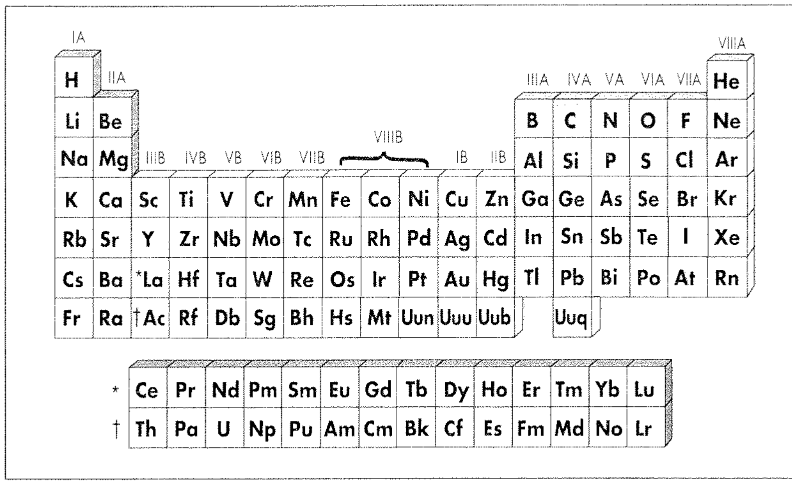
CARBON

Atomic Number **6**

Chemical Symbol **C**

Group **IVA**

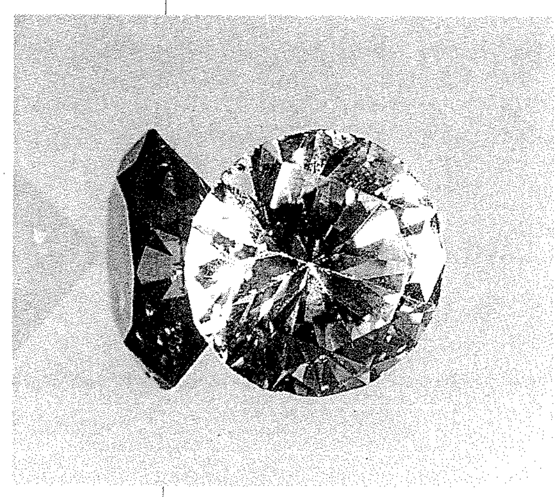


Carbon represents only 0.09 percent of the Earth's crust by mass, yet it is the element most essential for life on our planet. If we examine the molecules that make up plants and animals, almost all of them contain carbon. A whole branch of chemistry, called organic chemistry, is essentially the chemistry of carbon compounds. Among the more than 5 million compounds that are considered organic compounds are hydrocarbons, or coal and petroleum products, as well as perfumes, proteins, benzene, enzymes, carbohydrates, and a host of others too numerous to mention. Carbon owes its central position in the organic world to the ability of its atoms to link up with other carbon atoms to form long chains that are either straight or branched. These chains act as a backbone to which other elements are attached, yielding an almost endless number of possible carbon-containing molecules. One such long-chain carbon molecule is deoxyribonucleic acid, or DNA, found in the genetic material of all living creatures. DNA stores information for the construction of an immense number of proteins manufactured by plant and animal cells, and it can replicate itself, or produce copies of itself. Found in the nucleus of plant and animal cells, it is essential to the reproduction of living organisms.

Besides its occurrence in organic compounds, carbon also exists in its free state in nature, where it is found in several different forms. When an element can exist in several natural forms, these forms are called allotropes. In the case of carbon, the most spectacular of these allotropes is diamond, the hardest of materials. However, carbon is also found in the forms of graphite and coal. The atoms of carbon in graphite arrange themselves in layers, like the pages of a book. Because the forces between them are not very strong, the layers slide easily over one another, making graphite soft and slippery. It is useful as a lubricant and as a writing material in pencils.

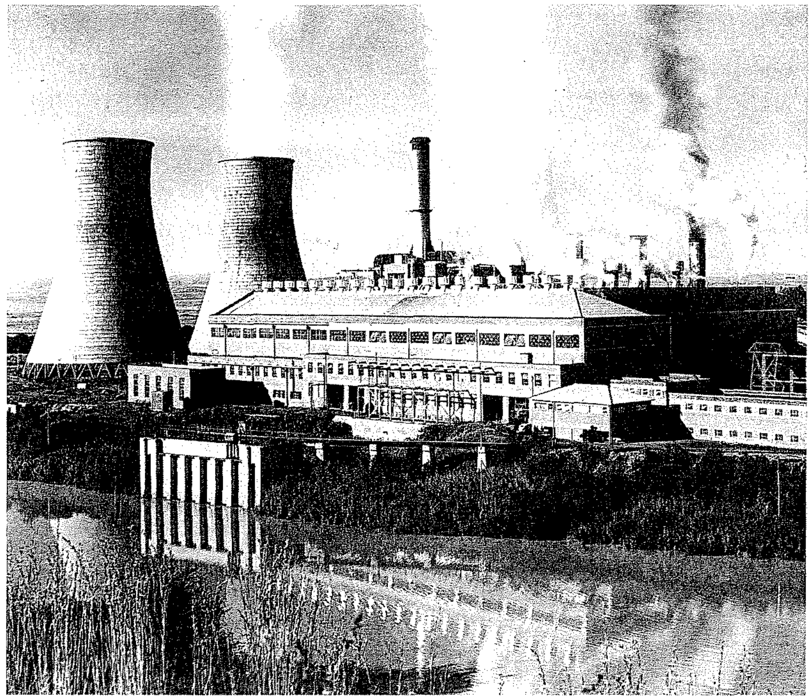
A new allotropic form of carbon, created in 1985, has caused quite a bit of excitement in the world of chemistry. This new molecule contains 60 carbon atoms arranged in a structure that looks very much like a soccer ball. It was first made by Harold W. Kroto at the University of Sussex in Brighton, England, and Richard E. Smalley at Rice University in Houston, Texas, using laser beams to vaporize graphite. They named the molecule buckminsterfullereen after the American architect Buckminster Fuller, who was famous for designing geodesic domes, structures that also resembled a soccer ball. Chemists impatient with long names have begun calling these unusual molecules "buckyballs." Variations of these molecules containing as many as 70 carbon atoms have been identified, and there is evidence that many more such clusters exist. The growing family of these compounds is called the fullerenes. There are indications that some fullerenes may be excellent conductors of electricity and may even become superconductors at temperatures close to room temperature. A superconducting material has no resistance whatsoever to the flow of electricity and is an immensely efficient and highly economical conductor of electric current. Most materials become superconductors only at temperatures that are hundreds of degrees below zero Celsius.

It is hard to imagine that graphite, the material found in every pencil, is made of the same material as diamond. But synthetic diamonds can be made from graphite by applying very high pressures and temperatures to it. The synthetic diamonds made in this way are not considered as beautiful as natural diamonds, but they are just as hard and are used in industry for their abrasive properties. The reverse transformation is also possible and in fact occurs spontaneously. Luckily, the process is a very slow one and can take several million years, but eventually diamonds will disintegrate.



Although diamonds—one of the hardest natural substances known—are prized for their beauty, their main use is industrial. Their hardness makes them excellent cutting tools.

Coal, a mixture of carbon and various other compounds, contains carbon in a noncrystalline form. It is a major source of energy for industry and domestic use. Like oil and natural gas, coal is considered a fossil fuel because it results from the decay of plants and animals over hundreds of millions of years. Hard or anthracite coal is the older variety of coal and is thought to be about 250 million years old. It contains about 80 percent carbon. Bituminous



When coal and other fossil fuels are burned, carbon dioxide (CO_2), which contributes to global warming, is released into the air.

or soft coal contains only about 40 to 50 percent carbon, and is a younger variety of coal. Data from the United States Department of Energy indicate that as of 1991, 23.2 percent of the energy used in the United States came from coal, approximately 40 percent from petroleum, and 24 percent from natural gas. Fossil fuels thus contribute about 90 percent of the total energy consumed in the United States.

Coke, which is used in great quantities in producing iron and steel, is produced by heating coal in the absence of air. In this process, almost all of the volatile substances and impurities in coal are burned off, leaving a fairly pure form of carbon. Coke or charcoal has been known since ancient times, and the name carbon is in fact derived from the Latin *carbo,* for "charcoal." A coke or charcoal fire is hotter than an ordinary wood fire and was of prime importance in the development of ancient techniques for recovering iron from its ore.

There are many problems associated with the use of coal and other fossil fuels as sources of energy. One of them is that many of these fuels also serve as raw materials for the manufacture of a host of useful products such as plastics and medicines. At the rate at which we are using these materials as fuels, it has been estimated that our petroleum and natural gas supplies will be completely depleted by the year 2030. Of more immediate concern, however, is that the products of carbon combustion represent a major source of pollution. They are responsible for acid rain and include large amounts of carbon dioxide, or CO_2, a colorless, odorless gas that is formed when carbon is burned in air and that contributes to the possibility of global warming.

Besides being formed by the combustion of carbon in air, carbon dioxide is also a by-product of metabolism in animals, all of whom exhale this gas as they breathe. Moreover, when animals and plants die, the process of their decomposition produces carbon dioxide. Volcanoes are usually not thought of as agents of pollution, but they are also a major source of carbon dioxide. Given all of these sources of the gas, it is fortunate that plants use carbon dioxide to produce carbohydrates through the process of photosynthesis. Until recently, the production and consumption of carbon dioxide resulted in a dynamic equilibrium, so that the concentration of this gas in the atmosphere was more or less constant. There seems to be evidence, however, that the rapid growth of industrial society with its excessive use of fossil fuels has led to a steadily increasing concentration of carbon dioxide in the atmosphere.

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Carbon dioxide influences the temperature on Earth by what is usually called the "greenhouse effect." Like the glass roof of a greenhouse, carbon dioxide in the atmosphere permits most of the energy radiated by the sun to reach the Earth. And like the glass of a greenhouse, carbon dioxide also absorbs the infrared radiation given off by the heated Earth, effectively trapping the heat generated by this radiation and thus warming the Earth. Many dire predictions have been made about the catastrophic consequences of allowing the buildup of carbon dioxide in the atmosphere to continue. Some environmentalists fear that the melting of icecaps and glaciers, from the warming produced by the gas, will cause the level of the oceans to rise and flood coastal areas. It is also feared that vast global changes in climate from the warming process could produce deserts in areas now fertile. A worldwide alert is in effect, and many advanced industrial countries are taking measures to reduce the levels of carbon dioxide and other substances emitted by the burning of fossil fuels.

Despite all of the ominous problems associated with the buildup of carbon dioxide in the Earth's atmosphere, it does have many beneficial uses. Commercially, carbon dioxide is obtained as a by-product in the manufacture of ammonia. Whenever you drink soda water, you are drinking water that has been carbonated by having carbon dioxide dissolved in it. All of the natural bodies of water on Earth also contain dissolved carbon dioxide. In solution it forms a weak acid called carbonic acid. Structurally, carbonic acid consists of two hydrogen ions, each of which is designated as H^+ because of its single positive charge, and a carbonate group, $(CO_3)^{=}$, which carries a double negative charge and is easily dissociated from the H^+ ions that give the acid its acidic properties. Because of this, it is not surprising that there are carbonate deposits in areas formerly covered by water. Carbonate is left in the Earth's crust chiefly as calcite, limestone, dolomite, marble, and chalk. Often, stalactites and stalagmites are formed in caves by the crystallization of carbonates that were dissolved in groundwater.

When carbon dioxide is frozen, it is called dry ice and is used as a refrigerant. Because carbon dioxide freezes at -78°C, dry ice is considerably colder than ice made from water. Another property that makes dry ice an excellent refrigerant is its ability to pass directly from the solid state to the gaseous state as it warms, without first becoming a liquid. Chemists call this process sublimation. When steaks are shipped from Omaha to New York by mail, for example, dry ice is the refrigerant of choice for preserving them because it eliminates the problem of having to deal with the liquid that would form from the melting of ordinary ice.

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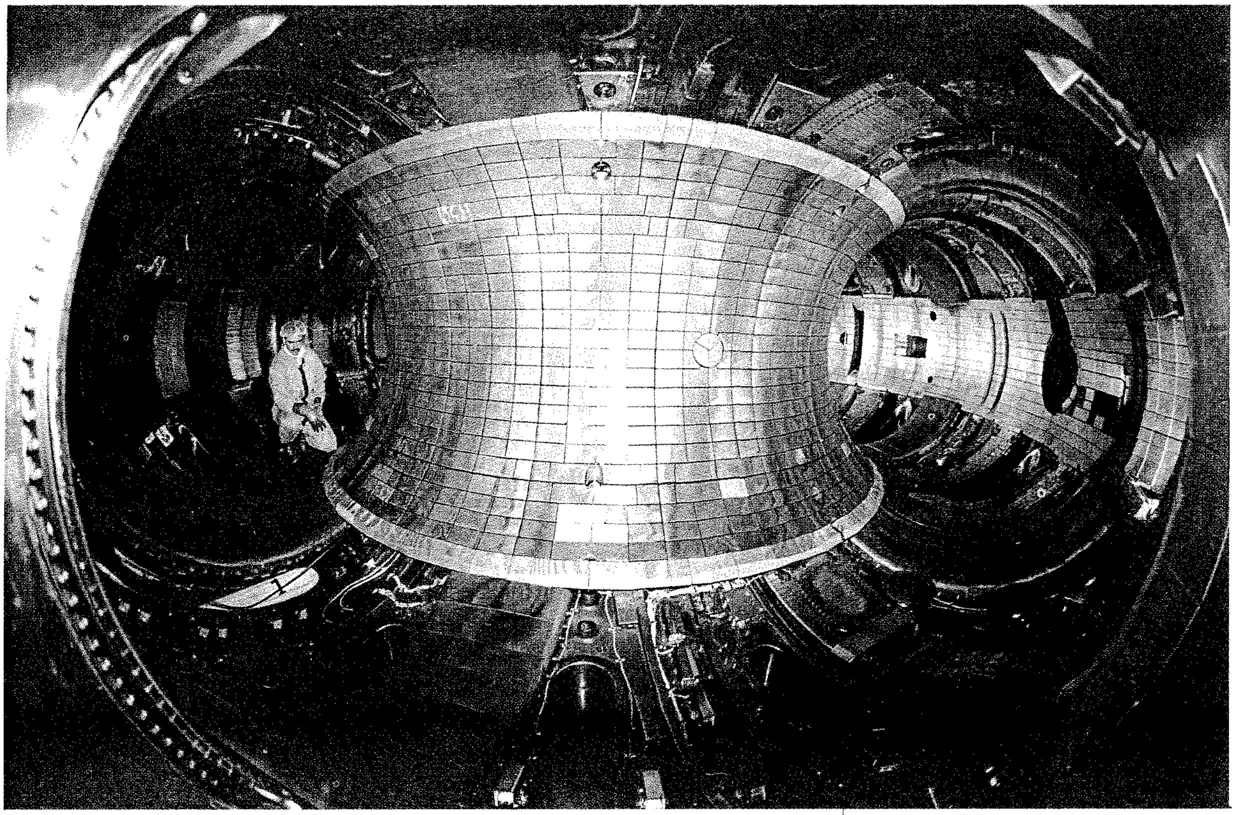
Nevertheless, it is possible to melt dry ice by heating it at high pressures. Under these conditions, the transition from solid to liquid takes place at a temperature of about -56°C. Liquid carbon dioxide is used as a solvent in extracting caffeine from coffee to make decaffeinated coffee. Its great advantage is that it leaves no residue in the coffee.

Carbon dioxide is a very heavy gas, with a density about 1.5 times greater than that of air. It tends to collect close to the ground in unventilated spaces, and by displacing the air it can be hazardous to humans. Every year, a number of workers are killed by carbon dioxide asphyxiation while cleaning out enclosed storage tanks aboard ships. At the same time, its property of excluding air makes carbon dioxide useful in fighting fires. Fire extinguishers often contain compressed carbon dioxide that is released to smother flames by displacing the air on which they feed, making combustion impossible.

When carbon is burned in the absence of sufficient oxygen, it forms a gas called carbon monoxide, CO. Industry uses carbon monoxide chiefly as a fuel, although it is also used in the metallurgical industry to help recover metals from their oxide ores. Unlike carbon dioxide, carbon monoxide is a very poisonous gas. It combines with the hemoglobin in blood, preventing the latter from carrying its usual load of oxygen to the tissues of the body. Even a small amount of carbon monoxide can cause drowsiness and severe headaches. An improperly vented garage or gas heater can produce carbon monoxide in large enough quantities to cause asphyxiation and death. Carbon monoxide is also produced in



Graphite tiles line the inner wall of the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory.

automobile exhaust and has become a major source of pollution in large cities.

The form of carbon known as activated charcoal consists of a very finely powdered charcoal. It has an enormous surface area, which may reach 1,000 square meters per gram. This surface is very effective in adsorbing other molecules, or attracting them and holding them on the surface of the charcoal granule. Activated charcoal is therefore used extensively in devices designed to remove pollutants from the air.

When natural gas, a carbon-containing gas left in the Earth in the form of deposits from decaying plant and animal matter, is burned in a special oven with little air, it produces a powdered carbon called carbon black or lampblack. Lampblack has been known and used for thousands of years. The ancient Egyptians used lampblack to make an ink that could be used for writing on papyrus. It is still used by the printing industry today. Lampblack is also used in the manufacture of automobile tires to increase their durability, and with the addition of proper adhesives, it can easily be molded into various shapes for special purposes. The cylinders of carbon that form the electrodes in a dry cell, for example, are made from lampblack.

When silicon is heated with carbon to a fairly high temperature, it forms a compound called silicon carbide, more commonly known as Carborundum. Carborundum is almost as hard as diamond and is used as an abrasive for polishing glass and metals.

The combination of carbon and nitrogen produces a class of organic chemical compounds called cyanides. Hydrogen cyanide, which has a characteristic aroma resembling that of bitter almonds, is a deadly poison and is the gas used in execution chambers. Even one- or two-tenths of a percent by volume of hydrogen cyanide in air can be fatal. Hydrogen cyanide is toxic because it interferes with the normal workings of iron-containing molecules in the body. By disabling a key enzyme used in metabolism, it can cause asphyxiation and death within minutes.

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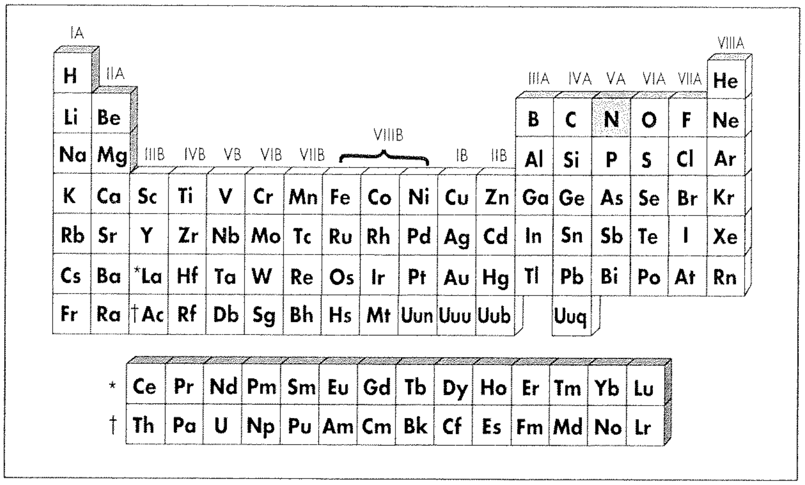
The isotope of carbon known as carbon-14 has become a very useful tool for dating relics and archaeological artifacts. The method for doing this was first developed by Willard F. Libby, an American chemist at the University of Chicago, who was awarded the Nobel Prize in chemistry in 1960 for this work.

Carbon-14 is radioactive, with a half-life of 5,730 years. It is constantly being made in the upper layers of the Earth's atmosphere by high-energy particles from outer space that interact with the nuclei of nitrogen molecules present in the atmosphere. This rain of energetic particles—called cosmic rays—has always been part of the background radiation to which all inhabitants of the Earth are subject.

The radioactive carbon-14 generated by this process behaves chemically like ordinary carbon and combines with oxygen to form carbon dioxide. This carbon dioxide is, however, radioactive, and when it is taken up by plants in photosynthesis it produces slightly radioactive living tissue. Animals feeding on these plants then take up the radioactive isotope and eliminate it as natural waste material. Experiments have shown that as a result of this cycle all living things maintain a fairly steady ratio of radioactive carbon to normal carbon. Once a plant or animal dies, however, the natural loss of carbon-14 as a result of radioactive decay continues without any compensating intake of the isotope. Once this happens, the ratio of the quantity of C-14 to that of ordinary carbon in the residue of the plant or animal acts as a clock, decreasing at a rate determined by the half-life of the radioisotope, and can be used to determine when the plant or animal died. This technique has been used to date ashes from ancient camp fires, parchments, bones from relics, and ancient fabrics. A fabric that made headlines recently was the famous Shroud of Turin, a material that supposedly dated from the time of Christ. Carbon dating at several laboratories established, however, that the shroud was less than 600 years old.



NITROGEN

Atomic Number **7**

Chemical Symbol **N**

Group **VA**

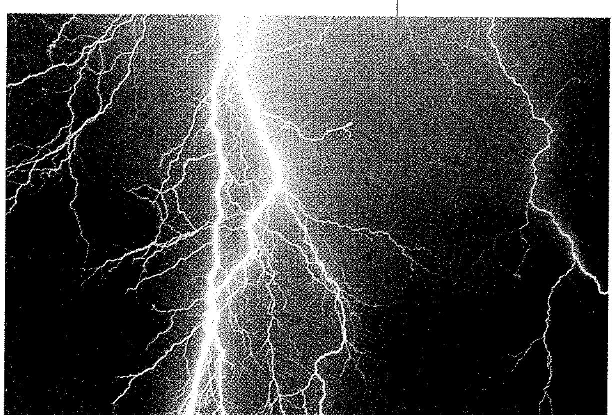
Nitrogen heads the family of elements that make up Group VA in the periodic table. Nitrogen is a gas, while all the other elements that make up the family in the group are either metals or metal-like. As a gas, nitrogen is relatively inert and is without color, taste, or odor. We are constantly breathing in large quantities of nitrogen as we inhale air, but its lack of any sense-stimulating property makes its presence unnoticed.

Nitrogen dominates the gases in the Earth's atmosphere, making up some 78 percent of the air by volume. It is striking to note that the volume of nitrogen in the air is about four times that of oxygen. Although a relatively unreactive gas, nitrogen forms hundreds of thousands of compounds that are of crucial importance for agriculture and industry. Considering the stability of nitrogen itself, some of these compounds are, ironically, extremely unstable and explosive.

Nitrogen was discovered in 1772 by Daniel Rutherford (1749-1819), an English chemist and physician. Using a bell jar to confine a sample of air, he first removed all the oxygen from the trapped air by burning a substance in it. By placing an unfortunate mouse inside the jar and demonstrating that it asphyxiated, he then showed that the residual gas in the jar, later named nitrogen, could not support life.

Approximately 30 million tons of gaseous nitrogen are produced each year from liquefied air. In this process, called fractional distillation, air is first cooled until it liquefies and is then gradually warmed. Each of the gases that make up the air has a different boiling point and boils off separately when this is done, so that it is relatively easy to separate the nitrogen, which has a boiling point of -195.8°C, from the remaining mixture and collect it. Liquid nitrogen is used industrially to freeze foods and to preserve biological specimens. Semen from a bull, for example, can be kept immersed in liquid nitrogen for long periods before being used in artificial insemination. Because it is nonreactive, liquid nitrogen is also the refrigerant of choice in experiments requiring very cold conditions, such as the testing of superconducting electrical materials.

Nitrogen in its gaseous form is often used in situations in which it is important to keep other, more reactive atmospheric gases away. It serves industry as a blanketing gas, for example, in protecting materials such as electronic components during production or storage. To prevent the oxidation of wine, wine bottles are often filled with nitrogen after the cork is removed. Nitrogen has recently also been used in blanketing fruit after it has been picked to protect it from deterioration. Apples, for example, can be stored for up to 30 months if they are kept at low temperatures in an atmosphere of nitrogen. In addition to these applications, nitrogen is used in oil production, in which it is pumped in compressed form underground to force oil to the surface. The method is called enhanced oil production. Ordinary air cannot be used for this purpose because some of the gases that make up air would react with the oil, producing undesired by-products.



The combination of nitrogen with oxygen in the internal combustion engines of automobiles produces nitrogen oxide in a reaction similar to the one caused by lightning.

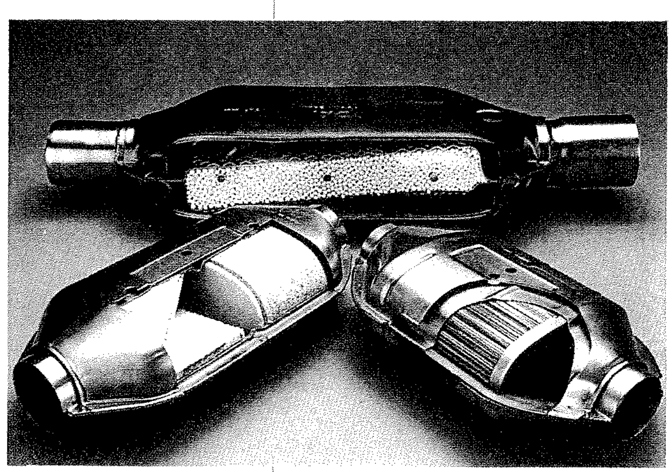
Many compounds that contain nitrogen are crucial for plant and animal life. Among the great variety of biological molecules that have nitrogen as a component are proteins and nucleic acids. Despite the lack of reactivity of nitrogen, nature has developed several mechanisms for converting nitrogen for use by living cells. The process of converting nitrogen from the atmosphere into usable nitrogen compounds is called nitrogen "fixing."

Some nitrogen is fixed by lightning. During electrical storms, the extremely high temperatures produced near a bolt of lightning supply enough energy to break apart the normally diatomic nitrogen molecule. The free nitrogen atoms that are formed can then combine with oxygen to form nitrogen oxide, NO, and nitrogen dioxide, NO_2. Most of the nitrogen dioxide dissolves in rainwater and then falls to the earth's surface, where nitrogen-fixing bacteria in the soil called cyanobacteria use the nitrogen dioxide to build nutrients such as proteins and amino acids. These nutrients are then taken up by the roots of plants, which are in turn eaten by animals, in whose tissues the nitrogen is used to create animal proteins. Bacteria in the soil then convert the inevitable waste products of nitrogen metabolism, such as urea, into amino acids and ammonia. The same denitrifying bacteria also break down these compounds to form gaseous nitrogen, which is returned to the atmosphere.

The complex natural system of reactions that leads from nitrogen fixing in the soil to the eventual return of nitrogen to the atmosphere is called the "nitrogen cycle." Another natural method of nitrogen fixation uses a class of plants called legumes. These plants, which include soybeans, alfalfa, and clover, have root nodules that contain nitrogen-fixing bacteria. These bacteria generate an enzyme called nitrogenase that converts nitrogen trapped in the soil directly into ammonia. How this is done is still a mystery, but these nitrogen-fixing plants are often planted in rotation with other food crops to restore the biological vigor of the soil.

Unfortunately, modern farming is very intensive and often depletes the soil of vital nitrogen compounds. In order to feed a rapidly growing population, artificial fertilizers are required, and ammonia is the compound most often used as a source of nitrogen for these fertilizers. Ammonia is probably the most important commercial compound of nitrogen. It is a colorless gas with a characteristic pungent odor that many people find irritating. The ammonia one buys in a grocery store is actually a solution of ammonia in water. The name for ammonia has an interesting derivation. A compound of ammonia that we now call ammonium chloride was originally prepared from animal wastes in ancient Egypt near a temple dedicated to the god Ammon. After being brought to Europe, it assumed the name of sal ammoniac, or the salt of Ammon.

The use of catalytic converters in automobiles has reduced the amount of harmful nitrogen oxides released into the atmosphere.



Almost all of the ammonia produced commercially today is made using the Haber process. In 1905 the German chemist Fritz Haber (1868–1934) accomplished what chemists had thought virtually impossible. He showed that it was possible to combine nitrogen and hydrogen directly to produce ammonia. The reaction required a temperature of about 500°C, a pressure as high as one thousand times normal atmospheric pressure, and an iron catalyst. Haber was awarded the Nobel Prize in 1918 for this pioneering work.

The Haber process proved to be of crucial importance for Germany during World War I, when that country was cut off from many essential raw materials by an Allied naval blockade. Not only was the process used to make crucial fertilizers but the ammonia generated by the Haber process was used to make nitric acid, a chemical essential for the manufacture of explosives.

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Some of the nitrogen oxides, formed by the combination of nitrogen with oxygen, have contributed to the pollution that has plagued many cities. The combination of nitrogen with oxygen in the internal combustion engines of automobiles produces nitrogen oxide, or NO, in a reaction similar to the one caused by lightning. When released into the air, this NO reacts with more oxygen to form nitrogen dioxide, NO_2, which is an extremely corrosive gas. The brownish haze that one often sees hovering over such cities as Los Angeles is due to the presence of nitrogen dioxide. Besides being corrosive, NO_2 is quite noxious and can cause considerable damage to plants and animals. To make matters worse, the ultraviolet radiation present in sunlight can dissociate, or break apart, nitrogen dioxide molecules to produce free oxygen atoms. These so-called *oxygen radicals* are extremely reactive and combine with oxygen molecules to form ozone, O_3. Ozone is a powerful oxidizing agent that is harmful to plants and animals as well as many structural materials such as rubber and plastic. It also reacts with the exhaust from automobiles to form a range of organic pollutants that are very irritating to the eyes and throat. Photochemical smog is the name usually given to the pollutants produced from automobile exhaust in the presence of sunlight. The word *smog* was originally used to describe the noxious combination of smoke and fog that occurred regularly in London in the 1950s.

Nitrogen dioxide in the air can also react with water in the air to form a corrosive acid known as nitric acid. In small quantities this can be beneficial, contributing nitrogen to the soil. In large quantities, however, the nitric acid droplets that fall to earth during rainstorms cause considerable damage to buildings, monuments, and animal life.

One of the chief methods of reducing the emission of nitrogen oxides has been through the use of catalytic converters. The catalytic converter built into the exhaust system of today's automobiles uses a mixture of powdered catalysts to decompose the nitrogen oxide in automobile exhaust into harmless nitrogen and oxygen.

A third oxide of nitrogen, nitrous oxide, or N_2O, has properties quite different from those of the two compounds described above. It is better known as "laughing gas," because a person inhaling this gas usually becomes lightheaded and some-what intoxicated. Nitrous oxide is a stable gas with a slightly sweet odor that is often used in dentistry as a mild anesthetic. The gas also dissolves in cream under pressure, making it useful as a propellant in whipped-cream dispensers. When the pressure is removed by dispensing the cream, the gas bubbles out of solution, forming a whipped-cream foam.

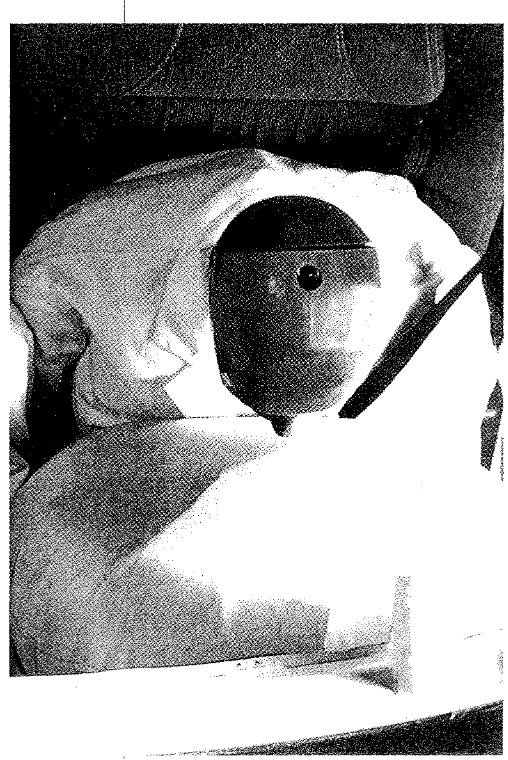
Nitric acid, or HNO_3, is of major commercial importance in the United States, where it is used to produce the fertilizer called ammonium nitrate, as well as for the manufacture of explosives and such plastics as nylon and polyurethane. Nitric acid was known to early chemists as *aqua fortis,* which in Latin means "strong water." More than 15 billion pounds of nitric acid were produced in the United States in 1992, chiefly by the Ostwald process. This process was discovered in 1902 by the German chemist Wilhelm Ostwald (1853–1932), who received the Nobel Prize in 1909 for his work on the importance of catalysts in chemical reactions. In the Ostwald process, high temperatures and platinum catalysts convert ammonia into nitric acid. Because nitric acid is used to make explosives, Ostwald's work allowed Germany to continue fighting in World War I after the Allies cut off all supplies of nitrates from Chile.

When nitric acid reacts with glycerol, a viscous type of alcohol, it creates an explosive compound of nitrogen called nitroglycerine. It is extremely dangerous to work with nitroglycerine because it can explode at the slightest shock, releasing large quantities of heat and large volumes of nitrogen and carbon dioxide gas. It is the rapid expansion of these gases that causes the shock wave associated with the explosion.

A useful derivative of nitroglycerine, called dynamite, was discovered in 1867 by Alfred Nobel (1833–96). He showed that when nitroglycerine is mixed with clay, it forms a relatively safe, shock-resistant explosive. Nobel later established the Nobel Prize with the fortune he made from this discovery.

When nitric acid is neutralized with bases such as sodium and potassium hydroxide, it forms compounds called nitrates. Nitrates and another group of nitrogen oxide compounds known as nitrites are added to canned and other preserved food to help prevent the growth of botulism bacteria and to preserve the appearance of meat products. After some time, stored meat begins to turn brown because of the oxidation of blood in the meat. Both nitrates and nitrites slow this process so that the meat becomes less objectionable to consumers. Many consumer

Sodium azide (NaN_3), an explosive compound of nitrogen, is used in the airbags found in cars today.



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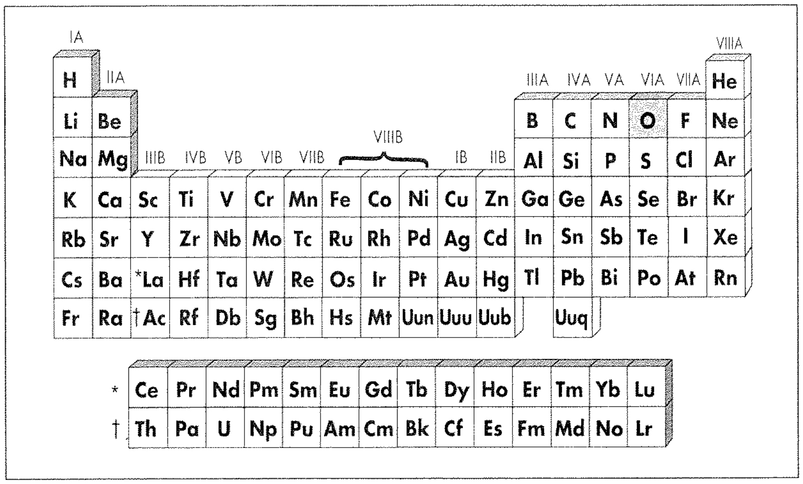
groups have objected to the use of these compounds, however, because there seems to be evidence that when eaten and subjected to the acidic conditions of the stomach, they give rise to a carcinogenic, or cancer causing, group of compounds called nitrosamines.

One of the isotopes of nitrogen, nitrogen-13, is used with the new medical technology known as positron emission tomography, or PET scanning. Nitrogen-13 is radioactive, giving off subatomic particles called positrons when it decays. Positrons are really positive electrons that interact with ordinary electrons to produce radiation resembling X rays. When a positron emitter like nitrogen-13 is injected into the body, a special scanner around the body records this radiation and is capable of producing a cross-sectional picture of the body, including internal organs. Because nitrogen-13 has a short half-life (9.97 minutes), a dose of this isotope that is administered to a patient is quickly dissipated by natural decay before it can cause any radiation damage. PET scans have proven particularly valuable in helping to diagnose diseases involving brain dysfunction, such as schizophrenia and Alzheimer's disease.

An interesting compound of nitrogen that has recently found widespread use is sodium azide, NaN_3. This colorless salt is used in the airbags found in almost every automobile today. Sodium azide is very explosive, and on impact or ignition it will very quickly decompose to form large volumes of nitrogen gas. The gas liberated by the explosion inflates the bag and provides a cushion to soften the effects of a collision.

In 1999, a team of chemists headed by Karl O. Christie and William W. Wilson at the Air Force Research Laboratory at the Edwards Air Force Base in California discovered a new form of nitrogen. The new compound is a molecule that consists of five nitrogen atoms bound to each other in the shape of a V.

The discovery surprised most experts, who felt that any molecule containing more than three nitrogen atoms would require so much energy and be so unstable that it would be impossible to fabricate in the laboratory. The new substance, which had the five nitrogen atoms bound to an ion of arsenic and fluorine, was indeed so sensitive that the few grains synthesized exploded, destroying most of the equipment being used to analyze it. More work on this new allotropic form of nitrogen is nevertheless continuing in the search for possible uses.

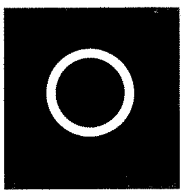


OXYGEN

Atomic Number **8**

Chemical Symbol **O**

Group **VIA**



Oxygen is one of the most important and abundant elements on Earth. It exists in the atmosphere as a gas, in water as part of the water molecule, and in the Earth's crust in an enormous variety of rocks and minerals. Some 46 percent of the Earth's crust is oxygen, and it is by far the most abundant element found there. It is essential for life and is part of almost every biological molecule in our bodies. The combustion of various fuels depends upon oxygen and provides most of the energy for industry and for heating.

In its most common elemental form, oxygen exists in the atmosphere as a diatomic molecule, O_2. It is colorless and odorless

Through the process of photosynthesis, plant cells containing chlorophyll—a green pigment present in most plants—use energy from the sun to convert carbon dioxide into carbohydrates and oxygen.

Oxygen is by far the most abundant element in the Earth's crust. It is essential for life and is part of almost every biological molecule in our bodies.

and makes up about 20.95 percent of the atmosphere by volume. Although many natural processes consume oxygen, such as combustion and the decay of organic matter, this gas is constantly being replenished by photosynthesis in plants. In photosynthesis, the chlorophyll in plants uses energy from the sun to convert carbon dioxide into complex carbohydrates and oxygen. Oxygen is then released into the atmosphere. It is thus continually being consumed and continually being produced in a cycle that has resulted in an almost constant amount of oxygen in Earth's atmosphere.

Credit for the discovery of oxygen is usually given to Joseph Priestley (1733–1804), an English chemist. In a famous experiment he heated an oxide of mercury, and noted that the gas it gave off caused a candle "to burn with a remarkably brilliant flame." The gas was oxygen. Credit for naming the element is usually given to the French chemist Antoine Laurent Lavoisier (1743–1794). The name is derived from the Greek words *oxys,* which means acid, and *gens,* which means creator or former.

We depend on oxygen to live, of course, because it is essential for so many of the biological processes that take place in our bodies. Oxygen is transported from our lungs to the cells in our bodies by means of a large protein molecule called hemoglobin. This molecule is enormous, being made up of some 574 chemical units called amino acids. Located in our red blood cells, the hemoglobin chemically binds oxygen to itself and then gives it up to our tissues. When charged with oxygen, the hemoglobin is bright red and gives our blood its characteristic color. When the oxygen is released, the color changes and becomes bluish.

Normal red blood cells are shaped like little discs. In some people, however, a few of the amino acids that make up the hemoglobin molecule are faulty. This causes a dramatic change in the shape of the molecule and the red blood cell. The cell now becomes sickle-shaped rather than disc-like. The change in shape causes serious problems in the transfer of oxygen, and produces a condition known as sickle cell anemia.

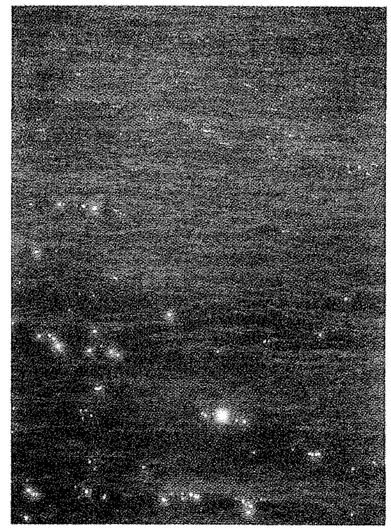
Oxygen also exists as a triatomic molecule called ozone, the chemical formula of which is O_3. Unlike ordinary oxygen, ozone has a faintly blue color and a characteristic, brackish odor. It can be created by passing electrical discharges through oxygen and is therefore very noticeable near high-voltage electrical motors in subway and railroad stations and during electrical storms.

Ozone is very reactive and is quite destructive to materials such as rubber and fabrics. It is also quite harmful to lung tissue, and during periods when there is an excess amount of ozone in the air, it is usually suggested that older people and children not engage in any strenuous physical activity that would increase the deep inhalation of ozone. State and local authorities carefully monitor the amount of ozone present in the air and compare it to the allowable amounts suggested in the U.S. National Ambient Air Quality Standard. The suggested maximum daily one-hour concentration of ozone at any location is 120 parts per million parts of air, an amount that is often exceeded in congested cities. The chief source of ozone in the lower atmosphere, sometimes called "bad ozone," is the photochemical destruction of nitrogen dioxide in the exhaust of automobiles. This process has already been described in the section on nitrogen.

In contrast to "bad ozone," "good ozone" exists in the upper layers of the Earth's atmosphere. This ozone shields the surface of the Earth from the ultraviolet radiation emitted by the sun, which would otherwise be strong enough to destroy living tissue.

Because oxygen combines with almost every element, the compounds it forms are too numerous to describe. The most common oxygen compounds in the Earth's crust are oxides. Some examples of these solid oxides, in comparison with gaseous oxides such as carbon dioxides and nitrogen oxides, are silicon dioxide, calcium oxide, aluminum oxide, and magnesium oxide. Hematite, or ferric oxide, is a common ore from which iron is extracted.

Oxygen combines with hydrogen to form water, or H_2O, which is one of the most common molecules on Earth. Water is unusual in that its density as a liquid is greater than its density as a solid. This explains why ice cubes float in water, and why ice forms on the surface of a freezing lake. If water did not have this physical property, lakes would freeze from the bottom up in winter, and no life would be possible in such bodies of water. Oxygen can also combine with hydrogen to form a liquid called hydrogen peroxide, H_2O_2, whose properties are quite different from those of water. Hydrogen peroxide is used chiefly as an industrial and cosmetic bleach, and as a disinfectant.



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Large quantities of pure oxygen for industrial and aerospace use are usually recovered from cooled liquid air by first boiling off the other major constituents of air, nitrogen and argon. The oxygen can then be transported and used in its cooled liquid state or stored as a gas under pressure. Small quantities of oxygen, however, are often supplied by heating sodium or potassium chlorate, usually in the presence of a catalyst to speed up the reaction. These compounds decompose to produce oxygen. On an airplane, for example, small canisters containing sodium chlorate and iron are placed above every seat. If for some reason oxygen is needed, a trigger-like device sets off a small explosion, mixing the two chemicals and producing oxygen.