[Template:About](/wiki/Template:About" \o "Template:About) [Template:Pp-semi-indef](/wiki/Template:Pp-semi-indef) [Template:Good article](/wiki/Template:Good_article) [Template:Infobox carbon](/wiki/Template:Infobox_carbon)

**Carbon** (from [Template:Lang-la](/wiki/Template:Lang-la) "coal") is a [chemical element](/wiki/Chemical_element) with symbol **C** and [atomic number](/wiki/Atomic_number) 6. On the [periodic table](/wiki/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](/wiki/Nonmetal) and [tetravalent](/wiki/Tetravalence)—making four [electrons](/wiki/Electrons) available to form [covalent](/wiki/Covalent_bond) chemical bonds. Three [isotopes](/wiki/Isotopes) occur naturally, [Template:SupC](/wiki/Template:Sup) and [Template:SupC](/wiki/Template:Sup) being stable while [Template:SupC](/wiki/Template:Sup) is [radioactive](/wiki/Radioactive), decaying with a [half-life](/wiki/Half-life) of about 5,730 years.[[1]](#cite_note-1) Carbon is one of the [few elements known since antiquity](/wiki/Discoveries_of_the_chemical_elements).<ref name=D2>[Template:Cite web](/wiki/Template:Cite_web)</ref>

Carbon is the 15th [most abundant](/wiki/Abundance_of_elements_in_Earth's_crust) element in the Earth's crust, and the [fourth most abundant element in the universe by mass](/wiki/Abundance_of_the_chemical_elements) after [hydrogen](/wiki/Hydrogen), [helium](/wiki/Helium), and [oxygen](/wiki/Oxygen). Carbon's abundance, its unique diversity of [organic compounds](/wiki/Organic_compounds), and its unusual ability to form [polymer](/wiki/Polymer)s at the temperatures commonly encountered on [Earth](/wiki/Earth) enables this element to serve as a common element of [all known life](/wiki/Carbon-based_life). It is the second most abundant element in the human body by mass (about 18.5%) after oxygen.[[2]](#cite_note-2) The atoms of carbon can be bonded together in different ways, termed [allotropes of carbon](/wiki/Allotropes_of_carbon). The best known are [graphite](/wiki/Graphite), [diamond](/wiki/Diamond), and [amorphous carbon](/wiki/Amorphous_carbon).[[3]](#cite_note-3) The [physical properties](/wiki/Physical_properties) of carbon vary widely with the allotropic form. For example, graphite is [opaque](/wiki/Opacity_(optics)) and black while diamond is highly [transparent](/wiki/Transparency_(optics)). Graphite is soft enough to form a streak on paper (hence its name, from the Greek verb "γράφειν" which means "to write"), while diamond is the hardest naturally-occurring material known. Graphite is a good electrical [conductor](/wiki/Electrical_conductor) while diamond has a low [electrical conductivity](/wiki/Electrical_conductivity). Under normal conditions, diamond, [carbon nanotubes](/wiki/Carbon_nanotube), and [graphene](/wiki/Graphene) have the highest [thermal conductivities](/wiki/Thermal_conductivity) of [all known materials](/wiki/List_of_thermal_conductivities). All carbon allotropes are solids under normal conditions, with graphite being the most [thermodynamically stable](/wiki/Thermodynamic_equilibrium) form. They are chemically resistant and require high temperature to react even with oxygen.

The most common [oxidation state](/wiki/Oxidation_state) of carbon in [inorganic compounds](/wiki/Inorganic_compounds) is +4, while +2 is found in [carbon monoxide](/wiki/Carbon_monoxide) and [transition metal](/wiki/Transition_metal) [carbonyl](/wiki/Metal_carbonyl) complexes. The largest sources of inorganic carbon are [limestones](/wiki/Limestone), [dolomites](/wiki/Dolomite) and [carbon dioxide](/wiki/Carbon_dioxide), but significant quantities occur in organic deposits of [coal](/wiki/Coal), [peat](/wiki/Peat), [oil](/wiki/Petroleum), and [methane clathrates](/wiki/Methane_clathrate). Carbon forms a vast number of [compounds](/wiki/Chemical_compound), more than any other element, with almost ten million compounds described to date,<ref name=lanl>[Template:Cite web](/wiki/Template:Cite_web)</ref> and yet that number is but a fraction of the number of theoretically possible compounds under standard conditions.

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## Characteristics[[edit](/index.php?title=(none)&action=edit&section=1)]

[thumb|left|Theoretically predicted phase diagram of carbon](/wiki/File:Carbon_basic_phase_diagram.png) The [*allotropes*](/wiki/Allotropes) of carbon (see below) includes [graphite](/wiki/Graphite), one of the softest known substances, and [diamond](/wiki/Diamond), the hardest naturally occurring substance. It [bonds](/wiki/Chemical_bond) readily with other small [atoms](/wiki/Atom) including other carbon atoms, and is capable of forming multiple stable [covalent](/wiki/Covalent) bonds with such atoms. Carbon is known to form almost ten million different compounds, a large majority of all [chemical compounds](/wiki/Chemical_compounds).<ref name=lanl/> Carbon also has the highest [sublimation](/wiki/Sublimation_(chemistry)) point of all elements. At [atmospheric pressure](/wiki/Atmospheric_pressure) it has no melting point as its [triple point](/wiki/Triple_point) is at 10.8 ± 0.2 MPa and 4,600 ± 300 K (~4,330 °C or 7,820 °F),<ref name=triple2/><ref name=triple3/> so it sublimes at about 3,900 K.[[4]](#cite_note-4)[[5]](#cite_note-5) 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](/wiki/Tungsten) or [rhenium](/wiki/Rhenium). Although thermodynamically prone to [oxidation](/wiki/Redox), carbon resists oxidation more effectively than elements such as [iron](/wiki/Iron) and [copper](/wiki/Copper) that are weaker reducing agents at room temperature.

Carbon compounds form the basis of all known life on [Earth](/wiki/Earth), and the [carbon-nitrogen cycle](/wiki/CNO_cycle) provides some of the energy produced by the [Sun](/wiki/Sun) and other [stars](/wiki/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](/wiki/Sulfuric_acid), [hydrochloric acid](/wiki/Hydrochloric_acid), [chlorine](/wiki/Chlorine) or any [alkalis](/wiki/Alkali_metals). At elevated temperatures, carbon reacts with [oxygen](/wiki/Oxygen) to form carbon [oxides](/wiki/Oxide), and will rob oxygen from metal [oxides](/wiki/Oxides) to leave the elemental metal. This [exothermic](/wiki/Exothermic) reaction is used in the iron and steel industry to smelt iron and to control the carbon content of [steel](/wiki/Steel):

[Template:Chem](/wiki/Template:Chem) + 4 C[Template:Sub](/wiki/Template:Sub) → 3 Fe[Template:Sub](/wiki/Template:Sub) + 4 CO[Template:Sub](/wiki/Template:Sub)

with [sulfur](/wiki/Sulfur) to form [carbon disulfide](/wiki/Carbon_disulfide) and with steam in the coal-gas reaction:

C[Template:Sub](/wiki/Template:Sub) + H[Template:SubOTemplate:Sub](/wiki/Template:Sub) → CO[Template:Sub](/wiki/Template:Sub) + H[Template:Sub](/wiki/Template:Sub).

Carbon combines with some metals at high temperatures to form metallic carbides, such as the iron carbide [cementite](/wiki/Cementite) in steel, and [tungsten carbide](/wiki/Tungsten_carbide), widely used as an [abrasive](/wiki/Abrasive) and for making hard tips for cutting tools.

As of 2009, [graphene](/wiki/Graphene) appears to be the strongest material ever tested.<ref name=lee>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> The process of separating it from [graphite](/wiki/Graphite) will require some further technological development before it is economical for industrial processes.[[6]](#cite_note-6) The system of carbon allotropes spans a range of extremes:

|  |  |
| --- | --- |
| Graphite is one of the softest materials known. | Synthetic [nanocrystalline diamond](/wiki/Aggregated_diamond_nanorod) is the hardest material known.[[7]](#cite_note-7) |
| Graphite is a very good [lubricant](/wiki/Lubricant), displaying [superlubricity](/wiki/Superlubricity).[[8]](#cite_note-8) | Diamond is the ultimate [abrasive](/wiki/Abrasive). |
| Graphite is a [conductor](/wiki/Electrical_conductor) of electricity.[[9]](#cite_note-9) | Diamond is an excellent electrical [insulator](/wiki/Insulator_(electrical)),[[10]](#cite_note-10) and has the highest breakdown electric field of any known material. |
| Some forms of graphite are used for [thermal insulation](/wiki/Thermal_insulation) (i.e. firebreaks and heat shields), but some [other forms](/wiki/Pyrolytic_graphite) are good thermal conductors. | Diamond is the best known naturally occurring [thermal conductor](/wiki/List_of_thermal_conductivities) |
| Graphite is [opaque](/wiki/Opacity_(optics)). | Diamond is highly transparent. |
| Graphite crystallizes in the [hexagonal system](/wiki/Hexagonal_(crystal_system)).[[11]](#cite_note-11) | Diamond crystallizes in the [cubic system](/wiki/Cubic_(crystal_system)). |
| Amorphous carbon is completely [isotropic](/wiki/Isotropic). | Carbon nanotubes are among the most [anisotropic](/wiki/Anisotropic) materials known. |

### Allotropes[[edit](/index.php?title=(none)&action=edit&section=2)]

[Template:Main](/wiki/Template:Main) [Atomic carbon](/wiki/Atomic_carbon) is a very short-lived species and, therefore, carbon is stabilized in various multi-atomic structures with different molecular configurations called [allotropes](/wiki/Allotropes). The three relatively well-known allotropes of carbon are [amorphous carbon](/wiki/Amorphous_carbon), [graphite](/wiki/Graphite), and [diamond](/wiki/Diamond). Once considered exotic, [fullerenes](/wiki/Fullerene) are nowadays commonly synthesized and used in research; they include [buckyballs](/wiki/Buckyball_(molecule)),[[12]](#cite_note-12)[[13]](#cite_note-13) [carbon nanotubes](/wiki/Carbon_nanotube),[[14]](#cite_note-14) [carbon nanobuds](/wiki/Carbon_nanobud)[[15]](#cite_note-15) and [nanofibers](/wiki/Carbon_nanofibers).[[16]](#cite_note-16)[[17]](#cite_note-17) Several other exotic allotropes have also been discovered, such as [lonsdaleite](/wiki/Lonsdaleite) (questionable),[[18]](#cite_note-18) [glassy carbon](/wiki/Glassy_carbon),[[19]](#cite_note-19) [carbon nanofoam](/wiki/Carbon_nanofoam)[[20]](#cite_note-20) and [linear acetylenic carbon](/wiki/Linear_acetylenic_carbon) (carbyne).<ref name=LAC>[Template:Cite book](/wiki/Template:Cite_book)</ref> [thumb|left|A large sample of glassy carbon.](/wiki/File:Glassy_carbon_and_a_1cm3_graphite_cube_HP68-79.jpg)

The [amorphous](/wiki/Amorphous) form is an assortment of carbon atoms in a non-crystalline, irregular, glassy state, which is essentially [graphite](/wiki/Graphite) but not held in a crystalline macrostructure. It is present as a powder, and is the main constituent of substances such as [charcoal](/wiki/Charcoal), [lampblack](/wiki/Lampblack) ([soot](/wiki/Soot)) and [activated carbon](/wiki/Activated_carbon). At normal pressures, carbon takes the form of [graphite](/wiki/Graphite), in which each atom is bonded trigonally to three others in a plane composed of fused [hexagonal](/wiki/Hexagon) rings, just like those in [aromatic hydrocarbons](/wiki/Aromatic_hydrocarbon).[[21]](#cite_note-21) The resulting network is 2-dimensional, and the resulting flat sheets are stacked and loosely bonded through weak [van der Waals forces](/wiki/Van_der_Waals_force). This gives graphite its softness and its [cleaving](/wiki/Cleavage_(crystal)) properties (the sheets slip easily past one another). Because of the delocalization of one of the outer electrons of each atom to form a [π-cloud](/wiki/Delocalized_electron), graphite conducts [electricity](/wiki/Electricity), but only in the plane of each [covalently bonded](/wiki/Covalent_bond) sheet. This results in a lower bulk [electrical conductivity](/wiki/Electrical_conductivity) for carbon than for most [metals](/wiki/Metals). The delocalization also accounts for the energetic stability of graphite over diamond at room temperature. [thumb|300px|Some allotropes of carbon: a)](/wiki/File:Eight_Allotropes_of_Carbon.png) [diamond](/wiki/Diamond); b) [graphite](/wiki/Graphite); c) [lonsdaleite](/wiki/Lonsdaleite); d–f) [fullerenes](/wiki/Fullerene) (C[Template:Sub](/wiki/Template:Sub), C[Template:Sub](/wiki/Template:Sub), C[Template:Sub](/wiki/Template:Sub)); g) [amorphous carbon](/wiki/Amorphous_carbon); h) [carbon nanotube](/wiki/Carbon_nanotube).

At very high pressures, carbon forms the more compact allotrope, [diamond](/wiki/Diamond), having nearly twice the density of graphite. Here, each atom is bonded [tetrahedrally](/wiki/Tetrahedron) to four others, forming a 3-dimensional network of puckered six-membered rings of atoms. Diamond has the same [cubic structure](/wiki/Cubic_crystal_system) as [silicon](/wiki/Silicon) and [germanium](/wiki/Germanium), and because of the strength of the carbon-carbon [bonds](/wiki/Chemical_bond), it is the hardest naturally occurring substance measured by [resistance to scratching](/wiki/Mohs_scale). Contrary to the popular belief that *"*[*diamonds are forever*](/wiki/Diamonds_Are_Forever_(novel))*"*, they are thermodynamically unstable under normal conditions and transform into [graphite](/wiki/Graphite).[[3]](#cite_note-3) 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](/wiki/Lonsdaleite), a [hexagonal](/wiki/Hexagonal) [crystal](/wiki/Crystal) lattice with all atoms covalently bonded and properties similar to those of diamond.[[18]](#cite_note-18) [Fullerenes](/wiki/Fullerene) are a synthetic[Template:Citation needed](/wiki/Template:Citation_needed) crystalline formation with a graphite-like structure, but in place of [hexagons](/wiki/Hexagonal_crystal_system), 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](/wiki/Buckyball_(molecule)), [buckytubes](/wiki/Carbon_nanotube), and [nanobuds](/wiki/Nanobud)) have not yet been fully analyzed and represent an intense area of research in [nanomaterials](/wiki/Nanomaterials). The names *"fullerene"* and *"buckyball"* are given after [Richard Buckminster Fuller](/wiki/Buckminster_Fuller), popularizer of [geodesic domes](/wiki/Geodesic_dome), which resemble the structure of fullerenes. The buckyballs are fairly large molecules formed completely of carbon bonded trigonally, forming [spheroids](/wiki/Spheroid) (the best-known and simplest is the soccerball-shaped C[Template:Sub](/wiki/Template:Sub) [buckminsterfullerene](/wiki/Buckminsterfullerene)).[[12]](#cite_note-12) Carbon nanotubes are structurally similar to buckyballs, except that each atom is bonded trigonally in a curved sheet that forms a hollow [cylinder](/wiki/Cylinder_(geometry)).[[13]](#cite_note-13)[[14]](#cite_note-14) 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.[[15]](#cite_note-15) Of the other discovered allotropes, [carbon nanofoam](/wiki/Carbon_nanofoam) is a [ferromagnetic](/wiki/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/m[Template:Sup](/wiki/Template:Sup).[[22]](#cite_note-22) Similarly, [glassy carbon](/wiki/Glassy_carbon) contains a high proportion of closed [porosity](/wiki/Porosity),[[19]](#cite_note-19) 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](/wiki/Linear_acetylenic_carbon)<ref name=LAC/> has the chemical structure[[23]](#cite_note-23) -(C:::C)[Template:Sub](/wiki/Template:Sub)-. Carbon in this modification is linear with *sp* [orbital hybridization](/wiki/Orbital_hybridization), and is a [polymer](/wiki/Polymer) with alternating single and triple bonds. This carbyne is of considerable interest to [nanotechnology](/wiki/Nanotechnology) as its [Young's modulus](/wiki/Young's_modulus) is forty times that of the hardest known material – diamond.[[24]](#cite_note-24) In 2015, a team at the [North Carolina State University](/wiki/North_Carolina_State_University) announced the development of another allotrope they have dubbed [Q-carbon](/wiki/Q-carbon), created by a high energy low duration laser pulse on amorphous carbon dust. Q-carbon is reported to exhibit ferromagetism, [fluorescence](/wiki/Fluorescence), and a hardness superior to diamonds.[[25]](#cite_note-25)

### Occurrence[[edit](/index.php?title=(none)&action=edit&section=3)]

[thumb|Graphite ore. Penny is included for scale.](/wiki/File:GraphiteOreUSGOV.jpg) [thumb|Raw diamond crystal.](/wiki/File:Rough_diamond.jpg) [thumb|"Present day" (1990s) sea surface](/wiki/File:WOA05_GLODAP_pd_DIC_AYool.png) [dissolved inorganic carbon](/wiki/Total_inorganic_carbon) concentration (from the [GLODAP](/wiki/Global_Ocean_Data_Analysis_Project) [climatology](/wiki/Climatology))

Carbon is the [fourth most abundant chemical element](/wiki/Abundance_of_the_chemical_elements) in the universe by mass after hydrogen, helium, and oxygen. Carbon is abundant in the [Sun](/wiki/Sun), [stars](/wiki/Star), [comets](/wiki/Comet), and in the [atmospheres](/wiki/Celestial_body's_atmosphere) of most [planets](/wiki/Planet).[[26]](#cite_note-26) Some [meteorites](/wiki/Meteorite) contain microscopic diamonds that were formed when the [solar system](/wiki/Solar_system) was still a [protoplanetary disk](/wiki/Protoplanetary_disk).[Template:Citation needed](/wiki/Template:Citation_needed) Microscopic diamonds may also be formed by the intense pressure and high temperature at the sites of meteorite impacts.[[27]](#cite_note-27) In 2014 [NASA](/wiki/NASA) announced a [greatly upgraded database](http://www.astrochem.org/pahdb/) for tracking [polycyclic aromatic hydrocarbons](/wiki/Polycyclic_aromatic_hydrocarbons) (PAHs) in the [universe](/wiki/Universe). More than 20% of the carbon in the universe may be associated with PAHs, complex compounds of carbon and hydrogen without oxygen.[[28]](#cite_note-28) These compounds figure in the [PAH world hypothesis](/wiki/PAH_world_hypothesis) where they are hypothesized to have a role in [abiogenesis](/wiki/Abiogenesis) and formation of [life](/wiki/Life#Extraterrestrial_life). PAHs seem to have been formed "a couple of billion years" after the [Big Bang](/wiki/Big_Bang), are widespread throughout the universe, and are associated with [new stars](/wiki/Star_formation) and [exoplanets](/wiki/Exoplanets).[[26]](#cite_note-26) It has been estimated that the solid earth as a whole contains 730 [ppm](/wiki/Parts_per_million) of carbon, with 2000 ppm in the core and 120 ppm in the combined mantle and crust.[[29]](#cite_note-29) Since the mass of the earth is [Template:Val](/wiki/Template:Val), this would imply 4360 million [gigatonnes](/wiki/Gigatonne) of carbon. This is much more than the amount of carbon in the oceans or atmosphere (below).

In combination with [oxygen](/wiki/Oxygen) in [carbon dioxide](/wiki/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 1,900 gigatonnes of carbon are present in the [biosphere](/wiki/Biosphere). [Hydrocarbons](/wiki/Hydrocarbons) (such as [coal](/wiki/Coal), [petroleum](/wiki/Petroleum), and [natural gas](/wiki/Natural_gas)) contain carbon as well. [Coal](/wiki/Coal) ["reserves" (not "resources")](/wiki/Mineral_resource_classification) amount to around 900 gigatonnes with perhaps 18 000 Gt of resources.[[30]](#cite_note-30) [Oil reserves](/wiki/Oil_reserves) are around 150 gigatonnes. Proven sources of natural gas are about 175 10[Template:Sup](/wiki/Template:Sup) cubic metres (containing about 105 gigatonnes of carbon), but studies estimate another 900 10[Template:Sup](/wiki/Template:Sup) cubic metres of "unconventional" deposits such as [shale gas](/wiki/Shale_gas), representing about 540 gigatonnes of carbon.[[31]](#cite_note-31) Carbon is also found in [methane hydrates](/wiki/Methane_hydrates) in polar regions and under the seas. Various estimates put this carbon between 500, 2500 [Gt](/wiki/Gigatonne),[[32]](#cite_note-32) or 3000 Gt.[[33]](#cite_note-33) 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.[[34]](#cite_note-34) 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](/wiki/Peat_bogs)) at almost 2000 Gt.[[35]](#cite_note-35) Carbon is a constituent (about 12% by mass) of the very large masses of [carbonate](/wiki/Carbonate) rock ([limestone](/wiki/Limestone), [dolomite](/wiki/Dolomite), [marble](/wiki/Marble) and so on). [Coal](/wiki/Coal) is very rich in carbon ([anthracite](/wiki/Anthracite) contains 92–98%)[[36]](#cite_note-36) and is the largest commercial source of mineral carbon, accounting for 4,000 gigatonnes or 80% of [fossil fuel](/wiki/Fossil_fuel).[[37]](#cite_note-37) As for individual carbon allotropes, graphite is found in large quantities in the [United States](/wiki/United_States) (mostly in [New York](/wiki/New_York) and [Texas](/wiki/Texas)), [Russia](/wiki/Russia), [Mexico](/wiki/Mexico), [Greenland](/wiki/Greenland), and [India](/wiki/India). Natural diamonds occur in the rock [kimberlite](/wiki/Kimberlite), found in ancient [volcanic](/wiki/Volcano) "necks", or "pipes". Most diamond deposits are in [Africa](/wiki/Africa), notably in [South Africa](/wiki/South_Africa), [Namibia](/wiki/Namibia), [Botswana](/wiki/Botswana), the [Republic of the Congo](/wiki/Republic_of_the_Congo), and [Sierra Leone](/wiki/Sierra_Leone). Diamond deposits have also been found in [Arkansas](/wiki/Arkansas), [Canada](/wiki/Canada), the Russian [Arctic](/wiki/Arctic), [Brazil](/wiki/Brazil), and in Northern and Western [Australia](/wiki/Australia). Diamonds are now also being recovered from the ocean floor off the [Cape of Good Hope](/wiki/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](/wiki/Cosmic_ray).[[38]](#cite_note-38) [Thermal neutrons](/wiki/Thermal_neutron) 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](/wiki/Asteroid_belt) in our [solar system](/wiki/Solar_system). These asteroids have not yet been directly sampled by scientists. The asteroids can be used in hypothetical [space-based carbon mining](/wiki/Asteroid_mining), which may be possible in the future, but is currently technologically impossible.[[39]](#cite_note-39)[[67]](#cite_note-67)[thumb|upright|](/wiki/File:Carl_Wilhelm_Scheele_from_Familj-Journalen1874.png)[Carl Wilhelm Scheele](/wiki/Carl_Wilhelm_Scheele) In 1722, [René Antoine Ferchault de Réaumur](/wiki/René_Antoine_Ferchault_de_Réaumur) demonstrated that iron was transformed into steel through the absorption of some substance, now known to be carbon.[[68]](#cite_note-68) In 1772, [Antoine Lavoisier](/wiki/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](/wiki/Carbon_dioxide) per [gram](/wiki/Gram). In 1779,[[69]](#cite_note-69) [Carl Wilhelm Scheele](/wiki/Carl_Wilhelm_Scheele) showed that graphite, which had been thought of as a form of [lead](/wiki/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.[[70]](#cite_note-70) In 1786, the French scientists [Claude Louis Berthollet](/wiki/Claude_Louis_Berthollet), [Gaspard Monge](/wiki/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.[[71]](#cite_note-71) 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](/wiki/Chemical_element) in his 1789 textbook.[[72]](#cite_note-72) A new [allotrope](/wiki/Allotrope) of carbon, [fullerene](/wiki/Fullerene), that was discovered in 1985[[73]](#cite_note-73) includes [nanostructured](/wiki/Nanostructure) forms such as [buckyballs](/wiki/Buckyball_(molecule)) and [nanotubes](/wiki/Carbon_nanotube).[[12]](#cite_note-12) Their discoverers – [Robert Curl](/wiki/Robert_Curl), [Harold Kroto](/wiki/Harold_Kroto) and [Richard Smalley](/wiki/Richard_Smalley) – received the [Nobel Prize](/wiki/Nobel_Prize) in Chemistry in 1996.[[74]](#cite_note-74) The resulting renewed interest in new forms lead to the discovery of further exotic allotropes, including [glassy carbon](/wiki/Glassy_carbon), and the realization that "[amorphous carbon](/wiki/Amorphous_carbon)" is not strictly [amorphous](/wiki/Amorphous).[[19]](#cite_note-19)

## Production[[edit](/index.php?title=(none)&action=edit&section=12)]

### Graphite[[edit](/index.php?title=(none)&action=edit&section=13)]

[Template:Main](/wiki/Template:Main) Commercially viable natural deposits of graphite occur in many parts of the world, but the most important sources economically are in [China](/wiki/China), [India](/wiki/India), [Brazil](/wiki/Brazil) and [North Korea](/wiki/North_Korea). Graphite deposits are of [metamorphic](/wiki/Metamorphic_rock) origin, found in association with [quartz](/wiki/Quartz), [mica](/wiki/Mica) and [feldspars](/wiki/Feldspar) in schists, [gneisses](/wiki/Gneiss) and metamorphosed [sandstones](/wiki/Sandstone) and [limestone](/wiki/Limestone) as [lenses](/wiki/Lens_(geology)) or [veins](/wiki/Vein_(geology)), sometimes of a metre or more in thickness. Deposits of graphite in [Borrowdale](/wiki/Borrowdale), [Cumberland](/wiki/Cumberland), [England](/wiki/England) were at first of sufficient size and purity that, until the 19th century, [pencils](/wiki/Pencil) 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.<ref name=USGS>[USGS Minerals Yearbook: Graphite, 2009](http://minerals.usgs.gov/minerals/pubs/commodity/graphite) and Graphite: Mineral Commodity Summaries 2011</ref>

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](/wiki/Flame_retardant). 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.<ref name=USGS/>

According to the [USGS](/wiki/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.<ref name=USGS/> [Template:Clear](/wiki/Template:Clear)

### Diamond[[edit](/index.php?title=(none)&action=edit&section=14)]

[Template:Main](/wiki/Template:Main) [thumb|upright=2.0|Diamond output in 2005](/wiki/File:Global_Diamond_Output_in_2005.png)

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](/wiki/X-ray_fluorescence), after which the final sorting steps are done by hand. Before the use of [X-rays](/wiki/X-ray) 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.[[75]](#cite_note-75) Historically diamonds were known to be found only in alluvial deposits in [southern India](/wiki/Southern_India).<ref name=Catelle1>[Template:Cite book](/wiki/Template:Cite_book) discussion on Alluvial diamonds in India and elsewhere as well as earliest finds</ref> India led the world in diamond production from the time of their discovery in approximately the 9th century BCE<ref name=Ball>[Template:Cite book](/wiki/Template:Cite_book) Ball was a Geologist in British service. Chapter I, Page 1</ref> 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.[[76]](#cite_note-76) 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.<ref name=giasummer2007>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> 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.<ref name=giasummer2007/>

In the United States, diamonds have been found in [Arkansas](/wiki/Arkansas), [Colorado](/wiki/Colorado) and [Montana](/wiki/Montana).<ref name=DGemGLorenz>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>[[77]](#cite_note-77) In 2004, a startling discovery of a microscopic diamond in the United States[[78]](#cite_note-78) led to the January 2008 bulk-sampling of [kimberlite pipes](/wiki/Kimberlite_pipes) in a remote part of [Montana](/wiki/Montana).[[79]](#cite_note-79) Today, most commercially viable diamond deposits are in [Russia](/wiki/Russia), [Botswana](/wiki/Botswana), [Australia](/wiki/Australia) and the [Democratic Republic of Congo](/wiki/Democratic_Republic_of_Congo).[[80]](#cite_note-80) In 2005, Russia produced almost one-fifth of the global diamond output, reports the [British Geological Survey](/wiki/British_Geological_Survey). Australia has the richest diamantiferous pipe with production reaching peak levels of [Template:Convert](/wiki/Template:Convert) per year in the 1990s.<ref name=DGemGLorenz/> There are also commercial deposits being actively mined in the [Northwest Territories](/wiki/Northwest_Territories) of [Canada](/wiki/Canada), [Siberia](/wiki/Siberia) (mostly in [Yakutia territory](/wiki/Sakha_Republic); for example, [Mir pipe](/wiki/Mir_Mine) and [Udachnaya pipe](/wiki/Udachnaya_pipe)), Brazil, and in Northern and Western [Australia](/wiki/Australia).

## Applications[[edit](/index.php?title=(none)&action=edit&section=15)]

[thumb|right|Pencil leads for mechanical pencils are made of](/wiki/File:Mechanical_pencil_lead_spilling_out_051907.jpg) [graphite](/wiki/Graphite) (often mixed with a clay or synthetic binder). [left|thumb|Sticks of vine and compressed](/wiki/File:Charcoal_sticks_051907.jpg) [charcoal](/wiki/Charcoal). [thumb|left|A cloth of woven carbon fibres](/wiki/File:Kohlenstofffasermatte.jpg) [thumb|right|](/wiki/File:SiC_p1390066.jpg)[Silicon carbide](/wiki/Silicon_carbide) [single crystal](/wiki/Single_crystal) [thumb|left|The *C*](/wiki/File:C60-Fulleren-kristallin.JPG)[Template:Sub](/wiki/Template:Sub) fullerene in crystalline form [thumb|right|](/wiki/File:Tungsten_carbide.jpg)[Tungsten carbide](/wiki/Tungsten_carbide) [endmills](/wiki/Endmills)

Carbon is essential to all known living systems, and without it life as we know it could not exist (see [alternative biochemistry](/wiki/Alternative_biochemistry)). The major economic use of carbon other than food and wood is in the form of hydrocarbons, most notably the [fossil fuel](/wiki/Fossil_fuel) [methane](/wiki/Methane) gas and [crude oil](/wiki/Crude_oil) (petroleum). [Crude oil](/wiki/Petroleum) is [distilled](/wiki/Distillation) in [refineries](/wiki/Refinery) by the [petrochemical industry](/wiki/Petrochemical_industry) to produce [gasoline](/wiki/Gasoline), [kerosene](/wiki/Kerosene), and other products. [Cellulose](/wiki/Cellulose) is a natural, carbon-containing polymer produced by plants in the form of [wood](/wiki/Wood), [cotton](/wiki/Cotton), [linen](/wiki/Linen), and [hemp](/wiki/Hemp). [Cellulose](/wiki/Cellulose) is used primarily for maintaining structure in plants. Commercially valuable carbon polymers of animal origin include [wool](/wiki/Wool), [cashmere](/wiki/Cashmere_wool) and [silk](/wiki/Silk). [Plastics](/wiki/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](/wiki/Alloys) with [iron](/wiki/Iron), of which the most common is [carbon steel](/wiki/Carbon_steel). [Graphite](/wiki/Graphite) is combined with [clays](/wiki/Clay) to form the 'lead' used in [pencils](/wiki/Pencil) used for [writing](/wiki/Writing) and [drawing](/wiki/Drawing). It is also used as a [lubricant](/wiki/Lubricant) and a [pigment](/wiki/Pigment), as a molding material in [glass](/wiki/Glass) manufacture, in [electrodes](/wiki/Electrodes) for dry [batteries](/wiki/Battery_(electricity)) and in [electroplating](/wiki/Electroplating) and [electroforming](/wiki/Electroforming), in [brushes](/wiki/Brush_(electric)) for [electric motors](/wiki/Electric_motors) and as a [neutron moderator](/wiki/Neutron_moderator) in [nuclear reactors](/wiki/Nuclear_reactors).

[Charcoal](/wiki/Charcoal) is used as a drawing material in [artwork](/wiki/Art), barbecue [grilling](/wiki/Grilling), [iron smelting](/wiki/Iron_smelting), and in many other applications. Wood, coal and oil are used as [fuel](/wiki/Fuel) for production of energy and [heating](/wiki/Heating). Gem quality [diamond](/wiki/Diamond) is used in jewelry, and [industrial diamonds](/wiki/Industrial_diamond) are used in drilling, cutting and polishing tools for machining metals and stone. Plastics are made from fossil hydrocarbons, and [carbon fiber](/wiki/Carbon_fiber), made by [pyrolysis](/wiki/Pyrolysis) of synthetic [polyester](/wiki/Polyester) [fibers](/wiki/Fiber) is used to reinforce plastics to form advanced, lightweight [composite materials](/wiki/Composite_materials).

[Carbon fiber](/wiki/Carbon_fiber) is made by pyrolysis of extruded and stretched filaments of [polyacrylonitrile](/wiki/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](/wiki/Specific_strength) than steel.[[81]](#cite_note-81) [Carbon black](/wiki/Carbon_black) is used as the black [pigment](/wiki/Pigment) in [printing](/wiki/Printing) [ink](/wiki/Ink), artist's oil paint and water colours, [carbon paper](/wiki/Carbon_paper), automotive finishes, [India ink](/wiki/India_ink) and [laser printer](/wiki/Laser_printer) [toner](/wiki/Toner). [Carbon black](/wiki/Carbon_black) is also used as a [filler](/wiki/Filler_(materials)) in [rubber](/wiki/Rubber) products such as tyres and in [plastic](/wiki/Plastic) compounds. [Activated charcoal](/wiki/Activated_charcoal) is used as an [absorbent](/wiki/Absorption_(chemistry)) and [adsorbent](/wiki/Adsorbent) in [filter](/wiki/Filter_(chemistry)) material in applications as diverse as [gas masks](/wiki/Gas_masks), [water purification](/wiki/Water_purification), and [kitchen](/wiki/Kitchen) [extractor hoods](/wiki/Extractor_hood), and in medicine to [absorb](/wiki/Absorption_(chemistry)) toxins, poisons, or gases from the [digestive system](/wiki/Human_digestive_system). Carbon is used in [chemical reduction](/wiki/Redox) at high temperatures. [Coke](/wiki/Coke_(fuel)) is used to reduce iron ore into iron (smelting). [Case hardening](/wiki/Case_hardening) of steel is achieved by heating finished steel components in carbon powder. [Carbides](/wiki/Carbide) of [silicon](/wiki/Silicon_carbide), [tungsten](/wiki/Tungsten_carbide), [boron](/wiki/Boron_carbide) and [titanium](/wiki/Titanium_carbide), are among the hardest known materials, and are used as [abrasives](/wiki/Abrasives) in cutting and grinding tools. Carbon compounds make up most of the materials used in clothing, such as natural and synthetic [textiles](/wiki/Textiles) and [leather](/wiki/Leather), and almost all of the interior surfaces in the [built environment](/wiki/Built_environment) other than glass, stone and metal. [Template:Clear](/wiki/Template:Clear)

### Diamonds[[edit](/index.php?title=(none)&action=edit&section=16)]

The [diamond](/wiki/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](/wiki/Precious_metal) such as [gold](/wiki/Gold) or [platinum](/wiki/Platinum), gem diamonds do not trade as a [commodity](/wiki/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 are relegated for industrial use (known as [*bort*](/wiki/Bort)*)*.[[82]](#cite_note-82) [synthetic diamonds](/wiki/Synthetic_diamond), invented in the 1950s, found almost immediate industrial applications; 3 billion carats (600 [tonnes](/wiki/Tonne)) of synthetic diamond is produced annually.[[83]](#cite_note-83) 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.[[84]](#cite_note-84) Specialized applications include use in laboratories as containment for [high pressure experiments](/wiki/Pressure_experiment) (see [diamond anvil cell](/wiki/Diamond_anvil_cell)), high-performance [bearings](/wiki/Bearing_(mechanical)), and limited use in specialized [windows](/wiki/Window).[[85]](#cite_note-85)[[86]](#cite_note-86) 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](/wiki/Semiconductor) suitable for [microchips](/wiki/Integrated_circuit), and because of its exceptional heat conductance property, as a [heat sink](/wiki/Heat_sink) in [electronics](/wiki/Electronics).[[87]](#cite_note-87)

## Precautions[[edit](/index.php?title=(none)&action=edit&section=17)]

[thumb|upright|Worker at](/wiki/File:Worker_at_carbon_black_plant2.jpg) [carbon black](/wiki/Carbon_black) plant in [Sunray, Texas](/wiki/Sunray,_Texas) (photo by [John Vachon](/wiki/John_Vachon), 1942)Pure carbon has extremely low [toxicity](/wiki/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](/wiki/Carbon_black) was probably one of the first pigments to be used for [tattooing](/wiki/Tattoo), and [Ötzi the Iceman](/wiki/Ötzi_the_Iceman) was found to have carbon tattoos that survived during his life and for 5200 years after his death.[[88]](#cite_note-88) Inhalation of coal dust or soot ([carbon black](/wiki/Carbon_black)) in large quantities can be dangerous, irritating lung tissues and causing the congestive [lung](/wiki/Human_lung) disease, [coalworker's pneumoconiosis](/wiki/Coalworker's_pneumoconiosis). Diamond dust used as an abrasive can harmful if ingested or inhaled. Microparticles of carbon are produced in diesel engine exhaust fumes, and may accumulate in the lungs.[[89]](#cite_note-89) 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](/wiki/Life); but carbon nanoparticles are deadly to [*Drosophila*](/wiki/Drosophila).[[90]](#cite_note-90) 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](/wiki/Spontaneous_combustion) when exposed to air in coal mine waste tips, ship cargo holds and coal bunkers,[[91]](#cite_note-91)[[92]](#cite_note-92) and storage dumps.

In [nuclear applications](/wiki/Nuclear_reactor) where graphite is used as a [neutron moderator](/wiki/Neutron_moderator), accumulation of [Wigner energy](/wiki/Wigner_energy) followed by a sudden, spontaneous release may occur. [Annealing](/wiki/Annealing_(metallurgy)) to at least 250 °C can release the energy safely, although in the [Windscale fire](/wiki/Windscale_fire) the procedure went wrong, causing other reactor materials to combust.

The great variety of carbon compounds include such lethal poisons as [tetrodotoxin](/wiki/Tetrodotoxin), the [lectin](/wiki/Lectin) [ricin](/wiki/Ricin) from seeds of the [castor oil plant](/wiki/Castor_oil_plant) [*Ricinus communis*](/wiki/Ricinus_communis), [cyanide](/wiki/Cyanide) (CN[Template:Sup](/wiki/Template:Sup)), and [carbon monoxide](/wiki/Carbon_monoxide_poisoning); and such essentials to life as [glucose](/wiki/Glucose) and [protein](/wiki/Protein).

## Bonding to carbon[[edit](/index.php?title=(none)&action=edit&section=18)]

[Template:Hide in print](/wiki/Template:Hide_in_print)

## See also[[edit](/index.php?title=(none)&action=edit&section=19)]

[Template:Wikipedia books](/wiki/Template:Wikipedia_books)

* [Carbon chauvinism](/wiki/Carbon_chauvinism)
* [Carbon footprint](/wiki/Carbon_footprint)
* [Low-carbon economy](/wiki/Low-carbon_economy)
* [Timeline of carbon nanotubes](/wiki/Timeline_of_carbon_nanotubes)

[Template:Portal bar](/wiki/Template:Portal_bar)

## References[[edit](/index.php?title=(none)&action=edit&section=20)]

[Template:Reflist](/wiki/Template:Reflist)

## External links[[edit](/index.php?title=(none)&action=edit&section=21)]

[Template:Sister project links](/wiki/Template:Sister_project_links)

* [Template:In Our Time](/wiki/Template:In_Our_Time)
* [Carbon](http://www.periodicvideos.com/videos/006.htm) at [*The Periodic Table of Videos*](/wiki/The_Periodic_Table_of_Videos) (University of Nottingham)
* [Carbon on Britannica](http://www.britannica.com/eb/article-80956/carbon-group-element)
* [Extensive Carbon page at asu.edu](http://invsee.asu.edu/nmodules/Carbonmod/everywhere.html)
* [Electrochemical uses of carbon](http://electrochem.cwru.edu/ed/encycl/art-c01-carbon.htm)
* [Carbon—Super Stuff. Animation with sound and interactive 3D-models.](http://www.forskning.no/Artikler/2006/juni/1149432180.36)

[Template:Compact periodic table](/wiki/Template:Compact_periodic_table) [Template:Carbon compounds](/wiki/Template:Carbon_compounds) [Template:Allotropes of carbon](/wiki/Template:Allotropes_of_carbon) [Template:Authority control](/wiki/Template:Authority_control)

[Carbon](/wiki/Category:Carbon) [Category:Carbonate minerals](/wiki/Category:Carbonate_minerals) [Carbon forms](/wiki/Category:Carbon_forms) [Category:Chemical elements](/wiki/Category:Chemical_elements) [Category:Polyatomic nonmetals](/wiki/Category:Polyatomic_nonmetals) [Category:Organic minerals](/wiki/Category:Organic_minerals) [Category:Biology and pharmacology of chemical elements](/wiki/Category:Biology_and_pharmacology_of_chemical_elements) [Category:Reducing agents](/wiki/Category:Reducing_agents)