer material, and it is being used in many experimental nuclear reactors to absorb the heat produced by the fissioning of uranium.

BERYLLIUM

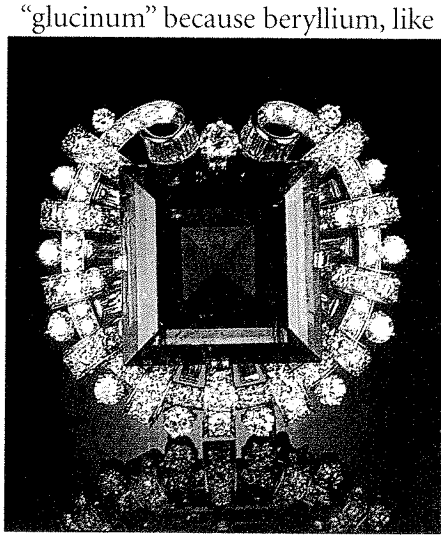


Be

Following lithium in the periodic table is the element beryllium. Beryllium heads the group of elements known as the alkaline-earth metals. The most abundant elements in this group are calcium and magnesium, but they all share common chemical and physical properties. Although several forms of beryllium are found in the earth's crust, it is a relatively scarce element, ranking 32nd in order of the relative abundance of the elements.

Beryllium in its pure state is a fairly hard, gray-white metal. It is one of the lightest of the metals, but hard enough to scratch glass. Like all the metals that make up the alkaline-earth group, it is much too chemically reactive to be found in its free state. It readily reacts, for example, with oxygen and many other elements. Its principal natural source is the mineral beryl, from which beryllium gets its name. Beryllium was formerly known as "glucinum" because beryllium, like many of its compounds, has a sweet taste. This name is now obsolete.

Crystals of this mineral are quite beautiful and often very valuable. Both emerald (green) and aquamarine (blue) are naturally occur-



The brilliant green color of this emerald comes from the presence of beryl, the mineral that is the principal source of beryllium.

Atomic Number **4**

Chemical Symbol **Be**

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


In 1932, the English physicist James Chadwick discovered neutrons by bombarding beryllium with alpha particles.

ring precious forms of beryl. When cut and polished, these crystals supply the gems that are used in many expensive bracelets and necklaces.

The mineral known as beryl is actually a complex compound of beryllium, silicon, and oxygen. Its scientific name is beryllium aluminum silicate. It is usually found, like most of the alkaline earth metals, in various mineral deposits distributed over Brazil, Argentina, and the United States. Crystals of beryl several feet long and weighing as much as a thousand pounds have been found. More commonly, however, these crystals are quite small.

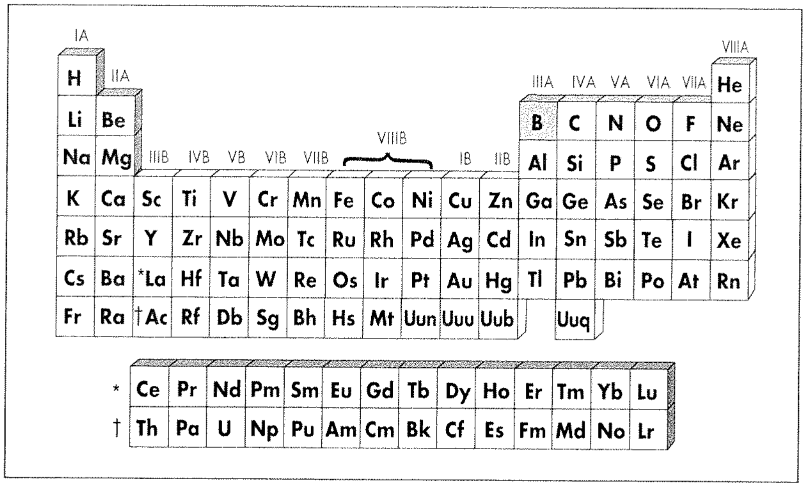
Beryllium was discovered in 1798 by the French chemist Louis-Nicolas Vauquelin, who was investigating the structures of beryl and emerald. The two gemstones were long thought to be different minerals. Vauquelin is also credited with the discovery of chromium.

Metallic beryllium in commercial quantities is made from the electrolysis of molten beryllium chloride ($BeCl_2$). The pure metal was not commercially available until 1957, but it has been found to have a number of desirable properties. Beryllium is, for example, extremely transparent to X rays and is therefore used as a sturdy, durable window for X-ray tubes.

Beryllium is often combined with other metals to form special alloys. One of these is the beryllium-copper alloy known as beryllium bronze, a fairly hard metal with the unusual property of not giving off sparks when struck. This makes it a valuable material for the electrical contacts and hammers employed in explosive environments. These might be chemical laboratories using hydrogen, or factories manufacturing rocket fuel.

Great care must be used in working with beryllium compounds because they are quite toxic. Exposure and inhalation of finely powdered beryllium compounds, such as beryllium oxide, can lead to a painful and fatal disease known as berylliosis.

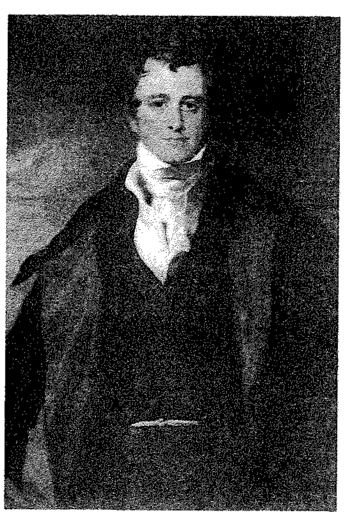
When beryllium is bombarded with alpha particles, it undergoes a nuclear reaction that causes it to emit neutrons. It was this reaction that led to the discovery of the neutron by the English physicist James Chadwick in 1932. This reaction is still used today as a convenient source of neutrons in laboratories doing research on atomic nuclei.



BORON

Boron is a hard, brittle, non-metallic element that stands at the head of the elements that make up Group IIIA in the periodic table. All the other elements of this group, which include aluminum, are metals. Boron is a rather scarce element, making up only about .0003 percent of the Earth's crust by mass. In its pure state, it is a brownish crystal that is almost as hard as diamond. It was first isolated in 1808 by the English chemist Sir Humphry Davy and two French chemists, Joseph-Louis Gay-Lussac and Louis-Jacques Thénard.

Although boron is much less reactive than the elements that immediately precede it in the periodic table, it is never found in its pure form in nature. Instead, it is usually combined with oxygen, water, and sodium in a compound called borax. Borax, the most important compound of boron and the substance that gives boron its name, is found in dry lake beds in the southwestern part of the United States. Borax is used mainly as a cleaning agent and water softener. Water is said to be "hard" if it contains some alkaline-earth ions such as magnesium and calcium, which combine with soap to produce a scumlike precipitate that can cause the familiar rings around sinks and tubs. When water is softened, the magnesium and



The English chemist Sir Humphry Davy isolated boron in 1808. He was also responsible for isolating seven other elements.

Atomic Number **5**

Chemical Symbol **B**

Group **IIIA**

calcium are removed and replaced with relatively harmless sodium and potassium.

Another common and important boron compound is boric acid. It is made by heating borax with either hydrochloric or sulfuric acid. Boric acid is a rather weak acid that has some antiseptic properties that make it useful as an eyewash. Industrially, it is used to make a special heat-resistant type of glass, known as borosilicate glass, which usually carries the commercial name of Pyrex. The most common use of Pyrex is in the kitchen, where Pyrex glass baking dishes and measuring cups are used because they can withstand rapid changes in temperature without cracking.

Boric acid—a compound of boron—is used to make a special heat-resistant type of glass, borosilicate glass, which is used to manufacture glass baking dishes.

Boron plays a very important role in the design and utilization of nuclear reactors. It became apparent quite early in the search for ways to produce energy from the nucleus that boron is a very efficient absorber of neutrons. The neutron, one of the fundamental particles that make up the nucleus of an atom, plays a crucial role in a nuclear reactor. When uranium-235, the most common fuel used in reactors, absorbs a neutron, it splits or "fissions" into two fragments, releasing energy and more neutrons. These new neutrons can then fission more uranium atoms and start a chain reaction. To prevent this chain reaction from running wild and producing an explosion, the number of neutrons available for fissioning must be controlled. Nuclear engineers commonly use boron "rods" that can be lowered into a reactor to absorb the neutrons, and so control the power being produced in the reactor. These rods are called control rods.

Boron has also become important in the manufacture of transistors. It is hard to conceive of life today without calculators, computers, and VCRs. All of these instruments use transistors, which are silicon or germanium chips to which impurities, such as boron, have been added in a carefully controlled manner.

When silicon atoms combine with each other to form a solid crystal of silicon, the outer electrons of all of these atoms share in forming the chemical bonds that hold the crystal together. Electrons are found in concentric "shells" about the nucleus of any atom, and there are certain rules, called quantum rules, that determine the number of electrons in each shell. The electrons found in the very outermost, or valence, shell usually determine how an atom reacts chemically, and it is these electrons that are used to form chemical "bonds" between atoms. These valence electrons hold the silicon crystal together.

When a small quantity of an element such as boron is added to a crystal of silicon, boron atoms take over some of the sites that were formerly occupied by silicon atoms in the crystal. Chemists usually refer to the addition of an impurity of this kind by saying that the silicon has been "doped" with boron. However, boron has only three outer electrons, whereas silicon has four. Consequently, the site occupied by the boron atom is deficient by one electron and its negative electric charge; the boron atom is said to form an electrically positive "hole" in the silicon crystal.

When an electrical force, or voltage, is applied to the boron-doped silicon, it induces an electron from a neighboring atom to leave its position and occupy the electrically positive hole that exists at the site of the boron atom. But as the electron leaves the neighboring atom in order to fill the hole, it leaves that atom with one less electron and so forms another positive hole in the process. The end result of this switching of electrons is that the positive charge that was originally present at the site of the boron atom seems to migrate through the silicon crystal, creating an electrical current. Because the carrier of electricity in this case is a positive charge, the transistor is called a p-type semiconductor. P-type semiconductors are also used in the manufacture of solar cells, in which light generates an electric current.

Although boron is much less reactive than the elements that immediately precede it in the periodic table, it is never found in its pure form in nature.