

= Carbon =

Carbon (from Latin : carbo " coal ") is a chemical element with symbol C and atomic number 6 . On the periodic table , it is the first (row 2) of six elements in column (group) 14 , which have in common the composition of their outer electron shell . It is nonmetallic and tetravalent ? making four electrons available to form covalent chemical bonds . Three isotopes occur naturally , ^{12}C and ^{13}C being stable while ^{14}C is radioactive , decaying with a half @-@ life of about 5 @,@ 730 years . Carbon is one of the few elements known since antiquity .

Carbon is the 15th most abundant element in the Earth 's crust , and the fourth most abundant element in the universe by mass after hydrogen , helium , and oxygen . Carbon 's abundance , its unique diversity of organic compounds , and its unusual ability to form polymers at the temperatures commonly encountered on Earth enables this element to serve as a common element of all known life . It is the second most abundant element in the human body by mass (about 18 @.@ 5 %) after oxygen .

The atoms of carbon can be bonded together in different ways , termed allotropes of carbon . The best known are graphite , diamond , and amorphous carbon . The physical properties of carbon vary widely with the allotropic form . For example , graphite is opaque and black while diamond is highly transparent . Graphite is soft enough to form a streak on paper (hence its name , from the Greek verb " ??????? " which means " to write ") , while diamond is the hardest naturally @-@ occurring material known . Graphite is a good electrical conductor while diamond has a low electrical conductivity . Under normal conditions , diamond , carbon nanotubes , and graphene have the highest thermal conductivities of all known materials . All carbon allotropes are solids under normal conditions , with graphite being the most thermodynamically stable form . They are chemically resistant and require high temperature to react even with oxygen .

The most common oxidation state of carbon in inorganic compounds is + 4 , while + 2 is found in carbon monoxide and transition metal carbonyl complexes . The largest sources of inorganic carbon are limestones , dolomites and carbon dioxide , but significant quantities occur in organic deposits of coal , peat , oil , and methane clathrates . Carbon forms a vast number of compounds , more than any other element , with almost ten million compounds described to date , and yet that number is but a fraction of the number of theoretically possible compounds under standard conditions .

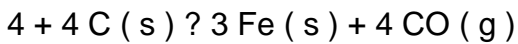
= = Characteristics = =

The allotropes of carbon (see below) includes graphite , one of the softest known substances , and diamond , the hardest naturally occurring substance . It bonds readily with other small atoms including other carbon atoms , and is capable of forming multiple stable covalent bonds with such atoms . Carbon is known to form almost ten million different compounds , a large majority of all chemical compounds . Carbon also has the highest sublimation point of all elements . At atmospheric pressure it has no melting point as its triple point is at 10 @.@ 8 ± 0 @.@ 2 MPa and 4 @,@ 600 ± 300 K (~ 4 @,@ 330°C or 7 @,@ 820°F) , so it sublimes at about 3 @,@ 900 K.

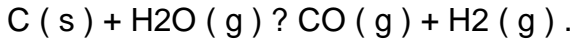
Carbon sublimes in a carbon arc which has a temperature of about 5 @,@ 800 K (5 @,@ 530°C ; 9 @,@ 980°F) . Thus , irrespective of its allotropic form , carbon remains solid at higher temperatures than the highest melting point metals such as tungsten or rhenium . Although thermodynamically prone to oxidation , carbon resists oxidation more effectively than elements such as iron and copper that are weaker reducing agents at room temperature .

Carbon compounds form the basis of all known life on Earth , and the carbon @-@ nitrogen cycle provides some of the energy produced by the Sun and other stars . Although it forms an extraordinary variety of compounds , most forms of carbon are comparatively unreactive under normal conditions . At standard temperature and pressure , it resists all but the strongest oxidizers . It does not react with sulfuric acid , hydrochloric acid , chlorine or any alkalis . At elevated temperatures , carbon reacts with oxygen to form carbon oxides , and will rob oxygen from metal oxides to leave the elemental metal . This exothermic reaction is used in the iron and steel industry to smelt iron and to control the carbon content of steel :

Fe
3O



with sulfur to form carbon disulfide and with steam in the coal @-@ gas reaction :



Carbon combines with some metals at high temperatures to form metallic carbides , such as the iron carbide cementite in steel , and tungsten carbide , widely used as an abrasive and for making hard tips for cutting tools .

As of 2009 , graphene appears to be the strongest material ever tested . The process of separating it from graphite will require some further technological development before it is economical for industrial processes .

The system of carbon allotropes spans a range of extremes :

= = = Allotropes = = =

Atomic carbon is a very short @-@ lived species and , therefore , carbon is stabilized in various multi @-@ atomic structures with different molecular configurations called allotropes . The three relatively well @-@ known allotropes of carbon are amorphous carbon , graphite , and diamond . Once considered exotic , fullerenes are nowadays commonly synthesized and used in research ; they include buckyballs , carbon nanotubes , carbon nanobuds and nanofibers . Several other exotic allotropes have also been discovered , such as lonsdaleite (questionable) , glassy carbon , carbon nanofoam and linear acetylenic carbon (carbyne) .

The amorphous form is an assortment of carbon atoms in a non @-@ crystalline , irregular , glassy state , which is essentially graphite but not held in a crystalline macrostructure . It is present as a powder , and is the main constituent of substances such as charcoal , lampblack (soot) and activated carbon . At normal pressures , carbon takes the form of graphite , in which each atom is bonded trigonally to three others in a plane composed of fused hexagonal rings , just like those in aromatic hydrocarbons . The resulting network is 2 @-@ dimensional , and the resulting flat sheets are stacked and loosely bonded through weak van der Waals forces . This gives graphite its softness and its cleaving properties (the sheets slip easily past one another) . Because of the delocalization of one of the outer electrons of each atom to form a ? @-@ cloud , graphite conducts electricity , but only in the plane of each covalently bonded sheet . This results in a lower bulk electrical conductivity for carbon than for most metals . The delocalization also accounts for the energetic stability of graphite over diamond at room temperature .

At very high pressures , carbon forms the more compact allotrope , diamond , having nearly twice the density of graphite . Here , each atom is bonded tetrahedrally to four others , forming a 3 @-@ dimensional network of puckered six @-@ membered rings of atoms . Diamond has the same cubic structure as silicon and germanium , and because of the strength of the carbon @-@ carbon bonds , it is the hardest naturally occurring substance measured by resistance to scratching . Contrary to the popular belief that " diamonds are forever " , they are thermodynamically unstable under normal conditions and transform into graphite . Due to a high activation energy barrier , the transition into graphite is so slow at normal temperature that it is unnoticeable . Under some conditions , carbon crystallizes as lonsdaleite , a hexagonal crystal lattice with all atoms covalently bonded and properties similar to those of diamond .

Fullerenes are a synthetic crystalline formation with a graphite @-@ like structure , but in place of hexagons , fullerenes are formed of pentagons (or even heptagons) of carbon atoms . The missing (or additional) atoms warp the sheets into spheres , ellipses , or cylinders . The properties of fullerenes (split into buckyballs , buckytubes , and nanobuds) have not yet been fully analyzed and represent an intense area of research in nanomaterials . The names " fullerene " and " buckyball " are given after Richard Buckminster Fuller , popularizer of geodesic domes , which resemble the structure of fullerenes . The buckyballs are fairly large molecules formed completely of carbon bonded trigonally , forming spheroids (the best @-@ known and simplest is the soccerball @-@ shaped C60 buckminsterfullerene) . Carbon nanotubes are structurally similar to buckyballs , except

that each atom is bonded trigonally in a curved sheet that forms a hollow cylinder . Nanobuds were first reported in 2007 and are hybrid bucky tube / buckyball materials (buckyballs are covalently bonded to the outer wall of a nanotube) that combine the properties of both in a single structure .

Of the other discovered allotropes , carbon nanofoam is a ferromagnetic allotrope discovered in 1997 . It consists of a low density cluster assembly of carbon atoms strung together in a loose three dimensional web , in which the atoms are bonded trigonally in six- and seven membered rings . It is among the lightest known solids , with a density of about 2 kg / m³ . Similarly , glassy carbon contains a high proportion of closed porosity , but contrary to normal graphite , the graphitic layers are not stacked like pages in a book , but have a more random arrangement . Linear acetylenic carbon has the chemical structure - (C : : : C)_n . Carbon in this modification is linear with sp orbital hybridization , and is a polymer with alternating single and triple bonds . This carbyne is of considerable interest to nanotechnology as its Young 's modulus is forty times that of the hardest known material ? diamond .

In 2015 , a team at the North Carolina State University announced the development of another allotrope they have dubbed Q carbon , created by a high energy low duration laser pulse on amorphous carbon dust . Q carbon is reported to exhibit ferromagnetism , fluorescence , and a hardness superior to diamonds .

= = = Occurrence = = =

Carbon is the fourth most abundant chemical element in the universe by mass after hydrogen , helium , and oxygen . Carbon is abundant in the Sun , stars , comets , and in the atmospheres of most planets . Some meteorites contain microscopic diamonds that were formed when the solar system was still a protoplanetary disk . Microscopic diamonds may also be formed by the intense pressure and high temperature at the sites of meteorite impacts .

In 2014 NASA announced a greatly upgraded database for tracking polycyclic aromatic hydrocarbons (PAHs) in the universe . More than 20 % of the carbon in the universe may be associated with PAHs , complex compounds of carbon and hydrogen without oxygen . These compounds figure in the PAH world hypothesis where they are hypothesized to have a role in abiogenesis and formation of life . PAHs seem to have been formed " a couple of billion years " after the Big Bang , are widespread throughout the universe , and are associated with new stars and exoplanets .

It has been estimated that the solid earth as a whole contains 730 ppm of carbon , with 2000 ppm in the core and 120 ppm in the combined mantle and crust . Since the mass of the earth is 5.972×10^{24} kg , this would imply 4360 million gigatonnes of carbon . This is much more than the amount of carbon in the oceans or atmosphere (below) .

In combination with oxygen in carbon dioxide , carbon is found in the Earth 's atmosphere (approximately 810 gigatonnes of carbon) and dissolved in all water bodies (approximately 36 000 gigatonnes of carbon) . Around 1 000 900 gigatonnes of carbon are present in the biosphere . Hydrocarbons (such as coal , petroleum , and natural gas) contain carbon as well . Coal " reserves " (not " resources ") amount to around 900 gigatonnes with perhaps 18 000 Gt of resources . Oil reserves are around 150 gigatonnes . Proven sources of natural gas are about 175 10¹² cubic metres (containing about 105 gigatonnes of carbon) , but studies estimate another 900 10¹² cubic metres of " unconventional " deposits such as shale gas , representing about 540 gigatonnes of carbon .

Carbon is also found in methane hydrates in polar regions and under the seas . Various estimates put this carbon between 500 , 2500 Gt , or 3000 Gt .

In the past , quantities of hydrocarbons were greater . According to one source , in the period from 1751 to 2008 about 347 gigatonnes of carbon were released as carbon dioxide to the atmosphere from burning of fossil fuels . Another source puts the amount added to the atmosphere for the period since 1750 at 879 Gt , and the total going to the atmosphere , sea , and land (such as peat bogs) at almost 2000 Gt .

Carbon is a constituent (about 12 % by mass) of the very large masses of carbonate rock (

limestone , dolomite , marble and so on) . Coal is very rich in carbon (anthracite contains 92 ? 98 %) and is the largest commercial source of mineral carbon , accounting for 4 @, @ 000 gigatonnes or 80 % of fossil fuel .

As for individual carbon allotropes , graphite is found in large quantities in the United States (mostly in New York and Texas) , Russia , Mexico , Greenland , and India . Natural diamonds occur in the rock kimberlite , found in ancient volcanic " necks " , or " pipes " . Most diamond deposits are in Africa , notably in South Africa , Namibia , Botswana , the Republic of the Congo , and Sierra Leone . Diamond deposits have also been found in Arkansas , Canada , the Russian Arctic , Brazil , and in Northern and Western Australia . Diamonds are now also being recovered from the ocean floor off the Cape of Good Hope . Diamonds are found naturally , but about 30 % of all industrial diamonds used in the U.S. are now manufactured .

Carbon @-@ 14 is formed in upper layers of the troposphere and the stratosphere at altitudes of 9 ? 15 km by a reaction that is precipitated by cosmic rays . Thermal neutrons are produced that collide with the nuclei of nitrogen @-@ 14 , forming carbon @-@ 14 and a proton .

Carbon @-@ rich asteroids are relatively preponderant in the outer parts of the asteroid belt in our solar system . These asteroids have not yet been directly sampled by scientists . The asteroids can be used in hypothetical space @-@ based carbon mining , which may be possible in the future , but is currently technologically impossible .

= = = Isotopes = = =

Isotopes of carbon are atomic nuclei that contain six protons plus a number of neutrons (varying from 2 to 16) . Carbon has two stable , naturally occurring isotopes . The isotope carbon @-@ 12 (^{12}C) forms 98 @. @ 93 % of the carbon on Earth , while carbon @-@ 13 (^{13}C) forms the remaining 1 @. @ 07 % . The concentration of ^{12}C is further increased in biological materials because biochemical reactions discriminate against ^{13}C . In 1961 , the International Union of Pure and Applied Chemistry (IUPAC) adopted the isotope carbon @-@ 12 as the basis for atomic weights . Identification of carbon in nuclear magnetic resonance (NMR) experiments is done with the isotope ^{13}C .

Carbon @-@ 14 (^{14}C) is a naturally occurring radioisotope , created in the upper atmosphere (lower stratosphere and upper troposphere) by interaction of nitrogen with cosmic rays . It is found in trace amounts on Earth of up to 1 part per trillion (0 @. @ 0000000001 %) , mostly confined to the atmosphere and superficial deposits , particularly of peat and other organic materials . This isotope decays by 0 @. @ 158 MeV ? ? emission . Because of its relatively short half @-@ life of 5730 years , ^{14}C is virtually absent in ancient rocks . The amount of ^{14}C in the atmosphere and in living organisms is almost constant , but decreases predictably in their bodies after death . This principle is used in radiocarbon dating , invented in 1949 , which has been used extensively to determine the age of carbonaceous materials with ages up to about 40 @, @ 000 years .

There are 15 known isotopes of carbon and the shortest @-@ lived of these is ^8C which decays through proton emission and alpha decay and has a half @-@ life of 1.98739×10^{-21} s . The exotic ^{19}C exhibits a nuclear halo , which means its radius is appreciably larger than would be expected if the nucleus were a sphere of constant density .

= = = Formation in stars = = =

Formation of the carbon atomic nucleus requires a nearly simultaneous triple collision of alpha particles (helium nuclei) within the core of a giant or supergiant star which is known as the triple @-@ alpha process , as the products of further nuclear fusion reactions of helium with hydrogen or another helium nucleus produce lithium @-@ 5 and beryllium @-@ 8 respectively , both of which are highly unstable and decay almost instantly back into smaller nuclei . This happens in conditions of temperatures over 100 megakelvin and helium concentration that the rapid expansion and cooling of the early universe prohibited , and therefore no significant carbon was created during the Big Bang .

According to current physical cosmology theory , carbon is formed in the interiors of stars in the horizontal branch by the collision and transformation of three helium nuclei . When those stars die as supernova , the carbon is scattered into space as dust . This dust becomes component material for the formation of second or third @-@ generation star systems with accreted planets . The Solar System is one such star system with an abundance of carbon , enabling the existence of life as we know it .

The CNO cycle is an additional fusion mechanisms that powers stars , wherein carbon operates as a catalyst .

Rotational transitions of various isotopic forms of carbon monoxide (for example , ^{12}CO , ^{13}CO , and ^{18}CO) are detectable in the submillimeter wavelength range , and are used in the study of newly forming stars in molecular clouds .

== Carbon cycle ==

Under terrestrial conditions , conversion of one element to another is very rare . Therefore , the amount of carbon on Earth is effectively constant . Thus , processes that use carbon must obtain it from somewhere and dispose of it somewhere else . The paths of carbon in the environment form the carbon cycle . For example , photosynthetic plants draw carbon dioxide from the atmosphere (or seawater) and build it into biomass , as in the Calvin cycle , a process of carbon fixation . Some of this biomass is eaten by animals , while some carbon is exhaled by animals as carbon dioxide . The carbon cycle is considerably more complicated than this short loop ; for example , some carbon dioxide is dissolved in the oceans ; if bacteria do not consume it , dead plant or animal matter may become petroleum or coal , which releases carbon when burned .

= Compounds =

== Organic compounds ==

Carbon can form very long chains of interconnecting C @-@ C bonds , a property that is called catenation . Carbon @-@ carbon bonds are strong and stable . Through catenation , carbon forms a countless number of compounds . A tally of unique compounds shows that more contain carbon than those that do not . A similar claim can be made for hydrogen because most organic compounds also contain hydrogen .

The simplest form of an organic molecule is the hydrocarbon ? a large family of organic molecules that are composed of hydrogen atoms bonded to a chain of carbon atoms . Chain length , side chains and functional groups all affect the properties of organic molecules .

Carbon occurs in all known organic life and is the basis of organic chemistry . When united with hydrogen , it forms various hydrocarbons that are important to industry as refrigerants , lubricants , solvents , as chemical feedstock for the manufacture of plastics and petrochemicals , and as fossil fuels .

When combined with oxygen and hydrogen , carbon can form many groups of important biological compounds including sugars , lignans , chitins , alcohols , fats , and aromatic esters , carotenoids and terpenes . With nitrogen it forms alkaloids , and with the addition of sulfur also it forms antibiotics , amino acids , and rubber products . With the addition of phosphorus to these other elements , it forms DNA and RNA , the chemical @-@ code carriers of life , and adenosine triphosphate (ATP) , the most important energy @-@ transfer molecule in all living cells .

== Inorganic compounds ==

Commonly carbon @-@ containing compounds which are associated with minerals or which do not contain hydrogen or fluorine , are treated separately from classical organic compounds ; the definition is not rigid (see reference articles above) . Among these are the simple oxides of carbon .

The most prominent oxide is carbon dioxide (CO_2). This was once the principal constituent of the paleoatmosphere , but is a minor component of the Earth 's atmosphere today . Dissolved in water , it forms carbonic acid (H_2CO_3) , but as most compounds with multiple single @-@ bonded oxygens on a single carbon it is unstable . Through this intermediate , though , resonance @-@ stabilized carbonate ions are produced . Some important minerals are carbonates , notably calcite . Carbon disulfide (CS_2) is similar .

The other common oxide is carbon monoxide (CO) . It is formed by incomplete combustion , and is a colorless , odorless gas . The molecules each contain a triple bond and are fairly polar , resulting in a tendency to bind permanently to hemoglobin molecules , displacing oxygen , which has a lower binding affinity . Cyanide (CN^-) , has a similar structure , but behaves much like a halide ion (pseudohalogen) . For example , it can form the nitride cyanogen molecule ($(\text{CN})_2$) , similar to diatomic halides . Other uncommon oxides are carbon suboxide (C_3O_2) , the unstable dicarbon monoxide (C_2O) , carbon trioxide (CO_3) , cyclopentanepentone (C_5O_5) cyclohexanehexone (C_6O_6) , and mellitic anhydride (C_{12}O_9) .

With reactive metals , such as tungsten , carbon forms either carbides (C_4 ?) , or acetylides (C_2 ?) to form alloys with high melting points . These anions are also associated with methane and acetylene , both very weak acids . With an electronegativity of 2 @.@ 5 , carbon prefers to form covalent bonds . A few carbides are covalent lattices , like carborundum (SiC) , which resembles diamond .

== Organometallic compounds ==

Organometallic compounds by definition contain at least one carbon @-@ metal bond . A wide range of such compounds exist ; major classes include simple alkyl @-@ metal compounds (for example , tetraethyllead) , ?2 @-@ alkene compounds (for example , Zeise 's salt) , and ?3 @-@ allyl compounds (for example , allylpalladium chloride dimer) ; metallocenes containing cyclopentadienyl ligands (for example , ferrocene) ; and transition metal carbene complexes . Many metal carbonyls exist (for example , tetracarbonylnickel) ; some workers consider the carbon monoxide ligand to be purely inorganic , and not organometallic .

While carbon is understood to exclusively form four bonds , an interesting compound containing an octahedral hexacoordinated carbon atom has been reported . The cation of the compound is [(Ph_3PAu) 6C] 2^+ . This phenomenon has been attributed to the aurophilicity of the gold ligands .

== History and etymology ==

The English name carbon comes from the Latin carbo for coal and charcoal , whence also comes the French charbon , meaning charcoal . In German , Dutch and Danish , the names for carbon are Kohlenstoff , koolstof and kulstof respectively , all literally meaning coal @-@ substance .

Carbon was discovered in prehistory and was known in the forms of soot and charcoal to the earliest human civilizations . Diamonds were known probably as early as 2500 BCE in China , while carbon in the form of charcoal was made around Roman times by the same chemistry as it is today , by heating wood in a pyramid covered with clay to exclude air .

In 1722 , René Antoine Ferchault de Réaumur demonstrated that iron was transformed into steel through the absorption of some substance , now known to be carbon . In 1772 , Antoine Lavoisier showed that diamonds are a form of carbon ; when he burned samples of charcoal and diamond and found that neither produced any water and that both released the same amount of carbon dioxide per gram . In 1779 , Carl Wilhelm Scheele showed that graphite , which had been thought of as a form of lead , was instead identical with charcoal but with a small admixture of iron , and that it gave " aerial acid " (his name for carbon dioxide) when oxidized with nitric acid . In 1786 , the

French scientists Claude Louis Berthollet , Gaspard Monge and C. A. Vandermonde confirmed that graphite was mostly carbon by oxidizing it in oxygen in much the same way Lavoisier had done with diamond . Some iron again was left , which the French scientists thought was necessary to the graphite structure . In their publication they proposed the name carbone (Latin carbonum) for the element in graphite which was given off as a gas upon burning graphite . Antoine Lavoisier then listed carbon as an element in his 1789 textbook .

A new allotrope of carbon , fullerene , that was discovered in 1985 includes nanostructured forms such as buckyballs and nanotubes . Their discoverers ? Robert Curl , Harold Kroto and Richard Smalley ? received the Nobel Prize in Chemistry in 1996 . The resulting renewed interest in new forms lead to the discovery of further exotic allotropes , including glassy carbon , and the realization that " amorphous carbon " is not strictly amorphous .

= = Production = =

= = = Graphite = = =

Commercially viable natural deposits of graphite occur in many parts of the world , but the most important sources economically are in China , India , Brazil and North Korea . Graphite deposits are of metamorphic origin , found in association with quartz , mica and feldspars in schists , gneisses and metamorphosed sandstones and limestone as lenses or veins , sometimes of a metre or more in thickness . Deposits of graphite in Borrowdale , Cumberland , England were at first of sufficient size and purity that , until the 19th century , pencils were made simply by sawing blocks of natural graphite into strips before encasing the strips in wood . Today , smaller deposits of graphite are obtained by crushing the parent rock and floating the lighter graphite out on water .

There are three types of natural graphite ? amorphous , flake or crystalline flake , and vein or lump . Amorphous graphite is the lowest quality and most abundant . Contrary to science , in industry " amorphous " refers to very small crystal size rather than complete lack of crystal structure . Amorphous is used for lower value graphite products and is the lowest priced graphite . Large amorphous graphite deposits are found in China , Europe , Mexico and the United States . Flake graphite is less common and of higher quality than amorphous ; it occurs as separate plates that crystallized in metamorphic rock . Flake graphite can be four times the price of amorphous . Good quality flakes can be processed into expandable graphite for many uses , such as flame retardants . The foremost deposits are found in Austria , Brazil , Canada , China , Germany and Madagascar . Vein or lump graphite is the rarest , most valuable , and highest quality type of natural graphite . It occurs in veins along intrusive contacts in solid lumps , and it is only commercially mined in Sri Lanka .

According to the USGS , world production of natural graphite was 1 @. @ 1 million tonnes in 2010 , to which China contributed 800 @, @ 000 t , India 130 @, @ 000 t , Brazil 76 @, @ 000 t , North Korea 30 @, @ 000 t and Canada 25 @, @ 000 t . No natural graphite was reported mined in the United States , but 118 @, @ 000 t of synthetic graphite with an estimated value of \$ 998 million was produced in 2009 .

= = = Diamond = = =

The diamond supply chain is controlled by a limited number of powerful businesses , and is also highly concentrated in a small number of locations around the world (see figure) .

Only a very small fraction of the diamond ore consists of actual diamonds . The ore is crushed , during which care has to be taken in order to prevent larger diamonds from being destroyed in this process and subsequently the particles are sorted by density . Today , diamonds are located in the diamond @-@ rich density fraction with the help of X @-@ ray fluorescence , after which the final sorting steps are done by hand . Before the use of X @-@ rays became commonplace , the separation was done with grease belts ; diamonds have a stronger tendency to stick to grease than

the other minerals in the ore .

Historically diamonds were known to be found only in alluvial deposits in southern India . India led the world in diamond production from the time of their discovery in approximately the 9th century BCE to the mid @-@ 18th century AD , but the commercial potential of these sources had been exhausted by the late 18th century and at that time India was eclipsed by Brazil where the first non @-@ Indian diamonds were found in 1725 .

Diamond production of primary deposits (kimberlites and lamproites) only started in the 1870s after the discovery of the Diamond fields in South Africa . Production has increased over time and now an accumulated total of 4 @.@ 5 billion carats have been mined since that date . About 20 % of that amount has been mined in the last 5 years alone , and during the last ten years 9 new mines have started production while 4 more are waiting to be opened soon . Most of these mines are located in Canada , Zimbabwe , Angola , and one in Russia .

In the United States , diamonds have been found in Arkansas , Colorado and Montana . In 2004 , a startling discovery of a microscopic diamond in the United States led to the January 2008 bulk @-@ sampling of kimberlite pipes in a remote part of Montana .

Today , most commercially viable diamond deposits are in Russia , Botswana , Australia and the Democratic Republic of Congo . In 2005 , Russia produced almost one @-@ fifth of the global diamond output , reports the British Geological Survey . Australia has the richest diamantiferous pipe with production reaching peak levels of 42 metric tons (41 long tons ; 46 short tons) per year in the 1990s . There are also commercial deposits being actively mined in the Northwest Territories of Canada , Siberia (mostly in Yakutia territory ; for example , Mir pipe and Udachnaya pipe) , Brazil , and in Northern and Western Australia .

= = Applications = =

Carbon is essential to all known living systems , and without it life as we know it could not exist (see alternative biochemistry) . The major economic use of carbon other than food and wood is in the form of hydrocarbons , most notably the fossil fuel methane gas and crude oil (petroleum) . Crude oil is distilled in refineries by the petrochemical industry to produce gasoline , kerosene , and other products . Cellulose is a natural , carbon @-@ containing polymer produced by plants in the form of wood , cotton , linen , and hemp . Cellulose is used primarily for maintaining structure in plants . Commercially valuable carbon polymers of animal origin include wool , cashmere and silk . Plastics are made from synthetic carbon polymers , often with oxygen and nitrogen atoms included at regular intervals in the main polymer chain . The raw materials for many of these synthetic substances come from crude oil .

The uses of carbon and its compounds are extremely varied . It can form alloys with iron , of which the most common is carbon steel . Graphite is combined with clays to form the ' lead ' used in pencils used for writing and drawing . It is also used as a lubricant and a pigment , as a molding material in glass manufacture , in electrodes for dry batteries and in electroplating and electroforming , in brushes for electric motors and as a neutron moderator in nuclear reactors .

Charcoal is used as a drawing material in artwork , barbecue grilling , iron smelting , and in many other applications . Wood , coal and oil are used as fuel for production of energy and heating . Gem quality diamond is used in jewelry , and industrial diamonds are used in drilling , cutting and polishing tools for machining metals and stone . Plastics are made from fossil hydrocarbons , and carbon fiber , made by pyrolysis of synthetic polyester fibers is used to reinforce plastics to form advanced , lightweight composite materials .

Carbon fiber is made by pyrolysis of extruded and stretched filaments of polyacrylonitrile (PAN) and other organic substances . The crystallographic structure and mechanical properties of the fiber depend on the type of starting material , and on the subsequent processing . Carbon fibers made from PAN have structure resembling narrow filaments of graphite , but thermal processing may re @-@ order the structure into a continuous rolled sheet . The result is fibers with higher specific tensile strength than steel .

Carbon black is used as the black pigment in printing ink , artist 's oil paint and water colours ,

carbon paper , automotive finishes , India ink and laser printer toner . Carbon black is also used as a filler in rubber products such as tyres and in plastic compounds . Activated charcoal is used as an absorbent and adsorbent in filter material in applications as diverse as gas masks , water purification , and kitchen extractor hoods , and in medicine to absorb toxins , poisons , or gases from the digestive system . Carbon is used in chemical reduction at high temperatures . Coke is used to reduce iron ore into iron (smelting) . Case hardening of steel is achieved by heating finished steel components in carbon powder . Carbides of silicon , tungsten , boron and titanium , are among the hardest known materials , and are used as abrasives in cutting and grinding tools . Carbon compounds make up most of the materials used in clothing , such as natural and synthetic textiles and leather , and almost all of the interior surfaces in the built environment other than glass , stone and metal .

= = = Diamonds = = =

The diamond industry falls into two categories : one dealing with gem @-@ grade diamonds and the other , with industrial @-@ grade diamonds . While a large trade in both types of diamonds exists , the two markets act in dramatically different ways .

Unlike precious metals such as gold or platinum , gem diamonds do not trade as a commodity : there is a substantial mark @-@ up in the sale of diamonds , and there is not a very active market for resale of diamonds .

Industrial diamonds are valued mostly for their hardness and heat conductivity , with the gemological qualities of clarity and color being mostly irrelevant . About 80 % of mined diamonds (equal to about 100 million carats or 20 tonnes annually) are unsuitable for use as gemstones and are relegated for industrial use (known as bort) . Synthetic diamonds , invented in the 1950s , found almost immediate industrial applications ; 3 billion carats (600 tonnes) of synthetic diamond is produced annually .

The dominant industrial use of diamond is in cutting , drilling , grinding , and polishing . Most of these applications do not require large diamonds ; in fact , most diamonds of gem @-@ quality except for their small size can be used industrially . Diamonds are embedded in drill tips or saw blades , or ground into a powder for use in grinding and polishing applications . Specialized applications include use in laboratories as containment for high pressure experiments (see diamond anvil cell) , high @-@ performance bearings , and limited use in specialized windows . With the continuing advances in the production of synthetic diamonds , new applications are becoming feasible . Garnering much excitement is the possible use of diamond as a semiconductor suitable for microchips , and because of its exceptional heat conductance property , as a heat sink in electronics .

= = Precautions = =

Pure carbon has extremely low toxicity to humans and can be handled and even ingested safely in the form of graphite or charcoal . It is resistant to dissolution or chemical attack , even in the acidic contents of the digestive tract . Consequently , once it enters into the body 's tissues it is likely to remain there indefinitely . Carbon black was probably one of the first pigments to be used for tattooing , and Ötzi the Iceman was found to have carbon tattoos that survived during his life and for 5200 years after his death . Inhalation of coal dust or soot (carbon black) in large quantities can be dangerous , irritating lung tissues and causing the congestive lung disease , coalworker 's pneumoconiosis . Diamond dust used as an abrasive can be harmful if ingested or inhaled . Microparticles of carbon are produced in diesel engine exhaust fumes , and may accumulate in the lungs . In these examples , the harm may result from contaminants (e.g. , organic chemicals , heavy metals) rather than from the carbon itself .

Carbon generally has low toxicity to life on Earth ; but carbon nanoparticles are deadly to *Drosophila* .

Carbon may burn vigorously and brightly in the presence of air at high temperatures . Large

accumulations of coal , which have remained inert for hundreds of millions of years in the absence of oxygen , may spontaneously combust when exposed to air in coal mine waste tips , ship cargo holds and coal bunkers , and storage dumps .

In nuclear applications where graphite is used as a neutron moderator , accumulation of Wigner energy followed by a sudden , spontaneous release may occur . Annealing to at least 250 ° C can release the energy safely , although in the Windscale fire the procedure went wrong , causing other reactor materials to combust .

The great variety of carbon compounds include such lethal poisons as tetrodotoxin , the lectin ricin from seeds of the castor oil plant *Ricinus communis* , cyanide (CN^-) , and carbon monoxide ; and such essentials to life as glucose and protein .

= = Bonding to carbon = =