

FLUORINE

Atomic Number **9**

Chemical Symbol **F**

Group **VIIA**—
The Halogens

IA												VIII A															
H	He																										
IIA												VIII A															
Li	Be																										
III B		IV B		V B		VI B		VII B		VIII B		IB		IIB		III A		IV A		V A		VI A		VII A		VIII A	
Na	Mg	Al	Si	P	S	Cl	Ar											Ne									
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr										
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe										
Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn										
Fr	Ra	†Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq															
		* Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu																									
		† Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr																									



Fluorine heads the column of elements in the periodic table known as the halogens, or “salt formers.” The other members of this family are chlorine, bromine, iodine, and astatine. Astatine, at the bottom of the group, is highly radioactive.

All halogen atoms react chemically by accepting electrons from other atoms and readily combine with metals to form compounds known as salts. The smaller the halogen atom, the closer to the nucleus the incoming electron will be and the greater the force that attracts it and makes the reaction occur. Fluorine is the smallest, lightest, and most reactive member of the halogen group.

Fluorine is a pale yellow gas whose molecules contain two atoms. It is, however, far too reactive to be found in nature in its diatomic form. Fairly large quantities of fluorine occur in the minerals fluorite or calcium fluoride (sometimes called fluorspar) and cryolite, which contains fluorine, aluminum, and sodium. Fluorine is also found in small quantities in seawater, teeth, bones, and blood.

The French chemist Henri Moissan won the Nobel Prize in 1906 for first producing fluorine in its pure elemental form. Its name is taken from the Latin word *fluere*, which means “to flow.” The origin of the name is probably due to the use of fluorite as a flux. A flux is added to many compounds and minerals to lower their melting point and make them more available for further chemical treatment. It was long known that fluorine compounds existed, but because of its extreme reactivity, pure fluorine had never been isolated. It took 75 years of continuous effort on the part of many chemists before it was finally isolated by Moissan in 1886.

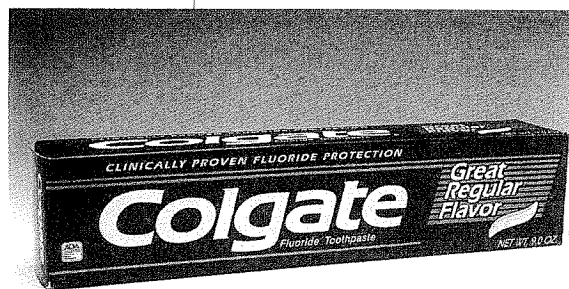
Fluorine is usually prepared by passing an electric current through molten fluoride salts. In 1986, however, Karl O. Christie, working at the Air Force laboratory at Edwards Air Force Base in California, astounded many chemists by successfully isolating pure fluorine from a fluorine compound using only chemical means. Because of the large amounts of energy required for such a procedure, it had long been believed that such a chemical separation was impossible.

Today fluorine is commercially prepared from fluorspar at the rate of thousands of tons a year. It is shipped as a liquid in special containers, cooled by liquid air.

Fluorine gas is used to produce a rather exotic gaseous compound of uranium called uranium hexafluoride (UF_6). It is in the form of this compound that uranium is usually shipped to huge gas diffusion plants, where the important uranium-235 isotope is then separated from the more common uranium-238 isotope. It is the U-235 isotope that is easily fissionable and plays such a major role in nuclear reactors and nuclear weapons.

Another important role for fluorine in nuclear research is in producing a gas for detecting the presence of neutrons. This sensitive gas is a compound of fluorine and boron called boron trifluoride (BF_3). As we have seen in the section on boron, this element readily absorbs neutrons and then emits highly charged alpha particles that are easily detected. However, there are technical obstacles to the use of pure, solid boron for such detectors, and it is far easier to construct a neutron detector that uses the gaseous, boron-containing molecules of BF_3 . BF_3 detectors, as they are called, are among the most important tools for this purpose.

Many communities in the United States now add fluorine, in the form of sodium fluoride, to their public water supplies. Research has shown that small quantities of fluorine can retard the occurrence of cavities in teeth. Teeth are protected by a hard enamel that is composed of a mineral called hydroxyapatite. This mineral is not very soluble, but in the presence of the weak acids that bacteria in the mouth produce from food that has a high sugar content, some breakdown of hydroxyapatite occurs. The resulting loss of enamel promotes the onset of tooth decay. One of the body's defenses against the loss of tooth enamel is to make new enamel constantly, a process called remineralization. In the presence of sodium fluoride, the remineralization process makes a modified form of enamel, called fluorapatite, that is more resistant to attack



Toothpastes containing fluorine, in the form of sodium fluoride, can help prevent cavities. In the presence of sodium fluoride, a process called remineralization makes a modified form of tooth enamel that is resistant to attack by acids.

Fluorocarbons in aerosol cans have been banned in the United States because these gases diffuse into the upper atmosphere and the resulting loss of ozone permits dangerous ultraviolet radiation to reach the surface of the Earth.

by acid than hydroxyapatite is. Manufacturers of toothpaste now routinely add sodium fluoride to their products.

Considering the extreme reactivity of fluorine gas, it is somewhat surprising that a plastic called Teflon, consisting of long, chainlike molecules of carbon linked chemically to fluorine, should be as inert as it is. Teflon is used for nonstick surfaces on frying pans and on a variety of other products that require smooth, nonreactive surfaces. It is also used to make artificial valves for the heart.

Other fluorinated compounds of carbon include aerosol propellants for spray cans and Freon, an inert gas used as a refrigerant. The use of fluorinated carbon gases, known as fluorocarbons, in aerosol cans has been banned in the United States since 1978 because it is known that these gases diffuse into the upper atmosphere and react with the ozone layer. The resulting loss of ozone permits dangerous ultraviolet radiation to reach the surface of the Earth.

In the presence of hydrogen, fluorine burns with explosive force. The reaction is spontaneous, and not even a match or spark is needed. The reaction forms hydrogen fluoride, which when dissolved in water is an acid. Hydrofluoric acid is extremely dangerous and must be carefully handled. A small amount on the skin can cause extreme pain. However, this acid has the ability to dissolve glass and is used to etch designs on glass objects.

An artificially made, radioactive isotope of fluorine, fluorine-18, is one of several isotopes used in the medical procedure called positron emission tomography (PET). Fluorine-18 spontaneously emits positrons, which are the antiparticles of electrons and resemble the latter in every respect but their electric charge. When a positron collides with an electron, the two particles “annihilate” each other, yielding a burst of energy that takes the form of X-ray-like radiation. If fluorine-18 is introduced into the body, this “annihilation” radiation is emitted within the body and can be scanned by special detecting instruments to produce cross-sectional pictures of portions of the body. Fluorine-18 is ideal for this technique because it has a half-life of only 109.8 minutes, which is important for minimizing radiation injury to the patient’s body tissues.

SODIUM

Atomic Number **11**

Chemical Symbol **Na**

Group **IA—The Alkali Metals**

IA												VIII A																																			
H											He																																				
II A												III A	IV A	V A	VIA	VII A	VIII A																														
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<table border="1"> <tr> <td>*</td> <td>Ce</td> <td>Pr</td> <td>Nd</td> <td>Pm</td> <td>Sm</td> <td>Eu</td> <td>Gd</td> <td>Tb</td> <td>Dy</td> <td>Ho</td> <td>Er</td> <td>Tm</td> <td>Yb</td> <td>Lu</td> </tr> <tr> <td>†</td> <td>Th</td> <td>Pa</td> <td>U</td> <td>Np</td> <td>Pu</td> <td>Am</td> <td>Cm</td> <td>Bk</td> <td>Cf</td> <td>Es</td> <td>Fm</td> <td>Md</td> <td>No</td> <td>Lr</td> </tr> </table>																		*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	†	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
*	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu																																	
†	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr																																	



Sodium is an extremely reactive, bright, silvery metal, light enough to float on water and soft enough to be cut with a knife. It is far too chemically active to be found as a pure element in nature. Even its storage presents a problem. It

reacts violently with water, producing enough heat, as it sizzles and bubbles on top of the water, to melt it. It is usually kept immersed in a liquid such as kerosene to prevent it from reacting with air or moisture. Sodium is the sixth most abundant element in the Earth's crust, present at a concentration of 2.63 percent by mass.

The English chemist Sir Humphry Davy first isolated and identified sodium as an element in 1807, using an electrolytic process to separate it from molten sodium hydroxide. The name *sodium* is derived from the English word *soda*, which itself is taken from the Latin word *sodanum*, a common headache remedy of ancient times. The modern commercial method of producing sodium uses essentially the same method of electrolysis developed by Davy. The only difference is that ordinary table salt, sodium chloride, is used in place of the hydroxide. Molten sodium chloride conducts electricity, which means that the sodium and chlorine atoms must be in their electrically charged form, known as ions. As ions they can move about easily through the melt when subjected to electrical forces. When two electrodes are placed in a bath of molten sodium chloride and connected to a source of high voltage, sodium collects at one electrode, the cathode, and chlorine at the other, the anode.

Sodium has a melting point of only 98°C, which is lower than the boiling point of water. It is therefore very easy to liquefy. When sodium is transported, for example, it is pumped in liquid form

into tank cars, where it solidifies. At its destination, special heating coils melt the metal and it is pumped out of the cars.

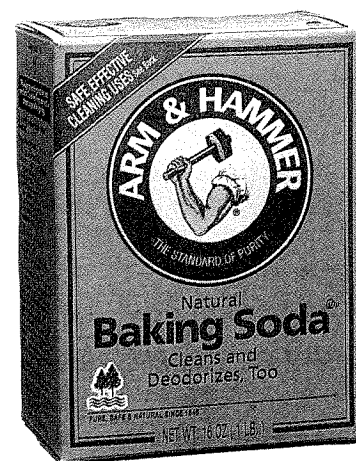
One use for liquid sodium is as a moderator in certain types of nuclear reactors. It has the right nuclear characteristics to support a chain reaction. It also has a very high specific heat, which means that a lot of heat energy is required to raise its temperature. This makes sodium an excellent material for transferring heat out of a nuclear reactor. Despite the chemical hazards of dealing with such a reactive material, reactors utilizing liquid sodium are considered safe enough to be used aboard submarines.

As a member of the alkali metals, sodium undergoes many of the chemical reactions common to these elements and is part of many important compounds that are found widely distributed throughout the Earth. The compounds of sodium are of enormous economic importance. Sodium chloride, the chemical name for common table salt, is mined in huge quantities from natural salt deposits. Seawater is another source of salt. Every gallon of seawater contains about a quarter of a pound of salt. As a nutrient and flavoring agent, table salt has been traded and bartered since early Roman times. The word *salary*, for example, is derived from the Latin word *sal* for “salt” and the fact that Roman soldiers were often given an allowance of salt as payment for their services.

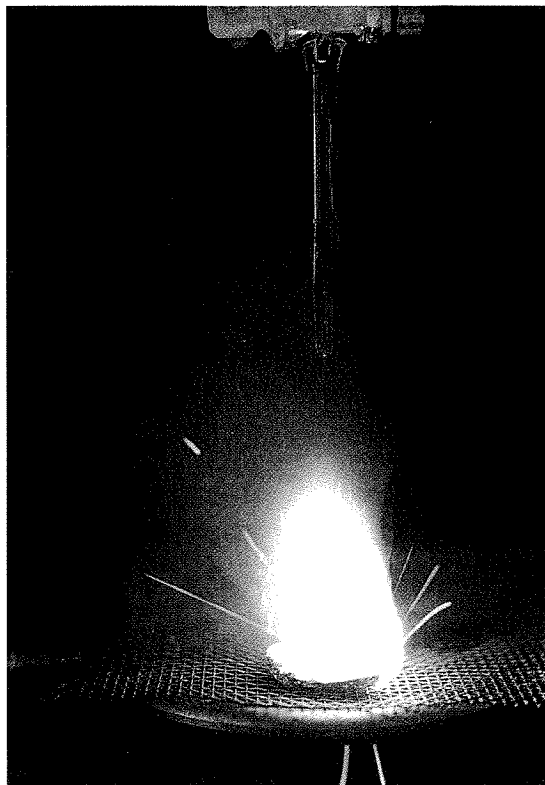
Sodium hydroxide, NaOH, is one of the most important industrial compounds of sodium. It is produced commercially by the electrolysis of a solution of sodium chloride in water, also known as aqueous sodium chloride. Sodium hydroxide is a strong base that is available in most markets under the name of lye or caustic soda and serves as a drain cleaner or oven cleaner. The secret of its ability to cut grease is that it reacts with fatty material, converting this material into a substance that will dissolve in water. Soap is a mixture of fat and sodium hydroxide. In the manufacture of soap, the sodium hydroxide *saponifies* the fat, creating a water-soluble sodium “salt” of the fat. Because sodium hydroxide reacts chemically with fat, it is quite dangerous to skin and must be handled with great care.

Another important sodium compound is sodium carbonate, which is a common cleaning agent and bleach. It is known commercially as soda ash and is mixed with sand and lime to make glass. Sodium carbonate is made on a large scale by the Solvay process, in which it is manufactured from sodium chloride and limestone. The raw limestone and salt that are used in the process are inexpensive.

Another widely used compound of sodium is sodium bicarbonate, commonly known as baking soda. As its name implies,



Sodium bicarbonate, commonly known as baking soda, is used to make baked goods rise when heated or pastry dough rise when baked. It is also used as an antacid and as an agent in fire extinguishers.



Great care must be taken when storing or transporting sodium. It reacts violently when mixed with water (above). Sodium is so reactive that it is never found as a pure element in nature.

baking soda is used as a leavening agent in baking. But it also serves as an antacid to help neutralize excessive stomach acidity and as an agent in fire extinguishers, in which it is mixed with an acid to generate carbon dioxide, which smothers fires.

The isotope of sodium known as sodium-24 is radioactive and is used in biological research as a radiotracer. Because the chemistry of sodium-24 is identical to that of the stable form of sodium found in nature, the isotope can form the same compounds. Sodium chloride can be made, for example, with sodium-24 instead of ordinary sodium. In this case, scientists refer to the sodium-24 chloride molecule as being “tagged” or “labeled” with a radioactive sodium atom. When the tagged salt is ingested, its movement through the body can be traced with detectors that sense the radiation emitted by the atoms of sodium-24. Because the half-life of sodium-24 is relatively short (only 14.97 hours), the isotope dissipates quickly, minimizing the danger of radiation damage to the body.

When sodium burns, or when an electrical discharge passes through sodium vapor, it gives off a characteristic yellow light. The wavelength of this light is very precise and is used in many scientific laboratories to calibrate spectrometers and other light-measuring devices.

Sodium is also used in some types of highway lights. It is, first of all, very efficient because it gives off a very intense beam of light at the expense of a relatively small amount of electricity. But highway engineers have been prompted to use sodium lights primarily because yellow light does not scatter as much in fog as other colors and because the eye is very sensitive to the color yellow. For the same reasons, many automobile manufacturers have constructed sodium fog lights for luxury cars.

Magnesium is the seventh most abundant element in the Earth's crust and is also present in large quantities in seawater.



Excess acids in the stomach can be neutralized by milk of magnesia, a suspension of magnesium hydroxide.

well as power tools, lawn mower housings, and racing bikes.

Magnesium is a chemically reactive metal. In the form of a powder or metal particles, it burns brilliantly in air, giving off an intense white light that is often seen in fireworks and flares. A flash-bulb consists of a thin magnesium wire that is ignited electrically by a battery. The interior of the bulb usually contains a pure oxygen atmosphere, so that the magnesium burns very rapidly. Interestingly, magnesium will also burn in carbon dioxide. Fire extinguishers that produce carbon dioxide to smother fires by preventing oxygen from getting to them would be useless in the case of a magnesium fire.

Magnesium oxide is an important compound of magnesium obtained directly from the mineral magnesite. It is used in animal feed to supply magnesium as a dietary supplement. Magnesium is also important for proper nutrition in humans because it is essential for the proper functioning of several enzymes. Additionally, it is present in chlorophyll, which plays an essential role in photosynthesis and therefore in the survival of green plants on the Earth.

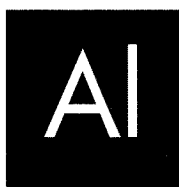
Milk of magnesia is a suspension of magnesium hydroxide, $\text{Mg}(\text{OH})_2$, in water. The familiar, creamy-looking suspension is somewhat basic and is used as an antacid because magnesium hydroxide neutralizes excess acid in the stomach.

Another common over-the-counter remedy containing magnesium is Epsom salts. These salts are a hydrated form of magnesium sulfate, which means that this molecule has several water molecules attached to it. First discovered in a well in Epsom, England, the medicinal properties of Epsom salts were noted as long ago as the early 17th century. They are still used as an aid in healing certain rashes of the skin. Magnesium is also used commercially in the tanning of leather and in the treatment of fabrics to make them accept dyes.

Relatively large concentrations of magnesium are found in some natural water supplies. This contributes to making the water "hard." The dissolved magnesium interferes with the action of detergents and forms scummy precipitates when the water is mixed with soap. The magnesium is usually removed in a process called water softening, in which it is replaced by dissolved sodium, which interferes much less with the action of detergents and soaps.

Magnesium also plays a crucial role in the makeup of the green chlorophylls present in all green plant cells. The ability of the chlorophyll to capture solar energy and convert it by photosynthesis to energy is the ultimate source of all biological energy. The structure of the chlorophyll molecule, a ring of complex atomic structures around the magnesium atom, endows the molecule with its deep color and its ability to absorb light. The role played by magnesium is to promote the formation of these light-absorbing structures.

IA																		VIII A							
H	He																	III A	IV A	V A	VIA	VII A	He		
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Aluminum is an extremely important commercial metal whose uses range from aluminum foil to airplane wings. As a pure element, it is a fairly soft, silvery-white metal. Usually found in nature combined with oxygen, aluminum is the third most abundant element in the Earth's crust and the most abundant metal in the crust.

Despite its abundance, aluminum remained a rather exotic and expensive metal until 1886, when Charles M. Hall in the United States and Paul L. T. Heroult in France independently discovered an inexpensive method of obtaining pure aluminum by electrolyzing aluminum oxide (Al_2O_3).

Both men discovered that aluminum oxide will dissolve in another aluminum-containing mineral called cryolite. Of vital importance is that the mixture not only conducts electricity but also has a low melting point. Pure aluminum can therefore be separated from its oxide and other compounds by passing an electric current through the molten mixture. All but a slight fraction of the world's supply of aluminum is now produced by this process. The production of aluminum consumes about 5 percent of all the electricity used in the United States today.

The principal ore of aluminum is bauxite, named after Les Baux in France, where it was discovered in 1821. This ore contains aluminum in the form of a hydrated oxide, an oxide that is combined with water molecules. Deposits of bauxite are found all over the world, but chiefly in tropical regions.

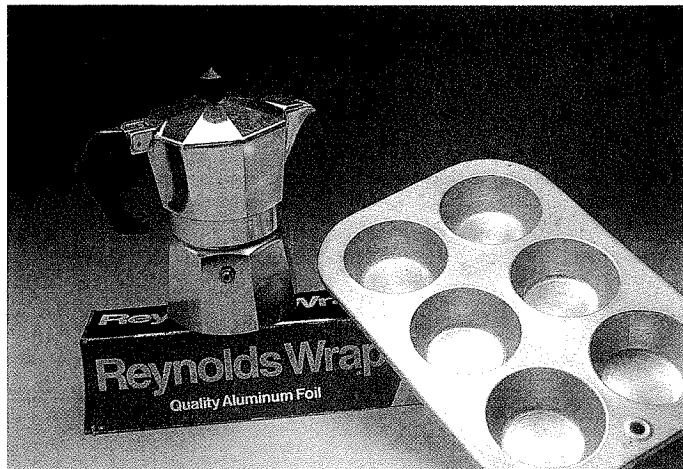
Aluminum oxide is known commercially as alumina, from which the element derives its name. The pure oxide is white and very hard. It can form crystals called corundum, one of the hardest materials known. Corundum is often used as an abrasive in

ALUMINUM

Atomic Number **13**

Chemical Symbol **Al**

Group **III A**



A sampling of products made from aluminum. This metal's light weight and its ability to withstand high temperatures make it an ideal ingredient for a wide range of products, from airplane wings to cans.

sandpaper and for a variety of grinding tools. It also has a very high melting point and is therefore often used to make fire bricks to line the insides of ovens and furnaces as well as the white insulating material in automobile spark plugs. In addition to these uses, it is used as a protective film on the surface of transistors and in the cosmetics industry for creams and lotions.

Crystals of corundum often contain traces of impurities that not only give it a variety of colors but can increase its value by elevating it to the status of a gem. Some examples of gem-quality corundum are rubies (red), which contain traces of chromium, and sapphires (blue), which contain traces of iron and titanium.

Aluminum is lightweight and a good conductor of electricity, two properties that contribute to its great commercial value. Although the ability of aluminum to conduct electricity is only about 65 percent as good as that of copper, its light weight and low price make it an attractive choice for some high-voltage transmission lines. Aluminum is also an excellent reflector of radiation and is used for various types of antennas, heat reflectors, and solar mirrors.

The light weight of aluminum is a major factor in its use as a construction material. Its one drawback is that it is rather soft. This problem can be remedied by making alloys of aluminum with small quantities of copper or magnesium, which can greatly strengthen the metal.

Beyond these other properties, aluminum is also fairly reactive. When left unprotected, the surface of an aluminum object quickly becomes dull gray as the aluminum reacts with air to form an oxide. The oxide layer actually protects the metal and prevents it from further reactions with its environment, so that it is usually considered corrosion-resistant. For example, aluminum cans do not disintegrate in the way that coated steel cans do and seem ideal as beverage containers. Aluminum is also nontoxic, odorless, and tasteless, and it is a good conductor of heat, enabling beverages in aluminum containers to be cooled quickly. In a sense, it is too good a material for use in cans because its ability to resist oxidation or decay has become something of a drawback. Discarded aluminum cans that litter highways, landfills, beaches, and forests are a major environmental pollutant. Many communities have now adopted recycling as a solution to this problem.

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Si

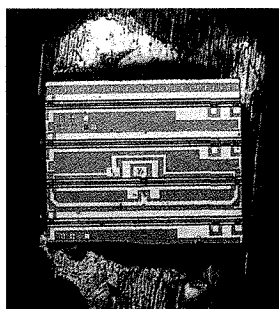
Silicon is the second most abundant element in the Earth's crust, exceeded only by oxygen. Compounds of silicon bound chemically to oxygen make up most of the Earth's sand, rock, and soil.

Silicon was first isolated in its pure form in 1824

by the Swedish chemist Jöns Jakob Berzelius (1779–1848). Today silicon forms the basis of the microelectronics industry, which for some time was centered in a region near San Francisco called Silicon Valley. The use of silicon chips in printed circuits has made possible the shrinking of room-size computers into ones that can rest on your lap.

The most important silicon compound is silica, or silicon dioxide (SiO_2). It exists in two familiar forms in nature: a crystalline form called quartz, small chips of which occur in sand, and a noncrystalline form called flint. Small gems and semiprecious stones such as amethyst, opal, agate, and jasper are crystals of quartz with colored impurities.

Flint has been known for thousands of years. When struck with an acute blow, it can be made to flake in such a manner as to produce a sharp cutting edge. Some of the earliest prehistoric tools were made of flint. Quartz crystals have a very interesting property known as the "piezoelectric effect," in which they produce an electrical current when compressed. Such crystals are used in phonograph pickups and in microphones. The opposite effect also occurs. When a quartz crystal is subjected to a vibrating electrical signal, it will exactly duplicate the vibration of the signals. Because of this effect, crystals of quartz are now so commonly used in watches



Tiny silicon chips such as this one form the basis of the microelectronics industry.

SILICON

Atomic Number **14**

Chemical Symbol **Si**

Group **IVA**

Silicon in its elementary form has the same crystal structure as diamond. This is not too surprising, because in the periodic table silicon is a member of the same group of elements as carbon.

and clocks that spring-wound watches have become almost obsolete. When a quartz crystal is subjected to an alternating voltage source, it will begin to vibrate mechanically. Each quartz crystal has a natural “resonant” frequency, that depends among other things on its size. One can understand resonance by thinking of a tuning fork, which only vibrates and gives off sound of a certain frequency, its “resonant” frequency. In a “quartz clock” this effect is used to great precision by applying electrical signals to the crystal, causing it to vibrate at its natural frequency. The vibrating crystal produces electrical signals, which are then ingeniously fed back to the crystal, keeping the frequency exactly that of the resonance. Since the frequency can be kept constant to one part in 10 billion, these quartz crystals are now used as time standards. Quartz crystals are also used as control devices for radio and television transmitters.

Asbestos is an important silicate mineral that forms long fibers that have great mechanical strength and resistance to heat. Until recently asbestos was used extensively as an insulating material. It is now well established that exposure to asbestos dust is very dangerous and can cause cancer of the lung and digestive tract. Many schools and factories are involved in a variety of expensive and time-consuming projects to remove asbestos from steam pipes, furnaces, automobile brakes, and a host of other products in which it was used for insulation. Prolonged exposure to silica dust itself can lead to a lung disease known as silicosis, which is a serious problem for quarry and stone workers.

Silica also produces one of the most useful and beautiful substances on Earth. When silica in the form of sand is mixed with soda ash (sodium carbonate) and limestone (calcium carbonate) and the mixture is melted, the result is glass. There are more than a thousand different kinds of glass made for different purposes and containing various chemical compounds, but silica is the basic ingredient in most of them. The transparency of glass to light makes possible windows for our houses, eyeglasses, and optical lenses for telescopes and microscopes. Glass is also very nonreactive and resistant to attack by strong chemicals and makes an excellent material for storage jars, bottles, and food containers.

Pyrex is a type of glass made by adding an oxide of boron to the mixture of silica, soda ash, and limestone. Pyrex does not undergo as much expansion and contraction with temperature changes as does ordinary glass and is ideal for making containers that will be subjected to heat. Yet another type of glass is made by the addition of an oxide of potassium to the mixture of silica, soda ash, and limestone. This results in a particularly hard glass that is scratch-resistant and is used for eyeglasses.

Ceramics are another important class of compounds based on

silicon. Like glass, ceramics have been known since antiquity, during which they served as containers for food and water. Ceramics are usually made from clay. Clays are silicates that result from the weathering of granite and other rocks. Clay has a sheetlike structure that causes it to absorb large amounts of water. When fired in a furnace, it loses that water and becomes very rigid. Earthenware is very porous clay pottery that has been fired below 1,200°C. Stoneware is a ceramic that has been fired above 1,200°C. Clays are also used to make porcelain and fine china.

Silicon in its elementary form has the same crystal structure as diamond. This is not too surprising, because in the periodic table silicon is a member of the same group of elements as carbon. Pure silicon is usually prepared by heating quartz sand with carbon in the form of coke to temperatures as high as 3,000°C. Although diamond is an insulator, silicon conducts electricity to a small degree. This conducting ability can be greatly enhanced by “doping” the silicon with trace amounts of carefully chosen impurities. When a small amount of arsenic or boron is added to silicon, for example, the resultant compound is called a semiconductor. Arsenic has one more valence electron than does silicon, and when it is used to dope silicon this extra electron is free to roam about in the crystal and conduct electricity. Boron has one less electron than silicon, and this electron vacancy, or “hole,” as it is called, also promotes the drift of electrons within a silicon crystal that has been doped with boron, as electrons jump from hole to hole.

Semiconductor materials made possible the invention of the transistor at Bell Laboratories in 1947. The transistor uses layers of these solid compounds to regulate the flow of electric current. Transistors have almost completely replaced vacuum tubes in modern electronic devices such as computers and television sets. Thousands of transistors can be connected together on a thin wafer of silicon.

Solar cells are also made from silicon wafers. A solar cell is composed of a silicon wafer doped with arsenic, over which is placed a thin layer of silicon doped with boron. When light falls on the wafer, electric current flows across the junction of the two materials. The silicon used in transistors and solar cells must be of extremely high purity.

Another interesting group of silicon compounds, formed by the combination of the element with organic materials, is the silicones. Silicones are polymers, or long molecular chains, made up of silicon atoms linked to oxygen atoms. Various organic compounds are often attached to the polymer to control and alter its physical properties. Silicones make up the rubbery, elastic bodies of such common toys as Silly Putty and Superball. Some silicones are designed to act as lubricants, while others have been used as implants in cosmetic surgery. The safety of silicone implants has been the subject of a great deal of controversy.



In 1947, scientists at Bell Laboratories invented the transistor, which incorporates layers of silicon-based semiconductors.



Soil without phosphorus is barren. Here, workers in Florida around 1890 mine phosphoric acid, which is used to make fertilizer.

approaching a few million tons a year by heating calcium phosphate in the presence of carbon and silicon dioxide.

Elemental phosphorus has two important forms: white phosphorus and red phosphorus. White phosphorus is extremely reactive and spontaneously bursts into flame when exposed to air at a temperature of about 35°C. As a safety measure, it is usually stored under water. The ease with which white phosphorus burns has made it useful to the military as an incendiary device. Additional caution must be taken in handling it because it is also very toxic and can be quite damaging to human tissues, especially the cartilage and bones of the nose and jaw. At temperatures below 35°C, white phosphorus reacts with the oxygen in the air and begins to glow, a reaction that resembles phosphorescence and is known as chemiluminescence.

Almost all of the elemental phosphorus produced commercially is used in the manufacture of phosphoric acid. Phosphoric acid is a solid that is usually sold as an 85-percent solution in water. Its major use is in the manufacture of triple-phosphate fertilizers. Soil without phosphorus is barren. Plant growth requires phosphate because so many key compounds in living plant cells are compounds of phosphorus.

The chief phosphate in detergents is sodium tripolyphosphate. It acts as a water-softening agent that inactivates magnesium and other “hard water” elements and also boosts the cleansing efficiency of detergents. Many areas ban the sale of laundry products that contain phosphate because they contribute to eutrophication, the overnourishment of plants and algae in lakes. When too many plants are allowed to grow in a relatively small body of water, the plants extract too much oxygen from the water, and fish and other marine organisms die.

*In many respects
the chemistry
of phosphorus
resembles that
of nitrogen, the
element just
above it in the
periodic table.
Like nitrogen,
it is an element
essential to life.*

SULFUR

Atomic Number **16**

Chemical Symbol **S**

Group **VIA**

IA												VIII A					
H	IIA										He						
Li	Be											B	C	N	O	F	Ne
Na	Mg	III B	IV B	V B	VIB	VII B	VIII B			IB	II B	Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	†Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq					
* Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu																	
† Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr																	



Sulfur is a reactive nonmetal found in nature both in its free elemental state and also in the form of widely distributed ores and minerals. Although it is not a very abundant element, constituting only about 0.06 percent of the

Earth's crust by mass, it is readily available.

In its free state, sulfur is normally a brittle, yellow solid deposited at the edges of some hot springs and geysers. It is also often found near volcanoes. Volcanic gases contain hydrogen sulfide and sulfur dioxide that react with one another to form free sulfur. It is not often recognized that volcanoes are a major source of atmospheric pollutants; however, it is estimated that volcanoes are the source of about two-thirds of the sulfur emitted into the atmosphere.

Sulfur burns with a beautiful blue flame. The old English name for sulfur was brimstone, which means "a stone that burns." The expression "fire and brimstone" is still used today to signify great heat. Solid sulfur in its crystalline form is made up of molecules that consist of eight sulfur atoms arranged in a ring.

Some common minerals of sulfur are gypsum, which is calcium sulfate, and pyrite, sometimes called "fool's gold," which is iron disulfide. Pyrite is called fool's gold because it has a golden color and often fooled novice miners into thinking they had found gold. Sulfur is also present in coal and petroleum products.

Most of the sulfur produced commercially in the United States comes from underground deposits of elemental sulfur found in Texas and Louisiana, as well as Mexico and Poland. The sulfur is mined using the Frasch process. This method was developed by the German chemical engineer Herman Frasch (1851–1914) in the 1890s. In this process pressurized water, whose temperature is above the melting point of sulfur (113°C), is pumped into a sulfur deposit to melt the

element. Compressed air then forces the molten mass to the surface.

When sulfur is heated above its melting point, interesting changes occur in its molecular size. Freshly melted sulfur is a straw-colored liquid that flows very easily, almost like water. At temperatures between 160°C and 195°C, however, the viscosity of the melt increases dramatically, and it becomes approximately 100,000 times thicker. Viscosity is a measure of the ease with which liquids flow. Maple syrup flows more slowly than water, for example, and is therefore more viscous than water.

The startling change in the viscosity of sulfur is caused by the S_8 molecule changing into a molecule that may be 300,000 atoms long. These long strands get entangled with each other and resist the smooth flow of the liquid. At temperatures above 200°C, the liquid sulfur turns dark red and becomes progressively less viscous. At these high temperatures there is enough energy to break the long chains into smaller sulfur molecules, so that they no longer interfere with each other when flowing.

Approximately 90 percent of all sulfur produced throughout the world is burned to form sulfur dioxide, a gas that has a characteristic suffocating odor often compared to the smell of burning matches. Most of the sulfur dioxide so produced is used to form sulfuric acid. Some, however, is used as a food preservative. Sulfur dioxide is especially toxic to molds and certain bacteria and is commonly used as an additive in wine and dried fruits. Because some people are allergic to sulfur dioxide, however, foods that contain it must be properly labeled. Sulfur dioxide is also used as a bleach for textiles and for wood pulp used in papermaking.

More sulfuric acid is produced in the United States than any other industrial chemical. A staggering 89 billion pounds of sulfuric acid were produced in 1992. This acid is the least expensive of the commercially used acids and can be prepared and shipped in pure form. Most sulfuric acid is used by the fertilizer industry to convert insoluble phosphate rock to a soluble phosphate called superphosphate, which supplies the phosphate atoms needed by growing plants. Sulfuric acid is also used for automobile batteries and in metal treatment for what is known as a “pickling process.” In this process iron metal parts are “pickled” by dipping them in a sulfuric acid bath to remove rust.

Pure sulfuric acid is a colorless, oily liquid, once known as oil of vitriol. Sulfuric acid has a strong affinity for water. It removes water from many organic compounds in a reaction that often generates a great deal of heat. When the acid is poured on sugar, for example, the sugar begins to froth violently and soon yields a charred black mass of carbon. Because of its strong affinity for water, sulfuric acid is ex-

Because it is used in so many industrial processes, a nation's level of industrial development is often measured by its per capita consumption of sulfur.



Sulfur is often found deposited at the edges of some geysers, such as this one at Yellowstone National Park.

More sulfuric acid is produced in the United States than any other industrial chemical.

tremely corrosive to the skin. If you spill a drop on your skin, the chances are you will get a burn or blister no matter how quickly you flush your hand with water.

Sulfuric acid is a substantial component of the acid in acid rain. Both oil and coal contain sulfur. Coal, for example, contains pyrite, which is iron disulfide. Although the burning of oil and coal with a high sulfur content is restricted in certain areas, both oil and coal are still used as major sources of energy. When they burn, they produce sulfur dioxide, which is then further oxidized to sulfur trioxide, which in turn reacts with water to form sulfuric acid. When the sulfur trioxide reacts with water vapor, it often forms sulfuric acid aerosols, consisting of small liquid droplets of sulfuric acid held in gaseous suspension. These aerosol clouds can often persist in the atmosphere for more than a year.

Hydrogen sulfide is a gas that is usually said to smell like rotten eggs. The smell of rotten eggs does actually come from hydrogen sulfide, which is formed by the bacterial decomposition of sulfur-containing proteins in the yolk of the egg. Hydrogen sulfide is an extremely toxic gas, even more poisonous than the better-known cyanides. It damages the body by attacking respiratory enzymes, and even small amounts of this gas can cause headaches and nausea.

In addition to their importance in making artificial fertilizers, preserving food, bleaching textiles, and cleaning metals, sulfur compounds have hundreds of other uses in recovering metals from ores and making rubber, detergents, paints and dyes, and synthetic fibers. Indeed, a nation's level of industrial development is often measured by its per capita consumption of sulfur, and in the United States that consumption now amounts to more than 100 pounds of sulfur per person per year.

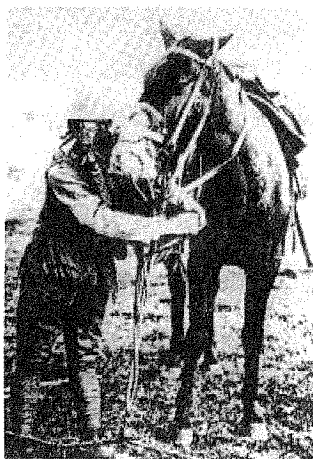
IA												VIII A					
H	He											B	C	N	O	F	Ne
IIA												III A					
Li	Be											Al	Si	P	S	Cl	Ar
III B		IV B		V B		VI B		VII B		VIII B		IB		IIB			
Na	Mg	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	†Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq					
* Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu																	
† Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr																	



Chlorine is a poisonous, yellowish-green, diatomic gas. It was first discovered by the Swedish chemist Carl Wilhelm Scheele (1742–86) in 1774 during his investigation of the mineral pyrolusite, but it was mistakenly identified as an oxygen-containing compound. The English chemist Sir Humphry Davy (1778–1829) finally identified chlorine as an element in 1810. Its name is derived from the Greek word *chloros*, meaning “greenish yellow.”

In nature chlorine occurs mostly in dissolved salts in seawater and in the deposits in salt mines. It is an important element for the chemical industry and is among the top 10 or 15 chemicals manufactured in the United States.

During World War I, chlorine was used as a poison gas on the battlefields of Europe. Chlorine is extremely dangerous, and



Chlorine was used as a poison gas during World War I. Here, a soldier and his horse demonstrate the proper use of gas masks.

inhaling even a small amount can cause extensive lung damage. The toxicity of chlorine makes it an excellent disinfectant for swimming pools and water supplies.

The bleaching action of chlorine is one of its best-known properties. The development of an effective bleach has a long history. Early attempts at dissolving chlorine in water were not very successful. The solution formed an acid called hydrochloric acid, which unfortunately had a tendency to dissolve cotton and linen. After many years of research the familiar liquid bleach

CHLORINE

Atomic Number **17**

Chemical Symbol **Cl**

Group **VIIA**—The
Halogens

Chlorine was first discovered by the Swedish chemist Carl Wilhelm Scheele in 1774, but he mistakenly identified it as an oxygen-containing compound. The English chemist Sir Humphry Davy finally identified chlorine as an element in 1810.

used in households today was developed. This bleach effectively contains a weak solution of sodium hypochlorite. It is the hypochlorite (OCl) that does the bleaching.

The large amounts of chlorine needed for industry are produced by the electrolysis of sodium chloride dissolved in water. A large amount of the chlorine commercially produced is used for the manufacture of polymers such as polyvinyl chloride. Polyvinyl chloride, or PVC as it is called, is a plastic that has replaced iron as a favored material for constructing waste and water pipes because it does not oxidize or easily corrode. It is also used to manufacture the colorless plastic bottles that have replaced glass as containers for most soft drinks.

An important compound of chlorine is hydrogen chloride (HCl). It is a colorless gas with a sharp, penetrating odor. About 3 million tons are produced annually. Hydrogen chloride gas dissolves very easily in water to produce a solution known as hydrochloric acid. This acid is used as a solvent and for removing rust from steel, a process called "pickling." This is usually done before galvanizing steel, or electroplating it with zinc to resist corrosion. Hydrochloric acid is also the acid present in the gastric juices of the stomach, where it is needed to activate protein-digesting enzymes.

Some well-known commercial solvents that are compounds of chlorine include carbon tetrachloride and chloroform. Chloroform is a volatile liquid that was long used as an anesthetic for surgery. Because of evidence that it can severely damage the liver and kidneys, it has been replaced by other compounds.

Carbon tetrachloride, or CCl_4 , is an excellent solvent for dissolving greases and oils. Until quite recently it was extensively used in the dry cleaning of clothes. Studies have shown, however, that carbon tetrachloride is extremely toxic to the liver, and its use is now illegal in many areas.

Large amounts of chlorine have also been used to produce insecticides such as DDT (dichloro-diphenyl-trichloro-ethane). Many of these compounds have, however, been banned because they are considered harmful to the environment. Other chlorine compounds known to cause environmental problems are the chlorofluorocarbons. As almost ideal refrigerants, they were until recently universally used in all types of air conditioners and refrigerators. Studies have shown, however, that chlorofluorocarbons generate chlorine "free radicals" in the upper layers of the atmosphere, which destroy the ozone layer that protects humans from harmful solar radiation.

IA										IIA										IIIA										IVA										VA										VIA										VIIA										VIII																																																																																																													
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Na										Mg										III B										IV B										V B										VI B										VII B										VIII B										I B										II B										Al										Si										P										S										Cl										Ar																													
K										Ca										Sc										Ti										V										Cr										Mn										Fe										Co										Ni										Cu										Zn										Ga										Ge										As										Se										Br										Kr									
Rb										Sr										Y										Zr										Nb										Mo										Tc										Ru										Rh										Pd										Ag										Cd										In										Sn										Sb										Te										I										Xe									
Cs										Ba										*La										Hf										Ta										W										Re										Os										Ir										Pt										Au										Hg										Tl										Pb										Bi										Po										At										Rn									
Fr										Ra										†Ac										Rf										Db										Sg										Bh										Hs										Mt										Uun										Uuu										Uub										Uuq																																																											
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Ar

Argon is a noble gas that is chemically inert. It has no color and is odorless. It constitutes about 1 percent of the Earth's atmosphere, making it the third most abundant gas in the air. It was long thought to form no compounds, but a

group of Finnish researchers demonstrated in August 2000 that in spite of its lack of chemical reactivity it was nevertheless possible to combine argon with other atoms to form a compound. This new compound is extremely fragile, and can exist only at the extremely low temperature of -446°F . It is formed with fluorine and hydrogen, and known as argon fluorohydride, or HArF .

Argon was the first noble gas to be discovered. It was identified in 1894 by the English physicist Lord Rayleigh and the Scottish chemist William Ramsay. They identified the new element by means of the light it gave off when an electrical discharge was passed through the gas. They called it argon, from the Greek word *argos*, meaning "lazy" or "inactive."

The discovery of argon was a beautiful example of scientific detective work. Lord Rayleigh was working with two samples of nitrogen. One was obtained from the air, the other from decomposing a nitrogen-containing compound such as ammonia. He noticed that there was a slight difference in the density of the two samples—a difference of only 0.05 percent. Rather than dismiss the results as an experimental error, he looked for the cause of the difference.



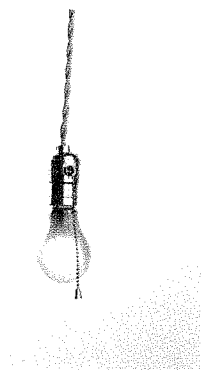
In 1894, English physicist Lord Rayleigh (above), working with William Ramsay, discovered argon, the first noble gas to be identified.

ARGON

Atomic Number **18**

Chemical Symbol **Ar**

Group **VIIIA—The Noble Gases**



Incandescent light bulbs are filled with argon instead of ordinary air because argon is a noble gas and, unlike oxygen, will not react with the tungsten filament.

The essential clue to this mystery was that the air sample had been obtained by removing all the gases known at that time to exist in air, such as oxygen, carbon dioxide, and water vapor. To account for the difference in density, Rayleigh, with the help of Ramsay, correctly guessed that the air sample must contain a small amount of an unknown gas heavier than nitrogen. Since it had escaped detection for so long, he also realized that it must be a chemically unreactive gas. This new gas was argon.

A new column in the periodic table, Group VIIIA, was created to place argon among the other elements. The elements in this column are now known as the noble gases. Lord Rayleigh was awarded the 1904 Nobel Prize in physics for his discovery of argon.

Commercially, argon is obtained by the distillation of liquid air. The boiling point of argon is between that of nitrogen and oxygen, and argon is usually a by-product of the production of these two other gases.

The commercial applications of argon make use of its lack of chemical reactivity. It is a relatively abundant gas, so that it is more commonly used than many of the other noble gases. Argon is used to fill incandescent light bulbs, for example, replacing ordinary air. This prevents corrosion of the tungsten filament in these bulbs and inhibits its vaporization, which can cause blackening of the bulbs. Argon is also used to supply an inert environment during welding. Fluorescent bulbs also contain argon instead of air.

Argon has also been used in laboratories engaged in nuclear physics. The probe that senses the presence of radiation in a Geiger counter, for example, is often filled with argon. Radiation passing through the window of the probe ionizes the argon, causing the probe to emit a small electrical discharge that can be detected.

Argon is also the decay product of an important radioisotope used for dating rock samples. The isotope is potassium-40, a naturally occurring radioactive isotope with an extremely long half-life of 1.25 billion years. Argon is formed as the product of the disintegration of the radioactive potassium. The technique is called potassium-argon dating. Because potassium is present in many rocks, an analysis of the amount of argon present in the rock will effectively reveal the date at which the rock solidified.