[This is a good article. Follow the link for more information.](https://en.wikipedia.org/wiki/Wikipedia:Good_articles)

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**Silicon**

From Wikipedia, the free encyclopedia

[Jump to navigation](https://en.wikipedia.org/wiki/Silicon#mw-head) [Jump to search](https://en.wikipedia.org/wiki/Silicon#p-search)

This article is about the chemical element. For other uses, see [Silicon (disambiguation)](https://en.wikipedia.org/wiki/Silicon_(disambiguation)).

Not to be confused with the silicon-containing synthetic polymer [silicone](https://en.wikipedia.org/wiki/Silicone).

"Element 14" redirects here. For other uses, see [Element 14 (disambiguation)](https://en.wikipedia.org/wiki/Element_14_(disambiguation)).

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| --- | --- |
| Silicon,  14Si | |
| [SiliconCroda.jpg](https://en.wikipedia.org/wiki/File:SiliconCroda.jpg) | |
| **General properties** | |
| **Pronunciation** | [/ˈsɪlɪkən/](https://en.wikipedia.org/wiki/Help:IPA/English) ​([*SIL-ə-kən*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | crystalline, reflective with bluish-tinged faces |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | [28.084, 28.086] conventional: 28.085 |
| **Silicon in the** [**periodic table**](https://en.wikipedia.org/wiki/Periodic_table) | |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 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[Neon](https://en.wikipedia.org/wiki/Neon) | | [Sodium](https://en.wikipedia.org/wiki/Sodium) | [Magnesium](https://en.wikipedia.org/wiki/Magnesium) |  | | | | | | | | | | | | | | | | | | | | | | | | [Aluminium](https://en.wikipedia.org/wiki/Aluminium) | Silicon | [Phosphorus](https://en.wikipedia.org/wiki/Phosphorus) | [Sulfur](https://en.wikipedia.org/wiki/Sulfur) | [Chlorine](https://en.wikipedia.org/wiki/Chlorine) | [Argon](https://en.wikipedia.org/wiki/Argon) | | [Potassium](https://en.wikipedia.org/wiki/Potassium) | [Calcium](https://en.wikipedia.org/wiki/Calcium) | [Scandium](https://en.wikipedia.org/wiki/Scandium) |  | | | | | | | | | | | | | | [Titanium](https://en.wikipedia.org/wiki/Titanium) | [Vanadium](https://en.wikipedia.org/wiki/Vanadium) | [Chromium](https://en.wikipedia.org/wiki/Chromium) | [Manganese](https://en.wikipedia.org/wiki/Manganese) | [Iron](https://en.wikipedia.org/wiki/Iron) | [Cobalt](https://en.wikipedia.org/wiki/Cobalt) | [Nickel](https://en.wikipedia.org/wiki/Nickel) | [Copper](https://en.wikipedia.org/wiki/Copper) | [Zinc](https://en.wikipedia.org/wiki/Zinc) | [Gallium](https://en.wikipedia.org/wiki/Gallium) | [Germanium](https://en.wikipedia.org/wiki/Germanium) | [Arsenic](https://en.wikipedia.org/wiki/Arsenic) | [Selenium](https://en.wikipedia.org/wiki/Selenium) | [Bromine](https://en.wikipedia.org/wiki/Bromine) | [Krypton](https://en.wikipedia.org/wiki/Krypton) | | [Rubidium](https://en.wikipedia.org/wiki/Rubidium) | [Strontium](https://en.wikipedia.org/wiki/Strontium) | [Yttrium](https://en.wikipedia.org/wiki/Yttrium) |  |  | | | | | | | | | | | | | [Zirconium](https://en.wikipedia.org/wiki/Zirconium) | [Niobium](https://en.wikipedia.org/wiki/Niobium) | [Molybdenum](https://en.wikipedia.org/wiki/Molybdenum) | [Technetium](https://en.wikipedia.org/wiki/Technetium) | [Ruthenium](https://en.wikipedia.org/wiki/Ruthenium) | [Rhodium](https://en.wikipedia.org/wiki/Rhodium) | [Palladium](https://en.wikipedia.org/wiki/Palladium) | [Silver](https://en.wikipedia.org/wiki/Silver) | [Cadmium](https://en.wikipedia.org/wiki/Cadmium) | [Indium](https://en.wikipedia.org/wiki/Indium) | [Tin](https://en.wikipedia.org/wiki/Tin) | [Antimony](https://en.wikipedia.org/wiki/Antimony) | [Tellurium](https://en.wikipedia.org/wiki/Tellurium) | [Iodine](https://en.wikipedia.org/wiki/Iodine) | [Xenon](https://en.wikipedia.org/wiki/Xenon) | | [Caesium](https://en.wikipedia.org/wiki/Caesium) | [Barium](https://en.wikipedia.org/wiki/Barium) | [Lanthanum](https://en.wikipedia.org/wiki/Lanthanum) | [Cerium](https://en.wikipedia.org/wiki/Cerium) | [Praseodymium](https://en.wikipedia.org/wiki/Praseodymium) | [Neodymium](https://en.wikipedia.org/wiki/Neodymium) | [Promethium](https://en.wikipedia.org/wiki/Promethium) | [Samarium](https://en.wikipedia.org/wiki/Samarium) | [Europium](https://en.wikipedia.org/wiki/Europium) | [Gadolinium](https://en.wikipedia.org/wiki/Gadolinium) | [Terbium](https://en.wikipedia.org/wiki/Terbium) | [Dysprosium](https://en.wikipedia.org/wiki/Dysprosium) | [Holmium](https://en.wikipedia.org/wiki/Holmium) | [Erbium](https://en.wikipedia.org/wiki/Erbium) | [Thulium](https://en.wikipedia.org/wiki/Thulium) | [Ytterbium](https://en.wikipedia.org/wiki/Ytterbium) | [Lutetium](https://en.wikipedia.org/wiki/Lutetium) | [Hafnium](https://en.wikipedia.org/wiki/Hafnium) | [Tantalum](https://en.wikipedia.org/wiki/Tantalum) | [Tungsten](https://en.wikipedia.org/wiki/Tungsten) | [Rhenium](https://en.wikipedia.org/wiki/Rhenium) | [Osmium](https://en.wikipedia.org/wiki/Osmium) | [Iridium](https://en.wikipedia.org/wiki/Iridium) | [Platinum](https://en.wikipedia.org/wiki/Platinum) | [Gold](https://en.wikipedia.org/wiki/Gold) | [Mercury (element)](https://en.wikipedia.org/wiki/Mercury_(element)) | [Thallium](https://en.wikipedia.org/wiki/Thallium) | [Lead](https://en.wikipedia.org/wiki/Lead) | [Bismuth](https://en.wikipedia.org/wiki/Bismuth) | [Polonium](https://en.wikipedia.org/wiki/Polonium) | [Astatine](https://en.wikipedia.org/wiki/Astatine) | [Radon](https://en.wikipedia.org/wiki/Radon) | | [Francium](https://en.wikipedia.org/wiki/Francium) | [Radium](https://en.wikipedia.org/wiki/Radium) | [Actinium](https://en.wikipedia.org/wiki/Actinium) | [Thorium](https://en.wikipedia.org/wiki/Thorium) | [Protactinium](https://en.wikipedia.org/wiki/Protactinium) | [Uranium](https://en.wikipedia.org/wiki/Uranium) | [Neptunium](https://en.wikipedia.org/wiki/Neptunium) | [Plutonium](https://en.wikipedia.org/wiki/Plutonium) | [Americium](https://en.wikipedia.org/wiki/Americium) | [Curium](https://en.wikipedia.org/wiki/Curium) | [Berkelium](https://en.wikipedia.org/wiki/Berkelium) | [Californium](https://en.wikipedia.org/wiki/Californium) | [Einsteinium](https://en.wikipedia.org/wiki/Einsteinium) | [Fermium](https://en.wikipedia.org/wiki/Fermium) | [Mendelevium](https://en.wikipedia.org/wiki/Mendelevium) | [Nobelium](https://en.wikipedia.org/wiki/Nobelium) | [Lawrencium](https://en.wikipedia.org/wiki/Lawrencium) | [Rutherfordium](https://en.wikipedia.org/wiki/Rutherfordium) | [Dubnium](https://en.wikipedia.org/wiki/Dubnium) | [Seaborgium](https://en.wikipedia.org/wiki/Seaborgium) | [Bohrium](https://en.wikipedia.org/wiki/Bohrium) | [Hassium](https://en.wikipedia.org/wiki/Hassium) | [Meitnerium](https://en.wikipedia.org/wiki/Meitnerium) | [Darmstadtium](https://en.wikipedia.org/wiki/Darmstadtium) | [Roentgenium](https://en.wikipedia.org/wiki/Roentgenium) | [Copernicium](https://en.wikipedia.org/wiki/Copernicium) | [Nihonium](https://en.wikipedia.org/wiki/Nihonium) | [Flerovium](https://en.wikipedia.org/wiki/Flerovium) | [Moscovium](https://en.wikipedia.org/wiki/Moscovium) | [Livermorium](https://en.wikipedia.org/wiki/Livermorium) | [Tennessine](https://en.wikipedia.org/wiki/Tennessine) | [Oganesson](https://en.wikipedia.org/wiki/Oganesson) | | [C](https://en.wikipedia.org/wiki/Carbon) ↑ **Si** ↓ [Ge](https://en.wikipedia.org/wiki/Germanium) | | [aluminium](https://en.wikipedia.org/wiki/Aluminium) ← **silicon** → [phosphorus](https://en.wikipedia.org/wiki/Phosphorus) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 14 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 14 (carbon group)](https://en.wikipedia.org/wiki/Carbon_group) |
| [**Period**](https://en.wikipedia.org/wiki/Period_(periodic_table)) | [period 3](https://en.wikipedia.org/wiki/Period_(periodic_table)#Period_3) |
| [**Block**](https://en.wikipedia.org/wiki/Block_(periodic_table)) | [p-block](https://en.wikipedia.org/wiki/P-block) |
| [**Element category**](https://en.wikipedia.org/wiki/Names_for_sets_of_chemical_elements#Category) | [metalloid](https://en.wikipedia.org/wiki/Metalloid) |
| [**Electron configuration**](https://en.wikipedia.org/wiki/Electron_configuration) | [[Ne](https://en.wikipedia.org/wiki/Neon)] 3s2 3p2 |
| Electrons per shell | 2, 8, 4 |
| **Physical properties** | |
| [**Phase**](https://en.wikipedia.org/wiki/Phase_(matter)) **at**[**STP**](https://en.wikipedia.org/wiki/Standard_conditions_for_temperature_and_pressure) | [solid](https://en.wikipedia.org/wiki/Solid) |
| [**Melting point**](https://en.wikipedia.org/wiki/Melting_point) | 1687 [K](https://en.wikipedia.org/wiki/Kelvin) ​(1414 °C, ​2577 °F) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | 3538 K ​(3265 °C, ​5909 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | 2.3290 g/cm3 |
| when liquid (at m.p.) | 2.57 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | 50.21 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporization**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | 383 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | 19.789 J/(mol·K) |
| [**Vapor pressure**](https://en.wikipedia.org/wiki/Vapor_pressure)   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | ***P***(Pa) | **1** | **10** | **100** | **1 k** | **10 k** | **100 k** | | **at *T***(K) | 1908 | 2102 | 2339 | 2636 | 3021 | 3537 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | **−4**, −3, −2, −1, +1[[1]](https://en.wikipedia.org/wiki/Silicon#cite_note-1) +2, +3, **+4** (an [amphoteric](https://en.wikipedia.org/wiki/Amphoterism) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 1.90 |
| [**Ionization energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 786.5 kJ/mol * 2nd: 1577.1 kJ/mol * 3rd: 3231.6 kJ/mol * ([more](https://en.wikipedia.org/wiki/Molar_ionization_energies_of_the_elements#silicon)) |
| [**Atomic radius**](https://en.wikipedia.org/wiki/Atomic_radius) | empirical: 111 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 111 pm |
| [**Van der Waals radius**](https://en.wikipedia.org/wiki/Van_der_Waals_radius) | 210 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Silicon_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of silicon** | |
| **Other properties** | |
| [**Crystal structure**](https://en.wikipedia.org/wiki/Crystal_structure) | ​[face-centered diamond-cubic](https://en.wikipedia.org/wiki/Diamond_cubic)  [Diamond cubic crystal structure for silicon](https://en.wikipedia.org/wiki/File:Diamond_cubic_crystal_structure.svg) |
| [**Speed of sound**](https://en.wikipedia.org/wiki/Speed_of_sound)thin rod | 8433 m/s (at 20 °C) |
| [**Thermal expansion**](https://en.wikipedia.org/wiki/Coefficient_of_thermal_expansion) | 2.6 µm/(m·K) (at 25 °C) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | 149 W/(m·K) |
| [**Electrical resistivity**](https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity) | 2.3×103 Ω·m (at 20 °C)[[2]](https://en.wikipedia.org/wiki/Silicon#cite_note-Eranna2014-2) |
| [**Band gap**](https://en.wikipedia.org/wiki/Band_gap) | 1.12 [eV](https://en.wikipedia.org/wiki/Electronvolt) (at 300 K) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | [diamagnetic](https://en.wikipedia.org/wiki/Diamagnetism)[[3]](https://en.wikipedia.org/wiki/Silicon#cite_note-3) |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | −3.9·10−6 cm3/mol (298 K)[[4]](https://en.wikipedia.org/wiki/Silicon#cite_note-4) |
| [**Young's modulus**](https://en.wikipedia.org/wiki/Young%27s_modulus) | 130–188 GPa[[5]](https://en.wikipedia.org/wiki/Silicon#cite_note-hopcroft-5) |
| [**Shear modulus**](https://en.wikipedia.org/wiki/Shear_modulus) | 51–80 GPa[[5]](https://en.wikipedia.org/wiki/Silicon#cite_note-hopcroft-5) |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | 97.6 GPa[[5]](https://en.wikipedia.org/wiki/Silicon#cite_note-hopcroft-5) |
| [**Poisson ratio**](https://en.wikipedia.org/wiki/Poisson%27s_ratio) | 0.064–0.28[[5]](https://en.wikipedia.org/wiki/Silicon#cite_note-hopcroft-5) |
| [**Mohs hardness**](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) | 6.5 |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7440-21-3 |
| **History** | |
| **Naming** | after Latin 'silex' or 'silicis', meaning [flint](https://en.wikipedia.org/wiki/Flint) |
| **Prediction** | [Antoine Lavoisier](https://en.wikipedia.org/wiki/Antoine_Lavoisier) (1787) |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) **and first isolation** | [Jöns Jacob Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jacob_Berzelius)[[6]](https://en.wikipedia.org/wiki/Silicon#cite_note-6)[[7]](https://en.wikipedia.org/wiki/Silicon#cite_note-7) (1823) |
| **Named by** | [Thomas Thomson](https://en.wikipedia.org/wiki/Thomas_Thomson_(chemist)) (1817) |
| **Main** [**isotopes of silicon**](https://en.wikipedia.org/wiki/Isotopes_of_silicon) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**Iso­tope**](https://en.wikipedia.org/wiki/Isotope) | [**Abun­dance**](https://en.wikipedia.org/wiki/Natural_abundance) | [**Half-life**](https://en.wikipedia.org/wiki/Half-life) **(*t*1/2)** | [**Decay mode**](https://en.wikipedia.org/wiki/Radioactive_decay) | [**Pro­duct**](https://en.wikipedia.org/wiki/Decay_product) | | **28Si** | 92.2% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | **29Si** | 4.7% | stable | | | | **30Si** | 3.1% | stable | | | | **31Si** | [trace](https://en.wikipedia.org/wiki/Trace_radioisotope) | 2.62 h | [β−](https://en.wikipedia.org/wiki/Beta_emission) | [31P](https://en.wikipedia.org/wiki/Phosphorus-31) | | **32Si** | trace | 153 y | β− | [32P](https://en.wikipedia.org/wiki/Phosphorus-32) | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_silicon) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_silicon) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_silicon&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Silicon** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **Si** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 14. It is a hard and brittle crystalline solid with a blue-grey metallic lustre; and it is a [tetravalent](https://en.wikipedia.org/wiki/Tetravalence) [metalloid](https://en.wikipedia.org/wiki/Metalloid) and [semiconductor](https://en.wikipedia.org/wiki/Semiconductor). It is a member of [group 14](https://en.wikipedia.org/wiki/Carbon_group) in the periodic table: [carbon](https://en.wikipedia.org/wiki/Carbon) is above it; and [germanium](https://en.wikipedia.org/wiki/Germanium), [tin](https://en.wikipedia.org/wiki/Tin), and [lead](https://en.wikipedia.org/wiki/Lead) are below it. It is relatively unreactive. Because of its large chemical affinity for oxygen, it was not until 1823 that [Jöns Jakob Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jakob_Berzelius) was first able to prepare it and characterize it in pure form. Its melting and boiling points of 1414 °C and 3265 °C respectively are the second-highest among all the metalloids and nonmetals, being only surpassed by [boron](https://en.wikipedia.org/wiki/Boron). Silicon is the eighth most [common element](https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements) in the universe by mass, but very rarely occurs as the pure element in the Earth's crust. It is most widely distributed in [dusts](https://en.wikipedia.org/wiki/Dust), [sands](https://en.wikipedia.org/wiki/Sand), [planetoids](https://en.wikipedia.org/wiki/Planetoids), and [planets](https://en.wikipedia.org/wiki/Planet) as various forms of [silicon dioxide](https://en.wikipedia.org/wiki/Silicon_dioxide) (silica) or [silicates](https://en.wikipedia.org/wiki/Silicate). More than 90% of the Earth's crust is composed of [silicate minerals](https://en.wikipedia.org/wiki/Silicate_minerals), making silicon the [second most abundant element](https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust) in the Earth's crust (about 28% by mass) after [oxygen](https://en.wikipedia.org/wiki/Oxygen).

Most silicon is used commercially without being separated, and often with little processing of the natural minerals. Such use includes industrial construction with [clays](https://en.wikipedia.org/wiki/Clays), [silica sand](https://en.wikipedia.org/wiki/Silica_sand), and [stone](https://en.wikipedia.org/wiki/Stone). Silicates are used in [Portland cement](https://en.wikipedia.org/wiki/Portland_cement) for [mortar](https://en.wikipedia.org/wiki/Mortar_(masonry)) and [stucco](https://en.wikipedia.org/wiki/Stucco), and mixed with silica sand and [gravel](https://en.wikipedia.org/wiki/Gravel) to make [concrete](https://en.wikipedia.org/wiki/Concrete) for walkways, foundations, and roads. They are also used in whiteware [ceramics](https://en.wikipedia.org/wiki/Ceramic) such as [porcelain](https://en.wikipedia.org/wiki/Porcelain), and in traditional [quartz](https://en.wikipedia.org/wiki/Quartz)-based [soda-lime glass](https://en.wikipedia.org/wiki/Soda-lime_glass) and many other specialty [glasses](https://en.wikipedia.org/wiki/Glass). Silicon compounds such as [silicon carbide](https://en.wikipedia.org/wiki/Silicon_carbide) are used as abrasives and components of high-strength ceramics. Silicon is the basis of the widely used synthetic polymers called [silicones](https://en.wikipedia.org/wiki/Silicone).

Elemental silicon also has a large impact on the modern world economy. Most free silicon is used in the [steel](https://en.wikipedia.org/wiki/Steel) refining, [aluminium](https://en.wikipedia.org/wiki/Aluminium)-casting, and fine chemical industries (often to make [fumed silica](https://en.wikipedia.org/wiki/Fumed_silica)). Even more visibly, the relatively small portion of very highly purified elemental silicon used in semiconductor electronics (< 10%) is essential to [integrated circuits](https://en.wikipedia.org/wiki/Integrated_circuits) — most computers, cell phones, and modern technology depend on it.

Silicon is an essential element in biology, although only traces are required by animals. However, various [sea sponges](https://en.wikipedia.org/wiki/Sea_sponges) and microorganisms, such as [diatoms](https://en.wikipedia.org/wiki/Diatoms) and [radiolaria](https://en.wikipedia.org/wiki/Radiolaria), secrete skeletal structures made of silica. Silica is deposited in many plant tissues.[[9]](https://en.wikipedia.org/wiki/Silicon#cite_note-Cutter-9)



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**History**

[](https://en.wikipedia.org/wiki/File:J%C3%B6ns_Jacob_Berzelius.jpg)

[Jöns Jacob Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jacob_Berzelius), discoverer of silicon

In 1787 [Antoine Lavoisier](https://en.wikipedia.org/wiki/Antoine_Lavoisier) suspected that [silica](https://en.wikipedia.org/wiki/Silica) might be an oxide of a fundamental [chemical element](https://en.wikipedia.org/wiki/Chemical_element),[[10]](https://en.wikipedia.org/wiki/Silicon#cite_note-10) but the [chemical affinity](https://en.wikipedia.org/wiki/Chemical_affinity) of silicon for oxygen is high enough that he had no means to reduce the oxide and isolate the element.[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11) After an attempt to isolate silicon in 1808, [Sir Humphry Davy](https://en.wikipedia.org/wiki/Sir_Humphry_Davy) proposed the name "silicium" for silicon, from the Latin *silex*, *silicis* for flint, and adding the "-ium" ending because he believed it to be a metal.[[12]](https://en.wikipedia.org/wiki/Silicon#cite_note-12) Most other languages use transliterated forms of Davy's name, sometimes adapted to local phonology (e.g. [German](https://en.wikipedia.org/wiki/German_language) *Silizium*, [Turkish](https://en.wikipedia.org/wiki/Turkish_language) *silisyum*). A few others use instead a [calque](https://en.wikipedia.org/wiki/Calque) of the Latin root (e.g. [Russian](https://en.wikipedia.org/wiki/Russian_language) *кремний*, from *кремень* "flint"; [Greek](https://en.wikipedia.org/wiki/Greek_language) *πυριτιο* from *πυρ* "fire"; [Finnish](https://en.wikipedia.org/wiki/Finnish_language) *pii* from *piikivi* "flint").[[13]](https://en.wikipedia.org/wiki/Silicon#cite_note-13)

[Gay-Lussac](https://en.wikipedia.org/wiki/Gay-Lussac) and [Thénard](https://en.wikipedia.org/wiki/Louis_Jacques_Th%C3%A9nard) are thought to have prepared impure [amorphous silicon](https://en.wikipedia.org/wiki/Amorphous_silicon) in 1811, through the heating of recently isolated [potassium](https://en.wikipedia.org/wiki/Potassium) metal with [silicon tetrafluoride](https://en.wikipedia.org/wiki/Silicon_tetrafluoride), but they did not purify and characterize the product, nor identify it as a new element.[[14]](https://en.wikipedia.org/wiki/Silicon#cite_note-14) Silicon was given its present name in 1817 by Scottish chemist [Thomas Thomson](https://en.wikipedia.org/wiki/Thomas_Thomson_(chemist)). He retained part of Davy's name but added "-on" because he believed that silicon was a [nonmetal](https://en.wikipedia.org/wiki/Nonmetal) similar to [boron](https://en.wikipedia.org/wiki/Boron) and [carbon](https://en.wikipedia.org/wiki/Carbon).[[15]](https://en.wikipedia.org/wiki/Silicon#cite_note-15) In 1823, [Jöns Jacob Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jacob_Berzelius) prepared amorphous silicon using approximately the same method as Gay-Lussac (reducing potassium fluorosilicate with molten potassium metal), but purifying the product to a brown powder by repeatedly washing it.[[16]](https://en.wikipedia.org/wiki/Silicon#cite_note-16) As a result, he is usually given credit for the element's discovery.[[17]](https://en.wikipedia.org/wiki/Silicon#cite_note-17)[[18]](https://en.wikipedia.org/wiki/Silicon#cite_note-18) The same year, Berzelius became the first to prepare [silicon tetrachloride](https://en.wikipedia.org/wiki/Silicon_tetrachloride); [silicon tetrafluoride](https://en.wikipedia.org/wiki/Silicon_tetrafluoride) had already been prepared long before in 1771 by [Carl Wilhelm Scheele](https://en.wikipedia.org/wiki/Carl_Wilhelm_Scheele) by dissolving silica in [hydrofluoric acid](https://en.wikipedia.org/wiki/Hydrofluoric_acid).[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11)

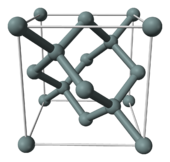
Silicon in its more common crystalline form was not prepared until 31 years later, by [Deville](https://en.wikipedia.org/wiki/Henri_Etienne_Sainte-Claire_Deville).[[19]](https://en.wikipedia.org/wiki/Silicon#cite_note-19)[[20]](https://en.wikipedia.org/wiki/Silicon#cite_note-20) By [electrolyzing](https://en.wikipedia.org/wiki/Electrolysis) a mixture of [sodium chloride](https://en.wikipedia.org/wiki/Sodium_chloride) and [aluminium chloride](https://en.wikipedia.org/wiki/Aluminium_chloride) containing approximately 10% silicon, he was able to obtain a slightly impure [allotrope](https://en.wikipedia.org/wiki/Allotrope) of silicon in 1854.[[21]](https://en.wikipedia.org/wiki/Silicon#cite_note-21) Later, more cost-effective methods have been developed to isolate several allotrope forms, the most recent being [silicene](https://en.wikipedia.org/wiki/Silicene) in 2010.[[22]](https://en.wikipedia.org/wiki/Silicon#cite_note-22)[[23]](https://en.wikipedia.org/wiki/Silicon#cite_note-23) Meanwhile, research on the chemistry of silicon continued; [Friedrich Wöhler](https://en.wikipedia.org/wiki/Friedrich_W%C3%B6hler) discovered the first volatile hydrides of silicon, synthesising [trichlorosilane](https://en.wikipedia.org/wiki/Trichlorosilane) in 1857 and [silane](https://en.wikipedia.org/wiki/Silane) itself in 1858, but a detailed investigation of the [silanes](https://en.wikipedia.org/wiki/Silanes) was only carried out in the early 20th century by [Alfred Stock](https://en.wikipedia.org/wiki/Alfred_Stock), despite early speculation on the matter dating as far back as the beginnings of synthetic organic chemistry in the 1830s.[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24) Similarly, the first [organosilicon compound](https://en.wikipedia.org/wiki/Organosilicon_compound), [tetraethylsilane](https://en.wikipedia.org/w/index.php?title=Tetraethylsilane&action=edit&redlink=1), was synthesised by [Charles Friedel](https://en.wikipedia.org/wiki/Charles_Friedel) and [James Crafts](https://en.wikipedia.org/wiki/James_Crafts) in 1863, but detailed characterisation of organosilicon chemistry was only done in the early 20th century by [Frederic Kipping](https://en.wikipedia.org/wiki/Frederic_Kipping).[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11)

Starting in the 1920s, the work of [William Lawrence Bragg](https://en.wikipedia.org/wiki/William_Lawrence_Bragg) on [X-ray crystallography](https://en.wikipedia.org/wiki/X-ray_crystallography) successfully elucidated the compositions of the silicates, which had previously been known from [analytical chemistry](https://en.wikipedia.org/wiki/Analytical_chemistry) but had not yet been understood, together with [Linus Pauling](https://en.wikipedia.org/wiki/Linus_Pauling)'s development of [crystal chemistry](https://en.wikipedia.org/wiki/Crystal_chemistry) and [Victor Goldschmidt](https://en.wikipedia.org/wiki/Victor_Goldschmidt)'s development of [geochemistry](https://en.wikipedia.org/wiki/Geochemistry). The middle of the 20th century saw the development of the chemistry and industrial use of [siloxanes](https://en.wikipedia.org/wiki/Siloxane) and the growing use of [silicone](https://en.wikipedia.org/wiki/Silicone) [polymers](https://en.wikipedia.org/wiki/Polymer), [elastomers](https://en.wikipedia.org/wiki/Elastomer), and [resins](https://en.wikipedia.org/wiki/Resin). In the late 20th century, the complexity of the crystal chemistry of [silicides](https://en.wikipedia.org/wiki/Silicide) was mapped, along with the solid-state chemistry of [doped](https://en.wikipedia.org/wiki/Doping_(semiconductor)) [semiconductors](https://en.wikipedia.org/wiki/Semiconductor).[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11)

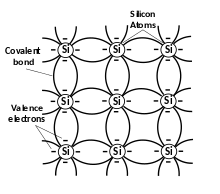
Because silicon is an important element in high-technology semiconductor devices, many places in the world bear its name. For example, [Santa Clara Valley](https://en.wikipedia.org/wiki/Santa_Clara_Valley) in California acquired the nickname [Silicon Valley](https://en.wikipedia.org/wiki/Silicon_Valley), as the element is the base material in the semiconductor industry there. Since then, many other places have been dubbed similarly, including [Silicon Forest](https://en.wikipedia.org/wiki/Silicon_Forest) in [Oregon](https://en.wikipedia.org/wiki/Oregon), [Silicon Hills](https://en.wikipedia.org/wiki/Silicon_Hills) in [Austin, Texas](https://en.wikipedia.org/wiki/Austin,_Texas), [Silicon Slopes](https://en.wikipedia.org/wiki/Silicon_Slopes) in [Salt Lake City, Utah](https://en.wikipedia.org/wiki/Salt_Lake_City,_Utah), [Silicon Saxony](https://en.wikipedia.org/wiki/Silicon_Saxony) in Germany, [Silicon Valley](https://en.wikipedia.org/wiki/Bangalore#Economy) in India, [Silicon Border](https://en.wikipedia.org/wiki/Mexicali#Silicon_Border) in [Mexicali, Mexico](https://en.wikipedia.org/wiki/Mexicali,_Mexico), [Silicon Fen](https://en.wikipedia.org/wiki/Silicon_Fen) in [Cambridge, England](https://en.wikipedia.org/wiki/Cambridge,_England), [Silicon Roundabout](https://en.wikipedia.org/wiki/Old_Street_Roundabout#Silicon_Roundabout) in London, [Silicon Glen](https://en.wikipedia.org/wiki/Silicon_Glen) in Scotland, and [Silicon Gorge](https://en.wikipedia.org/wiki/Silicon_Gorge) in [Bristol, England](https://en.wikipedia.org/wiki/Bristol,_England).[[25]](https://en.wikipedia.org/wiki/Silicon#cite_note-25)

**Characteristics**

**Physical and atomic**

[](https://en.wikipedia.org/wiki/File:Silicon-unit-cell-3D-balls.png)

Silicon crystallizes in a diamond cubic crystal structure

[](https://en.wikipedia.org/wiki/File:Covalent_bonding_in_silicon.svg)

Covalent bonding in silicon

A silicon atom has fourteen [electrons](https://en.wikipedia.org/wiki/Electrons). In the ground state, they are arranged in the electron configuration [Ne]3s23p2. Of these, four are [valence electrons](https://en.wikipedia.org/wiki/Valence_electron), occupying the 3s orbital and two of the 3p orbitals. Like the other members of its group, the lighter [carbon](https://en.wikipedia.org/wiki/Carbon) and the heavier [germanium](https://en.wikipedia.org/wiki/Germanium), [tin](https://en.wikipedia.org/wiki/Tin), and [lead](https://en.wikipedia.org/wiki/Lead), it has the same number of valence electrons as valence orbitals: hence, it can complete its [octet](https://en.wikipedia.org/wiki/Octet_rule) and obtain the stable [noble gas](https://en.wikipedia.org/wiki/Noble_gas) configuration of [argon](https://en.wikipedia.org/wiki/Argon) by forming [sp3 hybrid orbitals](https://en.wikipedia.org/wiki/Orbital_hybridization), forming tetrahedral SiX4 derivatives where the central silicon atom shares an electron pair with each of the four atoms it is bonded to.[[26]](https://en.wikipedia.org/wiki/Silicon#cite_note-King0-26) The first four [ionisation energies](https://en.wikipedia.org/wiki/Ionisation_energy) of silicon are 786.3, 1576.5, 3228.3, and 4354.4 kJ/mol respectively; these figures are high enough to preclude the possibility of simple cationic chemistry for the element. Following [periodic trends](https://en.wikipedia.org/wiki/Periodic_trend), its single-bond covalent radius of 117.6 pm is intermediate between those of carbon (77.2 pm) and germanium (122.3 pm). The hexacoordinate ionic radius of silicon may be considered to be 40 pm, although this must be taken as a purely notional figure given the lack of a simple Si4+ cation in reality.[[27]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood372-27)

At standard temperature and pressure, silicon is a shiny [semiconductor](https://en.wikipedia.org/wiki/Semiconductor) with a bluish-grey metallic lustre; as typical for semiconductors, its resistivity drops as temperature rises. This arises because silicon has a small energy gap between its highest occupied energy levels (the valence band) and the lowest unoccupied ones (the conduction band). The [Fermi level](https://en.wikipedia.org/wiki/Fermi_level) is about halfway between the [valence and conduction bands](https://en.wikipedia.org/wiki/Valence_and_conduction_bands) and is the energy at which a state is as likely to be occupied by an electron as not. Hence pure silicon is an insulator at room temperature. However, doping silicon with a [pnictogen](https://en.wikipedia.org/wiki/Pnictogen) such as [phosphorus](https://en.wikipedia.org/wiki/Phosphorus), [arsenic](https://en.wikipedia.org/wiki/Arsenic), or [antimony](https://en.wikipedia.org/wiki/Antimony) introduces one extra electron per dopant and these may then be excited into the conduction band either thermally or photolytically, creating an [n-type semiconductor](https://en.wikipedia.org/wiki/Extrinsic_semiconductor#N-type_semiconductors). Similarly, doping silicon with a [group 13 element](https://en.wikipedia.org/wiki/Boron_group) such as [boron](https://en.wikipedia.org/wiki/Boron), [aluminium](https://en.wikipedia.org/wiki/Aluminium), or [gallium](https://en.wikipedia.org/wiki/Gallium) results in the introduction of acceptor levels that trap electrons that may be excited from the filled valence band, creating a [p-type semiconductor](https://en.wikipedia.org/wiki/Extrinsic_semiconductor#P-type_semiconductors). Joining n-type silicon to p-type silicon creates a [p-n junction](https://en.wikipedia.org/wiki/P-n_junction) with a common Fermi level; electrons flow from n to p, while holes flow from p to n, creating a voltage drop. This p-n junction thus acts as a [diode](https://en.wikipedia.org/wiki/Diode) that can rectify alternating current that allows current to pass more easily one way than the other. A [transistor](https://en.wikipedia.org/wiki/Transistor) is an n-p-n junction, with a thin layer of weakly p-type silicon between two n-type regions. Biasing the emitter through a small forward voltage and the collector through a large reverse voltage allows the transistor to act as a [triode](https://en.wikipedia.org/wiki/Triode) amplifier.[[28]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood331-28)

Silicon crystallises in a giant covalent structure at standard conditions, specifically in a [diamond cubic](https://en.wikipedia.org/wiki/Diamond_cubic) lattice. It thus has a high melting point of 1414 °C, as a lot of energy is required to break the strong covalent bonds and melt the solid. It is not known to have any allotropes at standard pressure, but several other crystal structures are known at higher pressures. The general trend is one of increasing [coordination number](https://en.wikipedia.org/wiki/Coordination_number) with pressure, culminating in a [hexagonal close-packed](https://en.wikipedia.org/wiki/Hexagonal_close-packed) allotrope at about 40 [gigapascals](https://en.wikipedia.org/wiki/Gigapascal) known as Si–VII (the standard modification being Si–I). Silicon boils at 3265 °C: this, while high, is still lower than the temperature at which its lighter congener [carbon](https://en.wikipedia.org/wiki/Carbon) sublimes (3642 °C) and silicon similarly has a lower [heat of vaporisation](https://en.wikipedia.org/wiki/Heat_of_vaporisation) than carbon, consistent with the fact that the Si–Si bond is weaker than the C–C bond.[[28]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood331-28)

**Isotopes**

Main article: [Isotopes of silicon](https://en.wikipedia.org/wiki/Isotopes_of_silicon)

Naturally occurring silicon is composed of three stable [isotopes](https://en.wikipedia.org/wiki/Isotope), 28Si (92.23%), 29Si (4.67%), and 30Si (3.10%).[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) Out of these, only 29Si is of use in [NMR](https://en.wikipedia.org/wiki/NMR) and [EPR spectroscopy](https://en.wikipedia.org/wiki/EPR_spectroscopy),[[30]](https://en.wikipedia.org/wiki/Silicon#cite_note-30) as it is the only one with a nuclear spin (*I* = 1/2).[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31) All three are produced in stars through the [oxygen-burning process](https://en.wikipedia.org/wiki/Oxygen-burning_process), with 28Si being made as part of the [alpha process](https://en.wikipedia.org/wiki/Alpha_process) and hence the most abundant. The fusion of 28Si with alpha particles by [photodisintegration](https://en.wikipedia.org/wiki/Photodisintegration) rearrangement in stars is known as the [silicon-burning process](https://en.wikipedia.org/wiki/Silicon-burning_process); it is the last stage of [stellar nucleosynthesis](https://en.wikipedia.org/wiki/Stellar_nucleosynthesis) before the rapid collapse and violent explosion of the star in question in a [type II supernova](https://en.wikipedia.org/wiki/Type_II_supernova).[[32]](https://en.wikipedia.org/wiki/Silicon#cite_note-Cameron-32)

Twenty [radioisotopes](https://en.wikipedia.org/wiki/Radioisotopes) have been characterized, the two stablest being 32Si with a [half-life](https://en.wikipedia.org/wiki/Half-life) of about 150 years, and 31Si with a half-life of 2.62 hours.[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) All the remaining [radioactive](https://en.wikipedia.org/wiki/Radioactive_decay) isotopes have half-lives that are less than seven seconds, and the majority of these have half-lives that are less than one tenth of a second.[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) Silicon does not have any known [nuclear isomers](https://en.wikipedia.org/wiki/Nuclear_isomer).[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) 32Si undergoes low-energy [beta decay](https://en.wikipedia.org/wiki/Beta_decay) to [32P](https://en.wikipedia.org/wiki/Phosphorus-32) and then stable 32[S](https://en.wikipedia.org/wiki/Sulfur). 31Si may be produced by the [neutron activation](https://en.wikipedia.org/wiki/Neutron_activation) of natural silicon and is thus useful for quantitative analysis; it can be easily detected by its characteristic beta decay to stable 31[P](https://en.wikipedia.org/wiki/Phosphorus), in which the emitted electron carries up to 1.48 [MeV](https://en.wikipedia.org/wiki/Electronvolt) of energy.[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31)

The known isotopes of silicon range in [mass number](https://en.wikipedia.org/wiki/Mass_number) from 22 to 44.[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) The most common [decay mode](https://en.wikipedia.org/wiki/Decay_mode) of the isotopes with mass numbers lower than the three stable isotopes is [inverse beta decay](https://en.wikipedia.org/wiki/Inverse_beta_decay), primarily forming aluminium isotopes (13 protons) as [decay products](https://en.wikipedia.org/wiki/Decay_product).[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29) The most common decay mode for the heavier unstable isotopes is beta decay, primarily forming phosphorus isotopes (15 protons) as decay products.[[29]](https://en.wikipedia.org/wiki/Silicon#cite_note-NNDC-29)

**Chemistry and compounds**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| C–X and Si–X bond energies (kJ/mol)[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24) | | | | | | | | | |
| **X =** | **C** | **Si** | **H** | **F** | **Cl** | **Br** | **I** | **O–** | **N<** |
| **C–X** | 368 | 360 | 435 | 453 | 351 | 293 | 216 | ~360 | ~305 |
| **Si–X** | 360 | 340 | 393 | 565 | 381 | 310 | 234 | 452 | 322 |

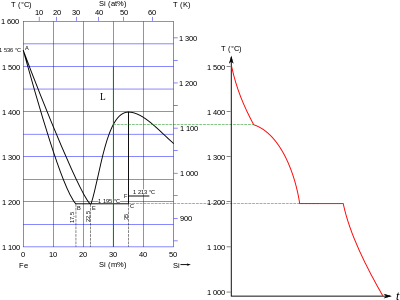
Crystalline bulk silicon is rather inert, but becomes more reactive at high temperatures. Like its neighbour aluminium, silicon forms a thin, continuous surface layer of [silicon dioxide](https://en.wikipedia.org/wiki/Silicon_dioxide) (SiO2) that protects the metal from oxidation. Thus silicon does not measurably react with the air below 900 °C, but formation of the [vitreous](https://en.wikipedia.org/wiki/Vitreous_lustre) dioxide rapidly increases between 950 °C and 1160 °C and when 1400 °C is reached, atmospheric [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) also reacts to give the nitrides SiN and Si3N4. Silicon reacts with gaseous [sulfur](https://en.wikipedia.org/wiki/Sulfur) at 600 °C and gaseous [phosphorus](https://en.wikipedia.org/wiki/Phosphorus) at 1000 °C. This oxide layer nevertheless does not prevent reaction with the [halogens](https://en.wikipedia.org/wiki/Halogen); [fluorine](https://en.wikipedia.org/wiki/Fluorine) attacks silicon vigorously at room temperature, [chlorine](https://en.wikipedia.org/wiki/Chlorine) does so at about 300 °C, and [bromine](https://en.wikipedia.org/wiki/Bromine) and [iodine](https://en.wikipedia.org/wiki/Iodine) at about 500 °C. Silicon does not react with most aqueous acids, but is oxidised and fluorinated by a mixture of concentrated [nitric acid](https://en.wikipedia.org/wiki/Nitric_acid) and [hydrofluoric acid](https://en.wikipedia.org/wiki/Hydrofluoric_acid); it readily dissolves in hot aqueous alkali to form [silicates](https://en.wikipedia.org/wiki/Silicate). At high temperatures, silicon also reacts with [alkyl halides](https://en.wikipedia.org/wiki/Alkyl_halide); this reaction may be catalysed by [copper](https://en.wikipedia.org/wiki/Copper) to directly synthesise [organosilicon](https://en.wikipedia.org/wiki/Organosilicon) chlorides as precursors to [silicone](https://en.wikipedia.org/wiki/Silicone) polymers. Upon melting, silicon becomes extremely reactive, alloying with most metals to form [silicides](https://en.wikipedia.org/wiki/Silicide), and reducing most metal oxides because the [heat of formation](https://en.wikipedia.org/wiki/Heat_of_formation) of silicon dioxide is so large. As a result, containers for liquid silicon must be made of [refractory](https://en.wikipedia.org/wiki/Refractory), unreactive materials such as [zirconium dioxide](https://en.wikipedia.org/wiki/Zirconium_dioxide) or group 4, 5, and 6 borides.[[28]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood331-28)

Tetrahedral coordination is a major structural motif in silicon chemistry just as it is for carbon chemistry. However, the 3p subshell is rather more diffuse than the 2p subshell and does not hybridise so well with the 3s subshell. As a result, the chemistry of silicon and its heavier congeners shows significant differences from that of carbon,[[33]](https://en.wikipedia.org/wiki/Silicon#cite_note-Kaupp-33) and thus octahedral coordination is also significant.[[28]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood331-28) For example, the [electronegativity](https://en.wikipedia.org/wiki/Electronegativity) of silicon (1.90) is much less than that of carbon (2.55), because the valence electrons of silicon are further from the nucleus than those of carbon and hence experience smaller electrostatic forces of attraction from the nucleus. The poor overlap of 3p orbitals also results in a much lower tendency toward [catenation](https://en.wikipedia.org/wiki/Catenation) (formation of Si–Si bonds) for silicon than for carbon, due to the concomitant weakening of the Si–Si bond compared to the C–C bond:[[34]](https://en.wikipedia.org/wiki/Silicon#cite_note-King43-34) the average Si–Si bond energy is approximately 226 kJ/mol, compared to a value of 356 kJ/mol for the C–C bond.[[35]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood374-35) This results in multiply bonded silicon compounds generally being much less stable than their carbon counterparts, an example of the [double bond rule](https://en.wikipedia.org/wiki/Double_bond_rule). On the other hand, the presence of 3d orbitals in the valence shell of silicon suggests the possibility of [hypervalence](https://en.wikipedia.org/wiki/Hypervalence), as seen in five and six-coordinate derivatives of silicon such as SiX−  
5 and SiF2−  
6.[[34]](https://en.wikipedia.org/wiki/Silicon#cite_note-King43-34) Lastly, because of the increasing energy gap between the valence s and p orbitals as the group is descended, the divalent state grows in importance from carbon to lead, so that a few unstable divalent compounds are known for silicon; this lowering of the main oxidation state, in tandem with increasing atomic radii, results in an increase of metallic character down the group. Silicon already shows some incipient metallic behavior, particularly in the behavior of its oxide compounds and its reaction with acids as well as bases (though this takes some effort), and is hence often referred to as a [metalloid](https://en.wikipedia.org/wiki/Metalloid) rather than a nonmetal.[[34]](https://en.wikipedia.org/wiki/Silicon#cite_note-King43-34) However, metallicity does not become clear in group 14 until germanium and dominant until tin, with the growing importance of the lower +2 oxidation state.[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11)

Silicon shows clear differences from carbon. For example, [organic chemistry](https://en.wikipedia.org/wiki/Organic_chemistry) has very few analogies with silicon chemistry, while [silicate](https://en.wikipedia.org/wiki/Silicate) minerals have a structural complexity unseen in [oxocarbons](https://en.wikipedia.org/wiki/Oxocarbon).[[11]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood328-11) Silicon tends to resemble germanium far more than it does carbon, and this resemblance is enhanced by the [d-block contraction](https://en.wikipedia.org/wiki/D-block_contraction), resulting in the size of the germanium atom being much closer to that of the silicon atom than periodic trends would predict.[[27]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood372-27) Nevertheless, there are still some differences because of the growing importance of the divalent state in germanium compared to silicon, which result in germanium being significantly more metallic than silicon. Additionally, the lower Ge–O bond strength compared to the Si–O bond strength results in the absence of "germanone" polymers that would be analogous to [silicone](https://en.wikipedia.org/wiki/Silicone) polymers.[[35]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood374-35)

**Silicides**

Main articles: [Silicide](https://en.wikipedia.org/wiki/Silicide) and [Binary compounds of silicon](https://en.wikipedia.org/wiki/Binary_compounds_of_silicon)

[](https://en.wikipedia.org/wiki/File:Diagramme_binaire_Fe_Si_analyse_thermique_30.svg)

Phase diagram of the Fe–Si system

Many metal [silicides](https://en.wikipedia.org/wiki/Silicide) are known, most of which have formulae that cannot be explained through simple appeals to [valence](https://en.wikipedia.org/wiki/Valence_(chemistry)): their bonding ranges from [metallic](https://en.wikipedia.org/wiki/Metallic_bond) to [ionic](https://en.wikipedia.org/wiki/Ionic_bond) and [covalent](https://en.wikipedia.org/wiki/Covalent_bond). Some known stoichiometries are M6Si, M5Si, M4Si, M15Si4, M3Si, M5Si2, M2Si, M5Si3, M3Si2, MSi, M2Si3, MSi2, MSi3, and MSi6. They are structurally more similar to the [borides](https://en.wikipedia.org/wiki/Boride) than the [carbides](https://en.wikipedia.org/wiki/Carbide), in keeping with the [diagonal relationship](https://en.wikipedia.org/wiki/Diagonal_relationship) between [boron](https://en.wikipedia.org/wiki/Boron) and silicon, although the larger size of silicon than boron means that exact structural analogies are few and far between. The heats of formation of the silicides are usually similar to those of the borides and carbides of the same elements, but they usually melt at lower temperatures.[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36) Silicides are known for all stable elements in groups 1–10, with the exception of [beryllium](https://en.wikipedia.org/wiki/Beryllium): in particular, [uranium](https://en.wikipedia.org/wiki/Uranium) and the transition metals of groups 4–10 show the widest range of stoichiometries. Except for [copper](https://en.wikipedia.org/wiki/Copper), the metals in groups 11–15 do not form silicides. Instead, most form [eutectic mixtures](https://en.wikipedia.org/wiki/Eutectic_mixture), although the heaviest [post-transition metals](https://en.wikipedia.org/wiki/Post-transition_metal) [mercury](https://en.wikipedia.org/wiki/Mercury_(element)), [thallium](https://en.wikipedia.org/wiki/Thallium), [lead](https://en.wikipedia.org/wiki/Lead), and [bismuth](https://en.wikipedia.org/wiki/Bismuth) are completely immiscible with liquid silicon.[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36)

Usually, silicides are prepared by direct reaction of the elements. For example, the [alkali metals](https://en.wikipedia.org/wiki/Alkali_metal) and [alkaline earth metals](https://en.wikipedia.org/wiki/Alkaline_earth_metal) react with silicon or silicon oxide to give silicides. Nevertheless, even with these highly electropositive elements true silicon anions are not obtainable, and most of these compounds are semiconductors. For example, the alkali metal silicides (M+  
)  
4(E4−  
4) contain pyramidal tricoordinate silicon in the Si4−  
4 anion, isoeelctronic with [white phosphorus](https://en.wikipedia.org/wiki/White_phosphorus), P4.[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36)[[37]](https://en.wikipedia.org/wiki/Silicon#cite_note-King45-37) Metal-rich silicides tend to have isolated silicon atoms (e. g. Cu5Si); with increasing silicon content, catenation increases, resulting in isolated clusters of two (e. g. U3Si2) or four silicon atoms (e. g. [K+]4[Si4]4−) at first, followed by chains (e. g. CaSi), layers (e. g. CaSi2), or three-dimensional networks of silicon atoms spanning space (e. g. α-ThSi2) as the silicon content rises even higher.[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36)

The silicides of the group 1 and 2 metals usually are more reactive than the transition metal silicides. The latter usually do not react with aqueous reagents, except for [hydrofluoric acid](https://en.wikipedia.org/wiki/Hydrofluoric_acid); however, they do react with much more aggressive reagents such as liquid [potassium hydroxide](https://en.wikipedia.org/wiki/Potassium_hydroxide), or gaseous fluorine or [chlorine](https://en.wikipedia.org/wiki/Chlorine) when red-hot. The pre-transition metal silicides instead readily react with water and aqueous acids, usually producing hydrogen or silanes:[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36)

Na2Si + 3 H2O → Na2SiO3 + 3 H2

Mg2Si + 2 H2SO4 → 2 MgSO4 + SiH4

Products often vary with the stoichiometry of the silicide reactant. For example, Ca2Si is polar and non-conducting and has the anti-PbCl2 structure with single isolated silicon atoms, and reacts with water to produce [calcium hydroxide](https://en.wikipedia.org/wiki/Calcium_hydroxide), hydrated silicon dioxide, and hydrogen gas. CaSi with its zigzag chains of silicon atoms instead reacts to give silanes and polymeric SiH2, while CaSi2 with its puckered layers of silicon atoms does not react with water, but will react with dilute hydrochloric acid: the product is a yellow polymeric solid with stoichiometry Si2H2O.[[36]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood335-36)

**Silanes**

Main article: [Silanes](https://en.wikipedia.org/wiki/Silanes)

Speculation on silicon hydride chemistry started in the 1830s, contemporary with the development of synthetic [organic chemistry](https://en.wikipedia.org/wiki/Organic_chemistry). [Silane](https://en.wikipedia.org/wiki/Silane) itself, as well as [trichlorosilane](https://en.wikipedia.org/wiki/Trichlorosilane), were first synthesised by [Friedrich Wöhler](https://en.wikipedia.org/wiki/Friedrich_W%C3%B6hler) and [Heinrich Buff](https://en.wikipedia.org/w/index.php?title=Heinrich_Buff&action=edit&redlink=1) in 1857 by reacting aluminium–silicon alloys with [hydrochloric acid](https://en.wikipedia.org/wiki/Hydrochloric_acid), and characterised as SiH4 and SiHCl3 by [Charles Friedel](https://en.wikipedia.org/wiki/Charles_Friedel) and [Albert Ladenburg](https://en.wikipedia.org/wiki/Albert_Ladenburg) in 1867. [Disilane](https://en.wikipedia.org/wiki/Disilane) (Si2H6) followed in 1902, when it was first made by [Henri Moissan](https://en.wikipedia.org/wiki/Henri_Moissan) and [Samuel Smiles](https://en.wikipedia.org/wiki/Samuel_Smiles) by the [protonolysis](https://en.wikipedia.org/wiki/Protonolysis) of [magnesium silicides](https://en.wikipedia.org/wiki/Magnesium_silicide). Further investigation had to wait until 1916 because of the great reactivity and thermal instability of the silanes; it was then that [Alfred Stock](https://en.wikipedia.org/wiki/Alfred_Stock) began to study silicon hydrides in earnest with new greaseless vacuum techniques, as they were found as contaminants of his focus, the [boron hydrides](https://en.wikipedia.org/wiki/Borane). The names *silanes* and *boranes* are his, based on analogy with the [alkanes](https://en.wikipedia.org/wiki/Alkane).[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24)[[38]](https://en.wikipedia.org/wiki/Silicon#cite_note-38)[[39]](https://en.wikipedia.org/wiki/Silicon#cite_note-39) The Moissan and Smiles method of preparation of silanes and silane derivatives via protonolysis of metal silicides is still used, although the yield is lowered by the hydrolysis of the products that occurs simultaneously, so that the preferred route today is to treat substituted silanes with hydride reducing agents such as [lithium aluminium hydride](https://en.wikipedia.org/wiki/Lithium_aluminium_hydride) in etheric solutions at low temperatures. Direct reaction of HX or RX with silicon, possibly with a catalyst such as copper, is also a viable method of producing substituted silanes.[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24)

The silanes comprise a [homologous series](https://en.wikipedia.org/wiki/Homologous_series) of silicon hydrides with a general formula of Si*n*H2*n*+ 2. They are all strong [reducing agents](https://en.wikipedia.org/wiki/Reducing_agent). Unbranched and branched trains are known up to *n*=8, and the cycles Si5H10 and Si6H12 are also known. The first two, silane and disilane, are colourless gases; the heavier members of the series are volatile liquids. All silanes are very reactive and catch fire or explode spontaneously in air. They become less thermally stable with room temperature, so that only silane is indefinitely stable at room temperature, although disilane does not decompose very quickly (only 2.5% of a sample decomposes after the passage of eight months).[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24) They decompose to form polymeric [polysilicon hydride](https://en.wikipedia.org/wiki/Polysilicon_hydride) and hydrogen gas.[[40]](https://en.wikipedia.org/wiki/Silicon#cite_note-40)[[41]](https://en.wikipedia.org/wiki/Silicon#cite_note-41) As expected from the difference in atomic weight, the silanes are less volatile than the corresponding alkanes and boranes, but more so than the corresponding germanes. They are much more reactive than the corresponding alkanes, because of the larger radius of silicon compared to carbon facilitating [nucleophilic attack](https://en.wikipedia.org/wiki/Nucleophile) at the silicon, the greater polarity of the Si–H bond compared to the C–H bond, and the ability of silicon to expand its octet and hence form adducts and lower the reaction's [activation energy](https://en.wikipedia.org/wiki/Activation_energy).[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24)

Silane [pyrolysis](https://en.wikipedia.org/wiki/Pyrolysis) gives polymeric species and finally elemental silicon and hydrogen; indeed ultrapure silicon is commercially produced by the pyrolysis of silane. While the thermal decomposition of alkanes starts by the breaking of a C–H or C–C bond and the formation of radical intermediates, polysilanes decompose by eliminating [silylenes](https://en.wikipedia.org/wiki/Silylene) :SiH2 or :SiHR, as the activation energy of this process (~210 kJ/mol) is much less than the Si–Si and Si–H bond energies. While pure silanes do not react with pure water or dilute acids, traces of alkali catalyse immediate hydrolysis to hydrated silicon dioxide. If the reaction is carried out in [methanol](https://en.wikipedia.org/wiki/Methanol), controlled solvolysis results in the products SiH2(OMe)2, SiH(OMe)3, and Si(OMe)4. The Si–H bond also adds to [alkenes](https://en.wikipedia.org/wiki/Alkene), a reaction which proceeds slowly and speeds up with increasing substitution of the silane involved. At 450 °C, silane participates in an [addition reaction](https://en.wikipedia.org/wiki/Addition_reaction) with [acetone](https://en.wikipedia.org/wiki/Acetone), as well as a [ring-opening reaction](https://en.wikipedia.org/wiki/Ring-opening_reaction) with [ethylene oxide](https://en.wikipedia.org/wiki/Ethylene_oxide). Direct reaction of the silanes with chlorine or bromine results in explosions at room temperature, but the reaction of silane with bromine at −80 °C is controlled and yields bromosilane and dibromosilane. The monohalosilanes may be formed by reacting silane with the appropriate [hydrogen halide](https://en.wikipedia.org/wiki/Hydrogen_halide) with an Al2X6 catalyst, or by reacting silane with a solid [silver](https://en.wikipedia.org/wiki/Silver) halide in a heated flow reactor:[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24)

SiH4 + 2 AgCl 260 °C→  SiH3Cl + HCl + 2 Ag

Among the derivatives of silane, [iodosilane](https://en.wikipedia.org/wiki/Iodosilane) (SiH3I) and [potassium silanide](https://en.wikipedia.org/w/index.php?title=Potassium_silanide&action=edit&redlink=1) (KSiH3) are very useful synthetic intermediates in the production of more complicated silicon-containing compounds: the latter is a colourless crystalline ionic solid containing K+ cations and SiH−  
3 anions in the [NaCl](https://en.wikipedia.org/wiki/Sodium_chloride) structure, and is made by the reduction of silane by [potassium](https://en.wikipedia.org/wiki/Potassium) metal.[[42]](https://en.wikipedia.org/wiki/Silicon#cite_note-King47-42) Additionally, the reactive hypervalent species SiH−  
5 is also known.[[24]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood337-24) With suitable organic substituents it is possible to produce stable polysilanes: they have surprisingly high electric conductivities, arising from [sigma](https://en.wikipedia.org/wiki/Sigma_bond) delocalisation of the electrons in the chain.[[43]](https://en.wikipedia.org/wiki/Silicon#cite_note-43)

**Halides**

Silicon and [silicon carbide](https://en.wikipedia.org/wiki/Silicon_carbide) readily react with all four stable halogens, forming the colourless, reactive, and volatile silicon tetrahalides.[[44]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood340-44) [Silicon tetrafluoride](https://en.wikipedia.org/wiki/Silicon_tetrafluoride) also may be made by fluorinating the other silicon halides, and is produced by the attack of [hydrofluoric acid](https://en.wikipedia.org/wiki/Hydrofluoric_acid) on glass.[[45]](https://en.wikipedia.org/wiki/Silicon#cite_note-King48-45) Heating two different tetrahalides together also produce a random mixture of mixed halides, which may also be produced by halogen exchange reactions. The melting and boiling points of these species usually rise with increasing atomic weight, though there are many exceptions: for example, the melting and boiling points drop as one passes from SiFBr3 through SiFClBr2 to SiFCl2Br. The shift from the hypoelectronic elements in group 13 and earlier to the group 14 elements is illustrated by the change from an infinite ionic structure in [aluminium fluoride](https://en.wikipedia.org/wiki/Aluminium_fluoride) to a lattice of simple covalent silicon tetrafluoride molecules, as dictated by the lower electronegativity of aluminium than silicon, the stoichiometry (the +4 oxidation state being too high for true ionicity), and the smaller size of the silicon atom compared to the aluminium atom.[[44]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood340-44) [Silicon tetrachloride](https://en.wikipedia.org/wiki/Silicon_tetrachloride) is manufactured on a huge scale as a precursor to the production of pure silicon, silicon dioxide, and some silicon [esters](https://en.wikipedia.org/wiki/Ester).[[44]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood340-44) The silicon tetrahalides hydrolyse readily in water, unlike the carbon tetrahalides, again because of the larger size of the silicon atom rendering it more open to nucleophilic attack and the ability of the silicon atom to expand its octet which carbon lacks.[[45]](https://en.wikipedia.org/wiki/Silicon#cite_note-King48-45) The reaction of silicon fluoride with excess [hydrofluoric acid](https://en.wikipedia.org/wiki/Hydrofluoric_acid) produces the octahedral [hexafluorosilicate](https://en.wikipedia.org/wiki/Hexafluorosilicic_acid) anion SiF2−  
6.[[45]](https://en.wikipedia.org/wiki/Silicon#cite_note-King48-45)

Analogous to the silanes, halopolysilanes Si*n*X2*n*+ 2 also are known. While catenation in carbon compounds is maximised in the hydrogen compounds rather than the halides, the opposite is true for silicon, so that the halopolysilanes are known up to at least Si14F30, Si6Cl14, and Si4Br10. A suggested explanation for this phenomenon is the compensation for the electron loss of silicon to the more electronegative halogen atoms by [pi backbonding](https://en.wikipedia.org/wiki/Pi_backbonding) from the filled pπ orbitals on the halogen atoms to the empty dπ orbitals on silicon: this is similar to the situation of [carbon monoxide](https://en.wikipedia.org/wiki/Carbon_monoxide) in [metal carbonyl complexes](https://en.wikipedia.org/wiki/Metal_carbonyl_complex) and explains their stability. These halopolysilanes may be produced by [comproportionation](https://en.wikipedia.org/wiki/Comproportionation) of silicon tetrahalides with elemental silicon, or by condensation of lighter halopolysilanes ([trimethylammonium](https://en.wikipedia.org/wiki/Trimethylammonium) being a useful catalyst for this reaction).[[44]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood340-44)

**Silica**

[Silicon dioxide](https://en.wikipedia.org/wiki/Silicon_dioxide) (SiO2), also known as silica, is one of the best-studied compounds, second only to [water](https://en.wikipedia.org/wiki/Properties_of_water). Twelve different crystal modifications of silica are known, the most common being α-[quartz](https://en.wikipedia.org/wiki/Quartz), a major constituent of many rocks such as [granite](https://en.wikipedia.org/wiki/Granite) and [sandstone](https://en.wikipedia.org/wiki/Sandstone). It also is known to occur in a pure form as [rock crystal](https://en.wikipedia.org/wiki/Rock_crystal); impure forms are known as [rose quartz](https://en.wikipedia.org/wiki/Rose_quartz), [smoky quartz](https://en.wikipedia.org/wiki/Smoky_quartz), [morion](https://en.wikipedia.org/wiki/Morion_(mineral)), [amethyst](https://en.wikipedia.org/wiki/Amethyst), and [citrine](https://en.wikipedia.org/wiki/Citrine_quartz). Some poorly crystalline forms of quartz are also known, such as [chalcedony](https://en.wikipedia.org/wiki/Chalcedony), [chrysoprase](https://en.wikipedia.org/wiki/Chrysoprase), [carnelian](https://en.wikipedia.org/wiki/Carnelian), [agate](https://en.wikipedia.org/wiki/Agate), [onyx](https://en.wikipedia.org/wiki/Onyx), [jasper](https://en.wikipedia.org/wiki/Jasper), [heliotrope](https://en.wikipedia.org/wiki/Heliotrope_(mineral)), and [flint](https://en.wikipedia.org/wiki/Flint). Other modifications of silicon dioxide are known in some other minerals such as [tridymite](https://en.wikipedia.org/wiki/Tridymite) and [cristobalite](https://en.wikipedia.org/wiki/Cristobalite), as well as the much less common [coesite](https://en.wikipedia.org/wiki/Coesite) and [stishovite](https://en.wikipedia.org/wiki/Stishovite). Biologically generated forms are also known as [kieselguhr](https://en.wikipedia.org/wiki/Kieselguhr) and [diatomaceous earth](https://en.wikipedia.org/wiki/Diatomaceous_earth). [Vitreous](https://en.wikipedia.org/wiki/Vitrification) silicon dioxide is known as [tektites](https://en.wikipedia.org/wiki/Tektite), and [obsidian](https://en.wikipedia.org/wiki/Obsidian), and rarely as [lechatelierite](https://en.wikipedia.org/wiki/Lechatelierite). Some synthetic forms are known as [keatite](https://en.wikipedia.org/wiki/Keatite) and [W-silica](https://en.wikipedia.org/w/index.php?title=W-silica&action=edit&redlink=1). [Opals](https://en.wikipedia.org/wiki/Opal) are composed of complicated crystalline aggregates of partially hydrated silicon dioxide.[[46]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood342-46)

* [](https://en.wikipedia.org/wiki/File:Quartz,_Tibet.jpg)

Quartz

* [](https://en.wikipedia.org/wiki/File:USDA_Mineral_Sandstone_93c3955.jpg)

Sandstone

* [](https://en.wikipedia.org/wiki/File:USDA_Mineral_Smokey_Quartz_93v3949.jpg)

Smoky quartz

* [](https://en.wikipedia.org/wiki/File:Amethyst._Magaliesburg,_South_Africa.jpg)

Amethyst

* [](https://en.wikipedia.org/wiki/File:Citrine-sample2.jpg)

Citrine

* [](https://en.wikipedia.org/wiki/File:Quartz_-_Agateplate,_redbrown-white.jpg)

Agate

* [](https://en.wikipedia.org/wiki/File:Chryzopras_Polsko.jpg)

Chrysoprase

* [](https://en.wikipedia.org/wiki/File:Onyx.jpg)

Onyx

* [](https://en.wikipedia.org/wiki/File:Jasper_outcrop_in_the_Bucegi_Mountains.jpg)

Jasper

* [](https://en.wikipedia.org/wiki/File:Quarz_-_Heliotrop_(Blutjaspis).JPG)

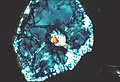
Heliotrope

* [](https://en.wikipedia.org/wiki/File:Tridymite_tabulars_-_Ochtendung,_Eifel,_Germany.jpg)

Tridymite

* [](https://en.wikipedia.org/wiki/File:Cristobalite-Fayalite-40048.jpg)

Cristobalite

* [](https://en.wikipedia.org/wiki/File:Coesiteimage.jpg)

Coesite

* [](https://en.wikipedia.org/wiki/File:Lechatelierite_created_by_high_voltage_power_line_arcing_on_rocky_soil-_2014-02-12_23-02.jpg)

Lechatelierite

Most crystalline forms of silica are made of infinite arrangements of {SiO4} tetrahedra (with Si at the center) connected at their corners, with each oxygen atom linked to two silicon atoms. In the thermodynamically stable room-temperature form, α-quartz, these tetrahedra are linked in intertwined helical chains with two different Si–O distances (159.7 and 161.7 pm) with a Si–O–Si angle of 144°. These helices can be either left- or right-handed, so that individual α-quartz crystals are optically active. At 537 °C, this transforms quickly and reversibly into the similar β-quartz, with a change of the Si–O–Si angle to 155° but a retention of handedness. Further heating to 867 °C results in another reversible phase transition to β-tridymite, in which some Si–O bonds are broken to allow for the arrangement of the {SiO4} tetrahedra into a more open and less dense hexagonal structure. This transition is slow and hence tridymite occurs as a metastable mineral even below this transition temperature; when cooled to about 120 °C it quickly and reversibly transforms by slight displacements of individual silicon and oxygen atoms to α-tridymite, similarly to the transition from α-quartz to β-quartz. β-tridymite slowly transforms to cubic β-cristobalite at about 1470 °C, which once again exists metastably below this transition temperature and transforms at 200–280 °C to α-cristobalite via small atomic displacements. β-cristobalite melts at 1713 °C; the freezing of silica from the melt is quite slow and [vitrification](https://en.wikipedia.org/wiki/Vitrification), or the formation of a [glass](https://en.wikipedia.org/wiki/Glass), is likely to occur instead. In vitreous silica, the {SiO4} tetrahedra remain corner-connected, but the symmetry and periodicity of the crystalline forms are lost. Because of the slow conversions between these three forms, it is possible upon rapid heating to melt β-quartz (1550 °C) or β-tridymite (1703 °C). Silica boils at approximately 2800 °C. Other high-pressure forms of silica are known, such as coesite and stishovite: these are known in nature, formed under the shock pressure of a meteorite impact and then rapidly quenched to preserve the crystal structure. Similar melting and cooling of silica occurs following [lightning](https://en.wikipedia.org/wiki/Lightning) strikes, forming glassy [lechatelierite](https://en.wikipedia.org/wiki/Lechatelierite). W-silica is an unstable low-density form involving {SiO4} tetrahedra sharing opposite edges instead of corners, forming parallel chains similarly to [silicon disulfide](https://en.wikipedia.org/wiki/Silicon_disulfide) (SiS2) and [silicon diselenide](https://en.wikipedia.org/w/index.php?title=Silicon_diselenide&action=edit&redlink=1) (SiSe2): it quickly returns to forming amorphous silica with heat or traces of water.[[46]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood342-46)

Condensed polysilicic acid

Silica is rather inert chemically. It is not attacked by any acids other than hydrofluoric acid. However, it slowly dissolves in hot concentrated alkalis, and does so rather quickly in fused metal hydroxides or carbonates, to give metal silicates. Among the elements, it is attacked only by fluorine at room temperature to form silicon tetrafluoride: hydrogen and carbon also react, but require temperatures over 1000 °C to do so. Silica nevertheless reacts with many metal and [metalloid](https://en.wikipedia.org/wiki/Metalloid) oxides to form a wide variety of compounds important in the glass and ceramic industries above all, but also have many other uses: for example, [sodium silicate](https://en.wikipedia.org/wiki/Sodium_silicate) is often used in detergents due to its [buffering](https://en.wikipedia.org/wiki/Buffer_(chemistry)), [saponifying](https://en.wikipedia.org/wiki/Saponification), and [emulsifying](https://en.wikipedia.org/wiki/Emulsification) properties.[[46]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood342-46)

**Silicic acids**

Adding water to silica drops its melting point by around 800 °C due to the breaking of the structure by replacing Si–O–Si linkages with terminating Si–OH groups. Increasing water concentration results in the formation of hydrated [silica gels](https://en.wikipedia.org/wiki/Silica_gel) and [colloidal](https://en.wikipedia.org/wiki/Colloid) silica dispersions. Many hydrates and [silicic acids](https://en.wikipedia.org/wiki/Silicic_acid) exist in the most dilute of aqueous solutions, but these are rather insoluble and quickly precipitate and condense and cross-link to form various polysilicic acids of variable combinations following the formula [SiO*x*(OH)4−2*x*]*n*, similar to the behaviour of [boron](https://en.wikipedia.org/wiki/Boron), [aluminium](https://en.wikipedia.org/wiki/Aluminium), and [iron](https://en.wikipedia.org/wiki/Iron), among other elements. Hence, although some simple silicic acids have been identified in dilute solutions, such as [orthosilicic acid](https://en.wikipedia.org/wiki/Orthosilicic_acid) Si(OH)4 and [metasilicic acid](https://en.wikipedia.org/wiki/Metasilicic_acid) SiO(OH)2, none of these are likely to exist in the solid state.[[46]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood342-46)

**Silicate minerals**

Main article: [Silicate minerals](https://en.wikipedia.org/wiki/Silicate_minerals)

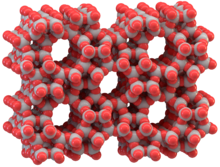
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Typical coordination of metal cations in silicates (ionic radii in [pm](https://en.wikipedia.org/wiki/Picometre))[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47) | | | | | |
| **CN 4** | LiI (59) | BeII (27) | AlIII (39) | SiIV (26) |  |
| **CN 6** | NaI (102) | MgII (72) | AlIII (54) | TiIV (61) | FeII (78) |
| **CN 8** | KI (151) | CaII (112) |  |  |  |
| **CN 12** | KI (164) |  |  |  |  |

About 95% of the Earth's [crustal](https://en.wikipedia.org/wiki/Crust_(geology)) rocks are made of silica or silicate and [aluminosilicate](https://en.wikipedia.org/wiki/Aluminosilicate) minerals, as reflected in oxygen, silicon, and aluminium being the three most common elements in the crust (in that order).[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47) Measured by mass, silicon makes up 27.7% of the [Earth's crust](https://en.wikipedia.org/wiki/Earth%27s_crust).[[48]](https://en.wikipedia.org/wiki/Silicon#cite_note-48) Pure silicon crystals are very rarely found in nature, but notable exceptions are crystals as large as to 0.3 mm across found during sampling gases from the [Kudriavy](https://en.wikipedia.org/wiki/Medvezhya) volcano on [Iturup](https://en.wikipedia.org/wiki/Iturup), one of the [Kuril Islands](https://en.wikipedia.org/wiki/Kuril_Islands).[[49]](https://en.wikipedia.org/wiki/Silicon#cite_note-KorzhinskyTkachenko1995-49)[[50]](https://en.wikipedia.org/wiki/Silicon#cite_note-50)

Silicate and aluminosilicate minerals have many different structures and varying stoichiometry, but they may be classified following some general principles. Tetrahedral {SiO4} units are common to almost all these compounds, either as discrete structures, or combined into larger units by the sharing of corner oxygen atoms. These may be divided into *neso*-silicates (discrete {SiO4} units) sharing no oxygen atoms, *soro*-silicates (discrete {Si2O7} units) sharing one, *cyclo*-silicates (closed ring structures) and *ino*-silicates (continuous chain or ribbon structures) both sharing two, *phyllo*-silicates (continuous sheets) sharing three, and *tecto*-silicates (continuous three-dimensional frameworks) sharing four. The lattice of oxygen atoms that results is usually close-packed, or close to it, with the charge being balanced by other cations in various different polyhedral sites according to size.[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47)

The [orthosilicates](https://en.wikipedia.org/wiki/Orthosilicate) MII  
2SiO  
4 (M = Be, Mg, Mn, Fe, Zn) and ZrSiO4 are *neso*-silicates. Be2SiO4 ([phenacite](https://en.wikipedia.org/wiki/Phenacite)) is unusual as both BeII and SiIV occupy tetrahedral four-coordinated sites; the other divalent cations instead occupy six-coordinated octahedral sites and often isomorphously replace each other as in [olivine](https://en.wikipedia.org/wiki/Olivine), (Mg,Fe,Mn)2SiO4. [Zircon](https://en.wikipedia.org/wiki/Zircon), ZrSiO4, demands eight-coordination of the ZrIV cations due to stoichiometry and because of their larger ionic radius (84 pm). Also significant are the [garnets](https://en.wikipedia.org/wiki/Garnet), [MII  
3MIII  
2(SiO  
4)  
3], in which the divalent cations (e.g. Ca, Mg, Fe) are eight-coordinated and the trivalent ones are six-coordinated (e.g. Al, Cr, Fe). Regular coordination is not always present: for example, it is not found in Ca2SiO4, which mixes six- and eight-coordinate sites for CaII. *Soro*-silicates, involving discrete double or triple tetrahedral units, are quite rare: metasilicates involving cyclic "[(SiO3)*n*]2*n*−" units of corner-abutting tetrahedra forming a polygonal ring are also known.[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47)

Chain metasilicates, {SiO2−  
3}  
∞, form by corner-sharing of an indefinite chain of linked {SiO4} tetrahedra. Many differences arise due to the differing repeat distances of conformation across the line of tetrahedra. A repeat distance of two is most common, as in most [pyroxene](https://en.wikipedia.org/wiki/Pyroxene) minerals, but repeat distances of one, three, four, five, six, seven, nine, and twelve are also known. These chains may then link across each other to form double chains and ribbons, as in the [asbestos](https://en.wikipedia.org/wiki/Asbestos) minerals, involving repeated chains of cyclic tetrahedron rings.[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47)

[](https://en.wikipedia.org/wiki/File:Zeolite-ZSM-5-vdW.png)

A typical zeolite structure

Layer silicates, such as the clay minerals and the [micas](https://en.wikipedia.org/wiki/Mica), are very common, and often are formed by horizontal cross-linking of metasilicate chains or planar condensation of smaller units. An example is [kaolinite](https://en.wikipedia.org/wiki/Kaolinite) [Al2(OH)4Si2O5]; in many of these minerals cation and anion replacement is common, so that for example tetrahedral SiIV may be replaced by AlIII, octahedral AlIII by MgII, and OH− by F−. Three-dimensional framework aluminosilicates are structurally very complex; they may be conceived of as starting from the SiO2 structure, but having replaced up to one-half of the SiIV atoms with AlIII, they require more cations to be included in the structure to balance charge. Examples include [feldspars](https://en.wikipedia.org/wiki/Feldspar) (the most abundant minerals on the Earth), [zeolites](https://en.wikipedia.org/wiki/Zeolite), and [ultramarines](https://en.wikipedia.org/wiki/Ultramarine). Many feldspars can be thought of as forming part of the ternary system NaAlSi3O8–KAlSi3O8–CaAl2Si2O8. Their lattice is destroyed by high pressure prompting AlIII to undergo six-coordination rather than four-coordination, and this reaction destroying feldspars may be a reason for the [Mohorovičić discontinuity](https://en.wikipedia.org/wiki/Mohorovi%C4%8Di%C4%87_discontinuity), which would imply that the crust and mantle have the same chemical composition, but different lattices, although this is not a universally held view. Zeolites have many polyhedral cavities in their frameworks ([truncated cuboctahedra](https://en.wikipedia.org/wiki/Truncated_cuboctahedron) being most common, but other polyhedra also are known as zeolite cavities), allowing them to include loosely bound molecules such as water in their structure. Ultramarines alternate silicon and aluminium atoms and include a variety of other anions such as Cl−, SO2−  
4, and S2−  
2, but are otherwise similar to the feldspars.[[47]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood347-47)

**Other inorganic compounds**

[Silicon disulfide](https://en.wikipedia.org/wiki/Silicon_disulfide) (SiS2) is formed by burning silicon in gaseous sulfur at 100 °C; sublimation of the resulting compound in nitrogen results in white, flexible long fibers reminiscent of [asbestos](https://en.wikipedia.org/wiki/Asbestos) with a structure similar to W-silica. This melts at 1090 °C and sublimes at 1250 °C; at high temperature and pressure this transforms to a crystal structure analogous to cristobalite. However, SiS2 lacks the variety of structures of SiO2, and quickly hydrolyses to silica and [hydrogen sulfide](https://en.wikipedia.org/wiki/Hydrogen_sulfide). It is also ammonoloysed quickly and completely by liquid [ammonia](https://en.wikipedia.org/wiki/Ammonia) as follows to form an [imide](https://en.wikipedia.org/wiki/Imide):[[51]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood359-51)

SiS2 + 4 NH3 → Si(NH)2 + 2 NH4SH

It reacts with the sulfides of sodium, magnesium, aluminium, and iron to form metal [thiosilicates](https://en.wikipedia.org/wiki/Thiosilicate): reaction with [ethanol](https://en.wikipedia.org/wiki/Ethanol) results in [tetraethylsilicate](https://en.wikipedia.org/wiki/Tetraethylsilicate) Si(OEt)4 and hydrogen sulfide. Ethylsilicate is useful as its controlled hydrolysis produces adhesive or film-like forms of silica. Reacting hydrogen sulfide with silicon tetrahalides yields silicon thiohalides such as S(SiCl)3, cyclic Cl2Si(μ-S)2SiCl2, and crystalline (SiSCl2)4. Despite the [double bond rule](https://en.wikipedia.org/wiki/Double_bond_rule), stable organosilanethiones RR'Si=S have been made thanks to the stabilising mechanism of intermolecular coordination via an [amine](https://en.wikipedia.org/wiki/Amine) group.[[51]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood359-51)

[Silicon nitride](https://en.wikipedia.org/wiki/Silicon_nitride), Si3N4, may be formed by directly reacting silicon with nitrogen above 1300 °C, but a more economical means of production is by heating silica and coke in a stream of nitrogen and hydrogen gas at 1500 °C. It would make a promising [ceramic](https://en.wikipedia.org/wiki/Ceramic) if not for the difficulty of working with and sintering it: chemically, it is near-totally inert, and even above 1000 °C it keeps its strength, shape, and continues to be resistant to wear and corrosion. It is very hard (9 on the [Mohs hardness scale](https://en.wikipedia.org/wiki/Mohs_hardness_scale)), dissociates only at 1900 °C at 1 atm, and is quite dense (density 3.185 g/cm3), because of its compact structure similar to that of phenacite (Be2SiO4). A similar refractory material is Si2N2O, formed by heating silicon and silica at 1450 °C in an argon stream containing 5% nitrogen gas, involving 4-coordinate silicon and 3-coordinate nitrogen alternating in puckered hexagonal tilings interlinked by non-linear Si–O–Si linkages to each other.[[51]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood359-51)

Reacting silyl halides with ammonia or alkylammonia derivatives in the gaseous phase or in ethanolic solution produces various volatile silylamides, which are silicon analogues of the [amines](https://en.wikipedia.org/wiki/Amine):[[51]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood359-51)

3 SiH3Cl + 4 NH3 → N(SiH3)3 + 3 NH4Cl

SiH3Br + 2 Me2NH → SiH3NMe2 + Me2NH2Br

4 SiH3I + 5 N2H4 → (SiH3)2NN(SiH3)2 + 4 N2H5I

Many such compounds have been prepared, the only known restriction being that the nitrogen is always tertiary, and species containing the SiH–NH group are unstable at room temperature. The stoichiometry around the nitrogen atom in compounds such as N(SiH3)3is planar, which has been attributed to a pπ–dπ interaction between a lone pair on nitrogen and an empty dπ orbital on silicon. Similarly, trisilylamines are weaker as ligands than their carbon analogues, the tertiary [amines](https://en.wikipedia.org/wiki/Amine), although substitution of some SiH3 groups by CH3 groups mitigates this weakness. For example, N(SiH3)3 does not form an [adduct](https://en.wikipedia.org/wiki/Adduct) with [BH3](https://en.wikipedia.org/wiki/Borane) at all, while MeN(SiH3)2 and Me2NSiH3 form adducts at low temperatures that decompose upon warming. Some silicon analogues of [imines](https://en.wikipedia.org/wiki/Imine), with a Si=N double bond, are known: the first found was Bu*t*2Si=N–SiBu*t*3, which was discovered in 1986.[[51]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood359-51)

[](https://en.wikipedia.org/wiki/File:SiC_p1390066.jpg)

Silicon carbide

[Silicon carbide](https://en.wikipedia.org/wiki/Silicon_carbide) (SiC) was first made by [Edward Goodrich Acheson](https://en.wikipedia.org/wiki/Edward_Goodrich_Acheson) in 1891, who named it carborundum to reference its intermediate hardness and abrasive power between [diamond](https://en.wikipedia.org/wiki/Diamond) (an allotrope of carbon) and [corundum](https://en.wikipedia.org/wiki/Corundum) ([aluminium oxide](https://en.wikipedia.org/wiki/Aluminium_oxide)). He soon founded a company to manufacture it, and today about one million tonnes are produced each year.[[52]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood334-52) Silicon carbide exists in about 250 crystalline forms.[[53]](https://en.wikipedia.org/wiki/Silicon#cite_note-53) The polymorphism of SiC is characterized by a large family of similar crystalline structures called polytypes. They are variations of the same chemical compound that are identical in two dimensions and differ in the third. Thus they can be viewed as layers stacked in a certain sequence.[[54]](https://en.wikipedia.org/wiki/Silicon#cite_note-jap-54) It is made industrially by reduction of quartz sand with excess coke or anthracite at 2000–2500 °C in an electric furnace:[[52]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood334-52)

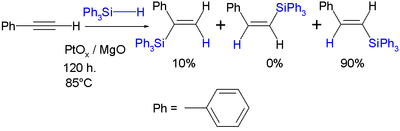
SiO2 + 2 C → Si + 2 CO

Si + C → SiC

It is the most thermally stable binary silicon compound, only decomposing through loss of silicon starting from around 2700 °C. It is resistant to most aqueous acids, [phosphoric acid](https://en.wikipedia.org/wiki/Phosphoric_acid) being an exception. It forms a protective layer of [silicon dioxide](https://en.wikipedia.org/wiki/Silicon_dioxide) on the surface and hence only oxidises appreciably in air above 1000 °C; removal of this layer by molten hydroxides or carbonates leads to quick oxidation. Silicon carbide is rapidly attacked by chlorine gas, which forms SiCl4 and carbon at 100 °C and SiCl4 and [CCl4](https://en.wikipedia.org/wiki/Carbon_tetrachloride) at 1000 °C. It is mostly used as an abrasive and a refractory material, as it is chemically stable and very strong, and it fractures to form a very sharp cutting edge. It is also useful as an intrinsic semiconductor, as well as an extrinsic semiconductor upon being doped.[[52]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood334-52) In its diamond-like behavior it serves as an illustration of the chemical similarity between carbon and silicon.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55)

**Organosilicon compounds**

Main article: [Organosilicon](https://en.wikipedia.org/wiki/Organosilicon)

[](https://en.wikipedia.org/wiki/File:HydrosilylationTriphenylsilylhydride.png)

A hydrosilylation reaction, in which Si–H is added to an unsaturated substrate

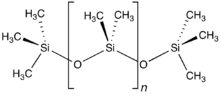
Because the Si–C bond is close in strength to the C–C bond, organosilicon compounds tend to be markedly thermally and chemically stable. For example, [tetraphenylsilane](https://en.wikipedia.org/w/index.php?title=Tetraphenylsilane&action=edit&redlink=1) (SiPh4) may be distilled in air even at its boiling point of 428 °C, and so may its substituted derivatives Ph3SiCl and Ph2SiCl2, which boil at 378 °C and 305 °C respectively. Furthermore, since carbon and silicon are chemical congeners, organosilicon chemistry shows some significant similarities with carbon chemistry, for example in the propensity of such compounds for catenation and forming multiple bonds.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55) However, significant differences also arise: since silicon is more electropositive than carbon, bonds to more electronegative elements are generally stronger with silicon than with carbon, and vice versa. Thus the Si–F bond is significantly stronger than even the [C–F bond](https://en.wikipedia.org/wiki/Carbon%E2%80%93fluorine_bond) and is one of the strongest single bonds, while the Si–H bond is much weaker than the C–H bond and is readily broken. Furthermore, the ability of silicon to expand its octet is not shared by carbon, and hence some organosilicon reactions have no organic analogues. For example, nucleophilic attack on silicon does not proceed by the [SN2](https://en.wikipedia.org/wiki/SN2_reaction) or [SN1](https://en.wikipedia.org/wiki/SN1_reaction) processes, but instead goes through a negatively charged true pentacoordinate intermediate and appears like a substitution at a hindered tertiary atom. This works for silicon, unlike for carbon, because the long Si–C bonds reduce the steric hindrance and the d-orbital of silicon is geometrically unconstrained for nucleophilic attack, unlike for example a C–O σ\* antibonding orbital. Nevertheless, despite these differences, the mechanism is still often called "SN2 at silicon" for simplicity.[[56]](https://en.wikipedia.org/wiki/Silicon#cite_note-Clayden668-56)

One of the most useful silicon-containing groups is [trimethylsilyl](https://en.wikipedia.org/wiki/Trimethylsilyl), Me3Si–. The Si–C bond connecting it to the rest of the molecule is reasonably strong, allowing it to remain while the rest of the molecule undergoes reactions, but is not so strong that it cannot be removed specifically when needed, for example by the [fluoride](https://en.wikipedia.org/wiki/Fluoride) ion, which is a very weak nucleophile for carbon compounds but a very strong one for organosilicon compounds. It may be compared to acidic [protons](https://en.wikipedia.org/wiki/Proton); while trisilylmethyl is removed by hard nucleophiles instead of bases, both removals usually promote elimination. As a general rule, while saturated carbon is best attacked by nucleophiles that are neutral compounds, those based on nonmetals far down on the periodic table (e.g. sulfur, [selenium](https://en.wikipedia.org/wiki/Selenium), or [iodine](https://en.wikipedia.org/wiki/Iodine)), or even both, silicon is best attacked by charged nucleophiles, particularly those involving such highly electronegative nonmetals as oxygen, fluorine, or chlorine. For example, enolates react at the carbon in [haloalkanes](https://en.wikipedia.org/wiki/Haloalkane), but at the oxygen in [silyl](https://en.wikipedia.org/wiki/Silyl) chlorides; and when trimethylsilyl is removed from an organic molecule using hydroxide as a nucleophile, the product of the reaction is not the silanol as one would expect from using carbon chemistry as an analogy, because the siloxide is strongly nucleophilic and attacks the original molecule to yield the [silyl ether](https://en.wikipedia.org/wiki/Silyl_ether) [hexamethyldisiloxane](https://en.wikipedia.org/wiki/Hexamethyldisiloxane), (Me3Si)2O. Conversely, while the SN2 reaction is mostly unaffected by the presence of a partial positive charge (δ+) at the carbon, the analogous "SN2" reaction at silicon is so affected. Thus, for example, the silyl [triflates](https://en.wikipedia.org/wiki/Triflate) are so electrophilic that they react 108 to 109 times faster than silyl chlorides with oxygen-containing nucleophiles. [Trimethylsilyl triflate](https://en.wikipedia.org/wiki/Trimethylsilyl_triflate) is in particular a very good [Lewis acid](https://en.wikipedia.org/wiki/Lewis_acid) and is used to convert [carbonyl](https://en.wikipedia.org/wiki/Carbonyl) compounds to [acetals](https://en.wikipedia.org/wiki/Acetal) and [silyl enol ethers](https://en.wikipedia.org/wiki/Silyl_enol_ether), reacting them together analogously to the [aldol reaction](https://en.wikipedia.org/wiki/Aldol_reaction).[[56]](https://en.wikipedia.org/wiki/Silicon#cite_note-Clayden668-56)

Si–C bonds are commonly formed in three ways. In the laboratory, preparation is often carried out in small quantities by reacting tetrachlorosilane with [organolithium](https://en.wikipedia.org/wiki/Organolithium), [Grignard](https://en.wikipedia.org/wiki/Grignard_reagent), or [organoaluminium](https://en.wikipedia.org/wiki/Organoaluminium) reagents, or by catalytic addition of Si–H across C=C double bonds. The second route has the drawback of not being applicable to the most important silanes, the methyl and phenyl silanes. Organosilanes are made industrially by directly reacting alkyl or aryl halides with silicon with 10% by weight metallic [copper](https://en.wikipedia.org/wiki/Copper) as a catalyst. Standard organic reactions suffice to produce many derivatives; the resulting organosilanes are often significantly more reactive than their carbon congeners, readily undergoing hydrolysis, ammonolysis, alcoholysis, and condensation to form cyclic oligomers or linear polymers.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55)

**Silicone polymers**

Main article: [Silicone](https://en.wikipedia.org/wiki/Silicone)

[](https://en.wikipedia.org/wiki/File:PmdsStructure.png)

Structure of [polydimethylsiloxane](https://en.wikipedia.org/wiki/Polydimethylsiloxane), the principal component of silicones

The word "silicone" was first used by Frederic Kipping in 1901. He invented the word to illustrate the similarity of chemical formulae between Ph2SiO and [benzophenone](https://en.wikipedia.org/wiki/Benzophenone), Ph2CO, although he also stressed the lack of chemical resemblance due to the polymeric structure of Ph2SiO, which is not shared by Ph2CO.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55)

Silicones may be considered analogous to mineral silicates, in which the methyl groups of the silicones correspond to the [isoelectronic](https://en.wikipedia.org/wiki/Isoelectronic) O− of the silicates.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55) They are quite stable to extreme temperatures, oxidation, and water, and have useful dielectric, antistick, and antifoam properties. Furthermore, they are resistant over long periods of time to ultraviolet radiation and weathering, and are inert physiologically. They are fairly unreactive, but do react with concentrated solutions bearing the hydroxide ion and fluorinating agents, and occasionally, may even be used as mild reagents for selective syntheses. For example, (Me3Si)2O is valuable for the preparation of derivatives of [molybdenum](https://en.wikipedia.org/wiki/Molybdenum) and [tungsten](https://en.wikipedia.org/wiki/Tungsten) oxyhalides, converting a [tungsten hexachloride](https://en.wikipedia.org/wiki/Tungsten_hexachloride) suspension in [dichloroethane](https://en.wikipedia.org/wiki/Dichloroethane) solution quantitatively to WOCl4 in under an hour at room temperature, and then to yellow WO2Cl2 at 100 °C in light petroleum at a yield of 95% overnight.[[55]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood361-55)

**Occurrence**

[](https://en.wikipedia.org/wiki/File:Olivine-gem7-10a.jpg)

Olivine

In the universe, silicon is the seventh most abundant element, coming after [hydrogen](https://en.wikipedia.org/wiki/Hydrogen), [helium](https://en.wikipedia.org/wiki/Helium), [carbon](https://en.wikipedia.org/wiki/Carbon), [nitrogen](https://en.wikipedia.org/wiki/Nitrogen), [oxygen](https://en.wikipedia.org/wiki/Oxygen), and [neon](https://en.wikipedia.org/wiki/Neon). These abundances are not replicated well on Earth due to substantial separation of the elements taking place during the formation of the [Solar System](https://en.wikipedia.org/wiki/Solar_System). Silicon makes up 27.2% of the Earth's crust by weight, second only to oxygen at 45.5%, with which it always is associated in nature. Further fractionation took place in the formation of the Earth by [planetary differentiation](https://en.wikipedia.org/wiki/Planetary_differentiation): [Earth's core](https://en.wikipedia.org/wiki/Earth%27s_core), which makes up 31.5% of the mass of the Earth, has approximate composition Fe25Ni2Co0.1S3; the [mantle](https://en.wikipedia.org/wiki/Mantle_(geology)) makes up 68.1% of the Earth's mass and is composed mostly of denser oxides and silicates, an example being [olivine](https://en.wikipedia.org/wiki/Olivine), (Mg,Fe)2SiO4; while the lighter siliceous minerals such as [aluminosilicates](https://en.wikipedia.org/wiki/Aluminosilicate) rise to the surface and form the crust, making up 0.4% of the Earth's mass.[[57]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood329-57)

The crystallisation of [igneous rocks](https://en.wikipedia.org/wiki/Igneous_rock) from magma depends on a number of factors; among them are the chemical composition of the magma, the cooling rate, and some properties of the individual minerals to be formed, such as [lattice energy](https://en.wikipedia.org/wiki/Lattice_energy), melting point, and complexity of their crystal structure. As magma is cooled, [olivine](https://en.wikipedia.org/wiki/Olivine) appears first, followed by [pyroxene](https://en.wikipedia.org/wiki/Pyroxene), [amphibole](https://en.wikipedia.org/wiki/Amphibole), [biotite](https://en.wikipedia.org/wiki/Biotite) mica, [orthoclase feldspar](https://en.wikipedia.org/wiki/Orthoclase_feldspar), [muscovite mica](https://en.wikipedia.org/wiki/Muscovite_mica), [quartz](https://en.wikipedia.org/wiki/Quartz), [zeolites](https://en.wikipedia.org/wiki/Zeolite), and finally, hydrothermal minerals. This sequence shows a trend toward increasingly complex silicate units with cooling, and the introduction of [hydroxide](https://en.wikipedia.org/wiki/Hydroxide) and [fluoride](https://en.wikipedia.org/wiki/Fluoride) anions in addition to oxides. Many metals may substitute for silicon. After these igneous rocks undergo [weathering](https://en.wikipedia.org/wiki/Weathering), transport, and deposition, [sedimentary rocks](https://en.wikipedia.org/wiki/Sedimentary_rock) like clay, shale, and sandstone are formed. [Metamorphism](https://en.wikipedia.org/wiki/Metamorphism) also may occur at high temperatures and pressures, creating an even vaster variety of minerals.[[57]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood329-57)

**Production**

Silicon of 96–99% purity is made by reducing [quartzite](https://en.wikipedia.org/wiki/Quartzite) or sand with highly pure [coke](https://en.wikipedia.org/wiki/Coke_(fuel)). The reduction is carried out in an [electric arc furnace](https://en.wikipedia.org/wiki/Electric_arc_furnace), with an excess of SiO2 used to stop [silicon carbide](https://en.wikipedia.org/wiki/Silicon_carbide) (SiC) from accumulating:[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31)

SiO2 + 2 C → Si + 2 CO

2 SiC + SiO2 → 3 Si + 2 CO

[](https://en.wikipedia.org/wiki/File:Ferrosilicon.JPG)

Ferrosilicon alloy

This reaction, known as carbothermal reduction of silicon dioxide, usually is conducted in the presence of scrap iron with low amounts of [phosphorus](https://en.wikipedia.org/wiki/Phosphorus) and [sulfur](https://en.wikipedia.org/wiki/Sulfur), producing [ferrosilicon](https://en.wikipedia.org/wiki/Ferrosilicon).[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31) Ferrosilicon, an iron-silicon alloy that contains varying ratios of elemental silicon and iron, accounts for about 80% of the world's production of elemental silicon, with China, the leading supplier of elemental silicon, providing 4.6 million [tonnes](https://en.wikipedia.org/wiki/Tonne) (or 2/3 of world output) of silicon, most of it in the form of ferrosilicon. It is followed by Russia (610,000 t), Norway (330,000 t), Brazil (240,000 t), and the United States (170,000 t).[[58]](https://en.wikipedia.org/wiki/Silicon#cite_note-58) Ferrosilicon is primarily used by the iron and steel industry (see below) with primary use as alloying addition in iron or steel and for de-oxidation of steel in integrated steel plants.[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31) Another reaction, sometimes used, is aluminothermal reduction of silicon dioxide, as follows:[[59]](https://en.wikipedia.org/wiki/Silicon#cite_note-Ullmann574-59)

3 SiO2 + 4 Al → 3 Si + 2 Al2O3

Leaching powdered 96–97% pure silicon with water results in ~98.5% pure silicon, which is used in the chemical industry. However, even greater purity is needed for semiconductor applications, and this is produced from the reduction of tetrachlorosilane or trichlorosilane. The former is made by chlorinating scrap silicon and the latter is a byproduct of [silicone](https://en.wikipedia.org/wiki/Silicone) production. These compounds are volatile and hence can be purified by repeated [fractional distillation](https://en.wikipedia.org/wiki/Fractional_distillation), followed by reduction to elemental silicon with very pure [zinc](https://en.wikipedia.org/wiki/Zinc) metal as the reducing agent. The spongy pieces of silicon thus produced are melted and then grown to form cylindrical single crystals, before being purified by [zone refining](https://en.wikipedia.org/wiki/Zone_refining). Other routes use the thermal decomposition of silane or tetraiodosilane. Another process used is the reduction of [sodium hexafluorosilicate](https://en.wikipedia.org/wiki/Sodium_hexafluorosilicate), a common waste product of the phosphate fertilizer industry, by metallic [sodium](https://en.wikipedia.org/wiki/Sodium): this is highly exothermic and hence requires no outside fuel source. Hyperfine silicon is made at a higher purity than almost every other material: [transistor](https://en.wikipedia.org/wiki/Transistor) production requires impurity levels in silicon crystals less than 1 part per 1010, and in special cases impurity levels below 1 part per 1012 are needed and attained.[[31]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood330-31)

**Applications**

**Compounds**

Most silicon is used industrially without being purified, and indeed, often with comparatively little processing from its natural form. More than 90% of the Earth's crust is composed of [silicate minerals](https://en.wikipedia.org/wiki/Silicate_minerals), which are compounds of silicon and oxygen, often with metallic ions when negatively charged silicate anions require cations to balance the charge. Many of these have direct commercial uses, such as clays, [silica](https://en.wikipedia.org/wiki/Silica) sand, and most kinds of building stone. Thus, the vast majority of uses for silicon are as structural compounds, either as the silicate minerals or silica (crude silicon dioxide). Silicates are used in making [Portland cement](https://en.wikipedia.org/wiki/Portland_cement) (made mostly of calcium silicates) which is used in [building mortar](https://en.wikipedia.org/wiki/Mortar_(masonry)) and modern [stucco](https://en.wikipedia.org/wiki/Stucco), but more importantly, combined with silica sand, and gravel (usually containing silicate minerals such as granite), to make the [concrete](https://en.wikipedia.org/wiki/Concrete) that is the basis of most of the very largest industrial building projects of the modern world.[[60]](https://en.wikipedia.org/wiki/Silicon#cite_note-Greenwood356-60)

Silica is used to make [fire brick](https://en.wikipedia.org/wiki/Fire_brick), a type of ceramic. Silicate minerals are also in whiteware [ceramics](https://en.wikipedia.org/wiki/Ceramic), an important class of products usually containing various types of fired [clay](https://en.wikipedia.org/wiki/Clay) minerals (natural aluminium phyllosilicates). An example is [porcelain](https://en.wikipedia.org/wiki/Porcelain), which is based on the silicate mineral [kaolinite](https://en.wikipedia.org/wiki/Kaolinite). Traditional [glass](https://en.wikipedia.org/wiki/Glass) (silica-based [soda-lime glass](https://en.wikipedia.org/wiki/Soda-lime_glass)) also functions in many of the same ways, and also is used for windows and containers. In addition, specialty silica based [glass fibers](https://en.wikipedia.org/wiki/Glass_fiber) are used for [optical fiber](https://en.wikipedia.org/wiki/Optical_fiber), as well as to produce [fiberglass](https://en.wikipedia.org/wiki/Fiberglass) for structural support and [glass wool](https://en.wikipedia.org/wiki/Glass_wool) for thermal insulation.

Silicones often are used in [waterproofing](https://en.wikipedia.org/wiki/Waterproofing) treatments, [molding](https://en.wikipedia.org/wiki/Molding_(process)) compounds, mold-[release agents](https://en.wikipedia.org/wiki/Release_agent), mechanical seals, high temperature [greases](https://en.wikipedia.org/wiki/Lubricant) and waxes, and [caulking](https://en.wikipedia.org/wiki/Caulking) compounds. Silicone is also sometimes used in [breast implants](https://en.wikipedia.org/wiki/Breast_implant), contact lenses, [explosives](https://en.wikipedia.org/wiki/Explosive) and [pyrotechnics](https://en.wikipedia.org/wiki/Pyrotechnics).[[61]](https://en.wikipedia.org/wiki/Silicon#cite_note-61) [Silly Putty](https://en.wikipedia.org/wiki/Silly_Putty) was originally made by adding [boric acid](https://en.wikipedia.org/wiki/Boric_acid) to [silicone oil](https://en.wikipedia.org/wiki/Silicone_oil).[[62]](https://en.wikipedia.org/wiki/Silicon#cite_note-62) Other silicon compounds function as high-technology abrasives and new high-strength ceramics based upon [silicon carbide](https://en.wikipedia.org/wiki/Silicon_carbide). Silicon is a component of some [superalloys](https://en.wikipedia.org/wiki/Superalloy).

**Alloys**

Elemental silicon is added to molten [cast iron](https://en.wikipedia.org/wiki/Cast_iron) as [ferrosilicon](https://en.wikipedia.org/wiki/Ferrosilicon) or silicocalcium alloys to improve performance in casting thin sections and to prevent the formation of [cementite](https://en.wikipedia.org/wiki/Cementite) where exposed to outside air. The presence of elemental silicon in molten iron acts as a sink for oxygen, so that the steel carbon content, which must be kept within narrow limits for each type of steel, can be more closely controlled. Ferrosilicon production and use is a monitor of the steel industry, and although this form of elemental silicon is grossly impure, it accounts for 80% of the world's use of free silicon. Silicon is an important constituent of [electrical steel](https://en.wikipedia.org/wiki/Electrical_steel), modifying its [resistivity](https://en.wikipedia.org/wiki/Resistivity) and [ferromagnetic](https://en.wikipedia.org/wiki/Ferromagnetic) properties.

The properties of silicon may be used to modify alloys with metals other than iron. "Metallurgical grade" silicon is silicon of 95–99% purity. About 55% of the world consumption of metallurgical purity silicon goes for production of aluminium-silicon alloys ([silumin](https://en.wikipedia.org/wiki/Silumin) alloys) for aluminium part [casts](https://en.wikipedia.org/wiki/Casting), mainly for use in the [automotive industry](https://en.wikipedia.org/wiki/Automotive_industry). Silicon's importance in aluminium casting is that a significantly high amount (12%) of silicon in aluminium forms a [eutectic mixture](https://en.wikipedia.org/wiki/Eutectic_mixture) which solidifies with very little thermal contraction. This greatly reduces tearing and cracks formed from stress as casting alloys cool to solidity. Silicon also significantly improves the hardness and thus wear-resistance of aluminium.[[63]](https://en.wikipedia.org/wiki/Silicon#cite_note-diecasting-63)[[64]](https://en.wikipedia.org/wiki/Silicon#cite_note-USGS-64)

**Electronics**

Main article: [Semiconductor device fabrication](https://en.wikipedia.org/wiki/Semiconductor_device_fabrication)

[](https://en.wikipedia.org/wiki/File:Silicon_wafer_with_mirror_finish.jpg)

Silicon wafer with mirror finish

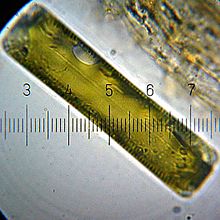
Most elemental silicon produced remains as a ferrosilicon alloy, and only approximately 20% is refined to metallurgical grade purity (a total of 1.3–1.5 million metric tons/year). An estimated 15% of the world production of metallurgical grade silicon is further refined to semiconductor purity.[[64]](https://en.wikipedia.org/wiki/Silicon#cite_note-USGS-64) This typically is the "nine-9" or 99.9999999% purity,[[65]](https://en.wikipedia.org/wiki/Silicon#cite_note-65) nearly defect-free single [crystalline](https://en.wikipedia.org/wiki/Crystalline) material.[[66]](https://en.wikipedia.org/wiki/Silicon#cite_note-66)

[Monocrystalline silicon](https://en.wikipedia.org/wiki/Monocrystalline_silicon) of such purity is usually produced by the [Czochralski process](https://en.wikipedia.org/wiki/Czochralski_process), is used to produce [silicon wafers](https://en.wikipedia.org/wiki/Wafer_(electronics)) used in the [semiconductor industry](https://en.wikipedia.org/wiki/Semiconductor_industry), in electronics, and in some high-cost and high-efficiency [photovoltaic](https://en.wikipedia.org/wiki/Photovoltaic) applications.[[67]](https://en.wikipedia.org/wiki/Silicon#cite_note-Ullmann590-67) Pure silicon is an [intrinsic semiconductor](https://en.wikipedia.org/wiki/Intrinsic_semiconductor), which means that unlike metals, it conducts [electron holes](https://en.wikipedia.org/wiki/Electron_hole) and electrons released from atoms by heat; silicon's [electrical conductivity](https://en.wikipedia.org/wiki/Electrical_conductivity) increases with higher temperatures. Pure silicon has too low a conductivity (i.e., too high a [resistivity](https://en.wikipedia.org/wiki/Resistivity)) to be used as a circuit element in electronics. In practice, pure silicon is [doped](https://en.wikipedia.org/wiki/Doping_(semiconductors)) with small concentrations of certain other elements, which greatly increase its conductivity and adjust its electrical response by controlling the number and charge ([positive](https://en.wikipedia.org/wiki/Electron_hole) or [negative](https://en.wikipedia.org/wiki/Electron)) of activated carriers. Such control is necessary for [transistors](https://en.wikipedia.org/wiki/Transistor), [solar cells](https://en.wikipedia.org/wiki/Solar_cell), [semiconductor detectors](https://en.wikipedia.org/wiki/Semiconductor_detector), and other [semiconductor devices](https://en.wikipedia.org/wiki/Semiconductor_device) used in the computer industry and other technical applications.[[68]](https://en.wikipedia.org/wiki/Silicon#cite_note-Ullmann573-68) In [silicon photonics](https://en.wikipedia.org/wiki/Silicon_photonics), silicon may be used as a continuous wave [Raman laser](https://en.wikipedia.org/wiki/Raman_laser) medium to produce coherent light.[[69]](https://en.wikipedia.org/wiki/Silicon#cite_note-dekker_2008-69)

In common [integrated circuits](https://en.wikipedia.org/wiki/Integrated_circuit), a wafer of monocrystalline silicon serves as a mechanical support for the circuits, which are created by doping and insulated from each other by thin layers of [silicon oxide](https://en.wikipedia.org/wiki/Silicon_dioxide), an insulator that is easily produced on Si surfaces by processes of [thermal oxidation](https://en.wikipedia.org/wiki/Thermal_oxidation) or [local oxidation (LOCOS)](https://en.wikipedia.org/wiki/LOCOS), which involve exposing the element to oxygen under the proper conditions that can be predicted by the [Deal–Grove model](https://en.wikipedia.org/wiki/Deal%E2%80%93Grove_model). Silicon has become the most popular material for both high power semiconductors and integrated circuits because it can withstand the highest temperatures and greatest electrical activity without suffering [avalanche breakdown](https://en.wikipedia.org/wiki/Avalanche_breakdown) (an [electron avalanche](https://en.wikipedia.org/wiki/Electron_avalanche) is created when heat produces free electrons and holes, which in turn pass more current, which produces more heat). In addition, the insulating oxide of silicon is not soluble in water, which gives it an advantage over [germanium](https://en.wikipedia.org/wiki/Germanium) (an element with similar properties which can also be used in semiconductor devices) in certain fabrication techniques.[[70]](https://en.wikipedia.org/wiki/Silicon#cite_note-70)

Monocrystalline silicon is expensive to produce, and is usually justified only in production of integrated circuits, where tiny crystal imperfections can interfere with tiny circuit paths. For other uses, other types of pure silicon may be employed. These include [hydrogenated amorphous silicon](https://en.wikipedia.org/wiki/Hydrogenated_amorphous_silicon) and upgraded metallurgical-grade silicon (UMG-Si) used in the production of low-cost, [large-area electronics](https://en.wikipedia.org/wiki/Large-area_electronics) in applications such as [liquid crystal displays](https://en.wikipedia.org/wiki/Liquid_crystal_display) and of large-area, low-cost, thin-film [solar cells](https://en.wikipedia.org/wiki/Solar_cells). Such semiconductor grades of silicon are either slightly less pure or polycrystalline rather than monocrystalline, and are produced in comparable quantities as the monocrystalline silicon: 75,000 to 150,000 metric tons per year. The market for the lesser grade is growing more quickly than for monocrystalline silicon. By 2013, polycrystalline silicon production, used mostly in solar cells, was projected to reach 200,000 metric tons per year, while monocrystalline semiconductor grade silicon was expected to remain less than 50,000 tons per year.[[64]](https://en.wikipedia.org/wiki/Silicon#cite_note-USGS-64)

**Biological role**

[](https://en.wikipedia.org/wiki/File:20110123_185042_Diatom.jpg)

A diatom, enclosed in a silica cell wall

Although silicon is readily available in the form of [silicates](https://en.wikipedia.org/wiki/Silicate), very few organisms use it directly. [Diatoms](https://en.wikipedia.org/wiki/Diatom), [radiolaria](https://en.wikipedia.org/wiki/Radiolaria), and [siliceous sponges](https://en.wikipedia.org/wiki/Siliceous_sponge) use [biogenic silica](https://en.wikipedia.org/wiki/Biogenic_silica) as a structural material for their skeletons. In more advanced plants, the silica [phytoliths](https://en.wikipedia.org/wiki/Phytolith) (opal phytoliths) are rigid microscopic bodies occurring in the cell; some plants, for example [rice](https://en.wikipedia.org/wiki/Rice), need silicon for their growth.[[71]](https://en.wikipedia.org/wiki/Silicon#cite_note-71)[[72]](https://en.wikipedia.org/wiki/Silicon#cite_note-abd-72)[[73]](https://en.wikipedia.org/wiki/Silicon#cite_note-plants-73) Silicon has been shown to improve plant cell wall strength and structural integrity in some plants.[[74]](https://en.wikipedia.org/wiki/Silicon#cite_note-Kim2002-74)

**Human nutrition**

There is some evidence that silicon is important to human health for their nail, hair, bone, and skin tissues,[[75]](https://en.wikipedia.org/wiki/Silicon#cite_note-75) for example, in studies that demonstrate that premenopausal women with higher dietary silicon intake have higher [bone density](https://en.wikipedia.org/wiki/Bone_density), and that silicon supplementation can increase bone volume and density in patients with [osteoporosis](https://en.wikipedia.org/wiki/Osteoporosis).[[76]](https://en.wikipedia.org/wiki/Silicon#cite_note-jugdaohsingh2007silicon-76) Silicon is needed for synthesis of [elastin](https://en.wikipedia.org/wiki/Elastin) and [collagen](https://en.wikipedia.org/wiki/Collagen), of which the [aorta](https://en.wikipedia.org/wiki/Aorta) contains the greatest quantity in the human body,[[77]](https://en.wikipedia.org/wiki/Silicon#cite_note-LoeperLoeper1978-77) and has been considered an [essential element](https://en.wikipedia.org/wiki/Mineral_(nutrient));[[78]](https://en.wikipedia.org/wiki/Silicon#cite_note-Niels-78) nevertheless, it is difficult to prove its essentiality, because silicon is very common, and hence, deficiency symptoms are difficult to reproduce.[[79]](https://en.wikipedia.org/wiki/Silicon#cite_note-lipp-79)

Silicon is currently under consideration for elevation to the status of a "plant beneficial substance by the Association of American Plant Food Control Officials (AAPFCO)."[[80]](https://en.wikipedia.org/wiki/Silicon#cite_note-80)[[81]](https://en.wikipedia.org/wiki/Silicon#cite_note-presentation-81)

**Safety**

People may be exposed to elemental silicon in the workplace by breathing it in, swallowing it, or having contact with the skin or eye. In the latter two cases, silicon poses a slight hazard as an irritant. It is hazardous if inhaled.[[82]](https://en.wikipedia.org/wiki/Silicon#cite_note-msds-82) The [Occupational Safety and Health Administration](https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration) (OSHA) has set the legal limit ([Permissible exposure limit](https://en.wikipedia.org/wiki/Permissible_exposure_limit)) for silicon exposure in the workplace as 15 mg/m3 total exposure and 5 mg/m3 respiratory exposure over an 8-hour workday. The [National Institute for Occupational Safety and Health](https://en.wikipedia.org/wiki/National_Institute_for_Occupational_Safety_and_Health) (NIOSH) has set a [Recommended exposure limit](https://en.wikipedia.org/wiki/Recommended_exposure_limit) (REL) of 10 mg/m3 total exposure and 5 mg/m3 respiratory exposure over an 8-hour workday.[[83]](https://en.wikipedia.org/wiki/Silicon#cite_note-83) Inhalation of [crystalline](https://en.wikipedia.org/wiki/Crystalline) silica dust may lead to [silicosis](https://en.wikipedia.org/wiki/Silicosis), an [occupational lung disease](https://en.wikipedia.org/wiki/Occupational_lung_disease) marked by [inflammation](https://en.wikipedia.org/wiki/Inflammation) and scarring in the form of [nodular lesions](https://en.wikipedia.org/wiki/Nodule_(medicine)) in the upper lobes of the [lungs](https://en.wikipedia.org/wiki/Lungs).[[84]](https://en.wikipedia.org/wiki/Silicon#cite_note-PlantVoulvoulis2012-84)

**See also**

* [Amorphous silicon](https://en.wikipedia.org/wiki/Amorphous_silicon)
* [Black silicon](https://en.wikipedia.org/wiki/Black_silicon)
* [Covalent superconductors](https://en.wikipedia.org/wiki/Covalent_superconductors)
* [List of countries by silicon production](https://en.wikipedia.org/wiki/List_of_countries_by_silicon_production)
* [List of silicon producers](https://en.wikipedia.org/wiki/List_of_silicon_producers)
* [Monocrystalline silicon](https://en.wikipedia.org/wiki/Monocrystalline_silicon)
* [Silicon Nanowires (SiNWs)](https://en.wikipedia.org/wiki/Silicon_Nanowire)
* [Polycrystalline silicon](https://en.wikipedia.org/wiki/Polycrystalline_silicon)
* [Printed silicon electronics](https://en.wikipedia.org/wiki/Printed_silicon_electronics)
* [Silicon tombac](https://en.wikipedia.org/wiki/Silicon_tombac)
* [Silicon Valley](https://en.wikipedia.org/wiki/Silicon_Valley)
* [Silicon Wadi](https://en.wikipedia.org/wiki/Silicon_Wadi)
* [Transistor](https://en.wikipedia.org/wiki/Transistor)

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  In his table of the elements, Lavoisier listed five "salifiable earths" (i.e., ores that could be made to react with acids to produce salts (*salis* = salt, in Latin): *chaux* (calcium oxide), *magnésie* (magnesia, magnesium oxide), *baryte* (barium sulfate), *alumine* (alumina, aluminium oxide), and *silice* (silica, silicon dioxide). About these "elements", Lavoisier speculates: "We are probably only acquainted as yet with a part of the metallic substances existing in nature, as all those which have a stronger affinity to oxygen than carbon possesses, are incapable, hitherto, of being reduced to a metallic state, and consequently, being only presented to our observation under the form of oxyds, are confounded with earths. It is extremely probable that barytes, which we have just now arranged with earths, is in this situation; for in many experiments it exhibits properties nearly approaching to those of metallic bodies. It is even possible that all the substances we call earths may be only metallic oxyds, irreducible by any hitherto known process." – from [page 218](https://books.google.com/books?id=adYKAAAAIAAJ&pg=PA218) of: Lavoisier with Robert Kerr, trans., *Elements of Chemistry*, … , 4th ed. (Edinburgh, Scotland: William Creech, 1799). (The original passage appears in: Lavoisier, *Traité Élémentaire de Chimie*, (Paris, France: Cuchet, 1789), vol. 1, [p. 174](https://books.google.com/books?id=hZch3yOrayUC&pg=PA174).)

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  Davy, Humphry (1808) ["Electro chemical researches, on the decomposition of the earths; with observations on the metals obtained from the alkaline earths, and on the amalgam procured from ammonia,"](https://books.google.com/books?id=Kg9GAAAAMAAJ&pg=PA333) *Philosophical Transactions of the Royal Society* [of London], **98** : 333–370. On [p. 353](https://books.google.com/books?id=Kg9GAAAAMAAJ&pg=PA353) Davy coins the name "silicium" : "Had I been so fortunate as to have obtained more certain evidences on this subject, and to have procured the metallic substances I was in search of, I should have proposed for them the names of silicium [silicon], alumium [aluminium], zirconium, and glucium [beryllium]."

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  See:

* Berzelius announced his discovery of silicon ("silicium") in: Berzelius, J. (presented: 1823; published: 1824) ["Undersökning af flusspatssyran och dess märkvärdigaste föreningar"](https://books.google.com/books?id=pJlPAAAAYAAJ&pg=PA46) (Investigation of hydrofluoric acid and of its most noteworthy compounds), *Kongliga Vetenskaps-Academiens Handlingar* [Proceedings of the Royal Science Academy], **12** : 46–98. The isolation of silicon and its characterization are detailed in the section titled "Flussspatssyrad kisseljords sönderdelning med kalium," pp. 46–68.
* The above article was reprinted in German in: J. J. Berzelius (1824) ["*II. Untersuchungen über Flussspathsäure und deren merkwürdigsten Verbindungen*"](http://gallica.bnf.fr/ark:/12148/bpt6k15086x/f185.image.langEN) (II. Investigations of hydrofluoric acid and its most noteworthy compounds), *Annalen der Physik*, **77**: 169–230. The isolation of silicon is detailed in the section titled: ["Zersetzung der flussspaths. Kieselerde durch Kalium"](http://gallica.bnf.fr/ark:/12148/bpt6k15086x/f220.image.langEN) (Decomposition of silicate fluoride by potassium), pp. 204–210.
* The above article was reprinted in French in: Berzelius (1824) ["Décomposition du fluate de silice par le potassium"](https://books.google.com/books?id=eHmstO7CmqAC&pg=PA337) (Decomposition of silica fluoride by potassium), *Annales de Chimie et de Physique*, **27**: 337–359.
* Reprinted in English in: Berzelius (1825) ["On the mode of obtaining silicium, and on the characters and properties of that substance,"](https://books.google.com/books?id=_UwwAAAAIAAJ&pg=PA254) *Philosophical Magazine*, **65** (324): 254–267.

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  In 1854, Deville was trying to prepare aluminium metal from aluminium chloride that was heavily contaminated with silicon chloride. Deville used two methods to prepare aluminium: heating aluminium chloride with sodium metal in an inert atmosphere (of hydrogen); and melting aluminum chloride with sodium chloride and then electrolyzing the mixture. In both cases, pure silicon was produced: the silicon dissolved in the molten aluminium, but crystallized upon cooling. Dissolving the crude aluminum in hydrochloric acid revealed flakes of crystallized silicon. See: Henri Sainte-Claire Deville (1854) ["Note sur deux procédés de préparation de l'aluminium et sur une nouvelle forme du silicium"](https://books.google.com/books?id=C3VFAAAAcAAJ&pg=PA321) (Note on two procedures for the preparation of aluminium and on a new form of silicon), *Comptes rendus*, **39**: 321–326.  
Subsequently, Deville obtained crystalline silicon by heating the chloride or fluoride of silicon with sodium metal, isolating the amorphous silicon, then melting the amorphous form with salt and heating the mixture until most of the salt evaporated. See: H. Sainte-Claire Deville (1855) ["Du silicium et du titane"](https://books.google.com/books?id=tZhDAQAAIAAJ&pg=PA1034) (On silicon and titanium), *Comptes rendus*, **40**: 1034–1036.

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* [Community portal](https://en.wikipedia.org/wiki/Wikipedia:Community_portal)
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* [Contact page](https://en.wikipedia.org/wiki/Wikipedia:Contact_us)

**Tools**

* [What links here](https://en.wikipedia.org/wiki/Special:WhatLinksHere/Silicon)
* [Related changes](https://en.wikipedia.org/wiki/Special:RecentChangesLinked/Silicon)
* [Upload file](https://en.wikipedia.org/wiki/Wikipedia:File_Upload_Wizard)
* [Special pages](https://en.wikipedia.org/wiki/Special:SpecialPages)
* [Permanent link](https://en.wikipedia.org/w/index.php?title=Silicon&oldid=873462619)
* [Page information](https://en.wikipedia.org/w/index.php?title=Silicon&action=info)
* [Wikidata item](https://www.wikidata.org/wiki/Special:EntityPage/Q670)
* [Cite this page](https://en.wikipedia.org/w/index.php?title=Special:CiteThisPage&page=Silicon&id=873462619)

**Print/export**

* [Create a book](https://en.wikipedia.org/w/index.php?title=Special:Book&bookcmd=book_creator&referer=Silicon)
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**In other projects**

* [Wikimedia Commons](https://commons.wikimedia.org/wiki/Category:Silicon)

**Languages**

* [Deutsch](https://de.wikipedia.org/wiki/Silicium)
* [Español](https://es.wikipedia.org/wiki/Silicio)
* [Français](https://fr.wikipedia.org/wiki/Silicium)
* [한국어](https://ko.wikipedia.org/wiki/%EA%B7%9C%EC%86%8C)
* [Italiano](https://it.wikipedia.org/wiki/Silicio)
* [Русский](https://ru.wikipedia.org/wiki/%D0%9A%D1%80%D0%B5%D0%BC%D0%BD%D0%B8%D0%B9)
* [Tagalog](https://tl.wikipedia.org/wiki/Silicon)
* [Tiếng Việt](https://vi.wikipedia.org/wiki/Silic)
* [中文](https://zh.wikipedia.org/wiki/%E7%A1%85)

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