Silicon, the second most abundant element on earth, is an essential part of the mineral world. Its stable tetrahedral configuration makes it incredibly versatile and is used in various ways in our everyday lives. Found in everything from spaceships to synthetic body parts, silicon can be found all around us, and sometimes even in us.

### Introduction

The name for silicon is taken from the Latin *silex* which means "flint". The element is second only to oxygen in abundance in the earth's crust and was discovered by Berzelius in 1824. The most common compound of silicon, \( \text{SiO}_2 \), is the most abundant chemical compound in the earth's crust, which we know it better as common beach sand.

### Properties

Silicon is a crystalline semi-metal or metalloid. One of its forms is shiny, grey and very brittle (it will shatter when struck with a hammer). It is a group 14 element in the same periodic group as carbon, but chemically behaves distinctly from all of its group counterparts. Silicon shares the bonding versatility of carbon, with its four valence electrons, but is otherwise a relatively inert element. However, under special conditions, silicon be made to be a good deal more reactive. Silicon exhibits metalloid properties, is able to expand its valence shell, and is able to be transformed into a semiconductor; distinguishing it from its periodic group members.

#### Table 1: Properties of Silicon

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Number</td>
<td>14</td>
</tr>
<tr>
<td>Group</td>
<td>14 (Carbon Family)</td>
</tr>
<tr>
<td>Electron Configuration</td>
<td>[Ne]3s²3p²</td>
</tr>
<tr>
<td>Atomic Weight</td>
<td>28.0855 g</td>
</tr>
<tr>
<td>Density</td>
<td>2.57 g/mL</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1414°C</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>3265°C</td>
</tr>
<tr>
<td>Oxidation States</td>
<td>4, 3, 2, 1, -1, -2, -3, -4</td>
</tr>
<tr>
<td>Electronegativity</td>
<td>1.90</td>
</tr>
<tr>
<td>Stable Isotopes</td>
<td>(^{28}\text{Si}, ^{29}\text{Si}, ^{30}\text{Si})</td>
</tr>
</tbody>
</table>

### Where Silicon is Found

27.6% of the Earth's crust is made up of silicon. Although it is so abundant, it is not usually found in its pure state, but
rather its dioxide and hydrates. $\text{(SiO}_2\text{)}$ is silicon's only stable oxide, and is found in many crystalline varieties. Its purest form being quartz, but also as jasper and opal. Silicon can also be found in feldspar, micas, olivines, pyroxenes and even in water (Figure 1). In another allotropic form silicon is a brown amorphous powder most familiar in "dirty" beach sand. The crystalline form of silicon is the foundation of the semiconductor age.

![Figure 1: Sand is an easy to find silicon deposit](image)

### Silicates

Silicon is most commonly found in silicate compounds. Silica is the one stable oxide of silicon, and has the empirical formula $\text{SiO}_2$. Silica is not a silicon atom with two double bonds to two oxygen atoms. Silica is composed of one silicon atom with four single bonds to four oxygen molecules (Figure 2).

![Figure 2: The net charge of silica is minus 4](image)

Silica, i.e. silicon dioxide, takes on this molecular form, instead of carbon dioxide's characteristic shape, because silicon's 3p orbitals make it more energetically favorable to create four single bonds with each oxygen rather than make two double bonds with each oxygen atom. This leads to silicates linking together in -Si-O-Si-O- networks called silicates. The empirical form of silica is $\text{SiO}_2$ because, with respect to the net average of the silicate, each silicon atom has two oxygen atoms.
The tetrahedral SiO$_4^{4-}$ complex (see Figure 3), the core unit of silicates, can bind together in a variety of ways, creating a wide array of minerals. Silicon is an integral component in minerals, just as Carbon is an essential component of organic compounds.

**Neosilicates**

In nesosilicates the silicate tetrahedral does not share any oxygen molecules with other silicate tetrahedrals, and instead balances out its charge with other metals. The core structure of neosilicate is simply a lone tetrahedral silica unit (Figure 4). The empirical formula for the core structure of a neosilicate is SiO$_4^{4-}$.

Neosilicates make up the outer fringes of a group of minerals known as olivines.

**Sorosilicates**

In sorosilicates two silicate tetrahedrals join together by sharing an oxygen atom at one of their corners. The core structure of a sorosilicate is a pair of silica tetrahedra. (see Figure 5)
Figure 5: The core of a sorosilicate

The mineral thortveitie is an example of a sorosilicate complex.

**Cyclosilicates**

In cyclosilicates three or more silica tetrahedrals share two corners of an oxygen atom. The core structure of a cyclosilicate is a closed ring of silica tetrahedra. (see Figure 6)

Figure 6: The core of a cyclosilicate

The mineral beryl is an example of a cyclosilicate complex.

**Inosilicates**

Inosilicates are complexes where each tetrahedral share two corners with another silica tetrahedral to create a single chain (see Figure 7) or three corners to create a double chain (Figure 8). The core structure of an inosilicate is either an infinite single or double chain of silica tetrahedrals.
Figure 7: The core of a single chain inosilicate

The mineral group pyroxenes are examples of single chain inosilicates.

Figure 8: The core of a double chain inosilicate

The mineral amphibole is an example of a double chain inosilicate.

**Phyllosilicates**

Phyllosilicates are silica complexes where each tetrahedral shares three corners and creates a sheet of silicon and oxygen. (see Figure 9) The core complex of a phyllosilicate is an infinite sheet of connected silica tetrahedrals.

Figure 9: The core of phyllosilicate

The mineral talc is an example of a phyllosilicate complex.
Tectosilicates

Tectosilicates are three dimensional silicate structures. The core structure of a tectosilicate is an infinite network of connected silica tetrahedrals. (see Figure 10)

![Figure 10: The 3d core of tectosilicate](image)

The mineral quartz is an example of a tectosilicate complex.

Although many silica complexes form network covalent solids, quartz is a particularly good example of a network solid. Silicates in general share the properties of covalent solids, and this affiliated array of properties makes them very useful in modern day industry.

Silanes

Silanes are silicon-hydrogen compounds. Carbon-hydrogen compounds form the backbone of the living world with seemingly endless chains of hydrocarbons. With the same valence configuration, and thus the same chemical versatility, silicon could conceivably play a role of similar organic importance. But silicon does not play an integral role in our day to day biology. One principal reasons underlies this.

Like hydrocarbons, silanes progressively grow in size as additional silicon atoms are added. But there is a very quick end to this trend. The largest silane has a maximum of six silicon atoms. (see Figure 11)

![Figure 11: The largest silane, hexasilane](image)

Hexasilane is the largest possible silane because Si-Si bonds are not particularly strong. In fact, silanes are rather prone to decomposition. Silanes are particularly prone to decomposition via oxygen. Silanes also have a tendency to swap out their hydrogens for other elements and become organosilanes. (see Figure 12)
Silanes have a variety of industrial and medical uses. Among other things, silanes are used as water repellents and sealants.

**Silicones**

Silicones are a synthetic silicon compound, they are not found in nature. When specific silanes are made to undergo a specific reaction, they are turned into silicone, a very special silicon complex. Silicone is a polymer and is prized for its versatility, temperature durability, low volatility, general chemical resistance and thermal stability. Silicone has a unique chemical structure, but it shares some core structural elements with both silicates and silanes. (See Figure 13)

**Silicone polymers** are used for a huge array of things. Among numerous other things, breast implants are made out of silicone.

**Silicon Halides**

Silicon has a tendency to readily react with halogens. The general formula depicting this is SiX₄, where X represents any halogen. Silicon can also expand its valence shell, and the laboratory preparation of [SiF₆]²⁻ is a definitive example of this. However, it is unlikely that silicon could create such a complex with any other halogen than fluorine, because six of the larger halogen ions cannot physically fit around the central silicon atom.
Silicon halides are synthesized to purify silicon complexes. Silicon halides can easily be made to give up their silicon via specific chemical reactions that result in the formation of pure silicon.

Applications

Silicon is a vital component of modern day industry. Its abundance makes it all the more useful. Silicon can be found in products ranging from concrete to computer chips.

Electronics

The high tech sectors adoption of the title Silicon Valley underscores the importance of silicon in modern day technology. Pure silicon, that is essentially pure silicon, has the unique ability of being able to discretely control the number and charge of the current that passes through it. This makes silicon play a role of utmost importance in devices such as transistors, solar cells, integrated circuits, microprocessors, and semiconductor devices, where such current control is a necessity for proper performance. Semiconductors exemplify silicon's use in contemporary technology.

Semiconductors

Semiconductors are unique materials that have neither the electrical conductivity of a conductor nor of an insulator. Semiconductors lie somewhere in between these two classes giving them a very useful property. Semiconductors are able to manipulate electric current. They are used to rectify, amplify, and switch electrical signals and are thus integral components of modern day electronics.

Semiconductors can be made out of a variety of materials, but the majority of semiconductors are made out of silicon. But semiconductors are not made out of silicates, or silanes, or silicones, they are made out pure silicon, that is essentially pure silicon crystal. Like carbon, silicon can make a diamond like crystal. This structure is called a silicon lattice. (see Figure 15) Silicon is perfect for making this lattice structure because its four valence electrons allow it too perfectly bond to four of its silicon neighbors.

Figure 15: an example of a silicon lattice

However, this silicon lattice is essentially an insulator, as there are no free electrons for any charge movement, and is therefore not a semiconductor. This crystalline structure is turned into a semiconductor when it is doped. Doping refers to a process by which impurities are introduced into ultra pure silicon, thereby changing its electrical properties and turning it into a semiconductor. Doping turns pure silicon into a semiconductor by adding or removing a very very small amount
of electrons, thereby making it neither an insulator nor a conductor, but a semiconductor with limited charge conduction. Subtle manipulation of pure silicon lattices via doping generates the wide variety of semiconductors that modern day electrical technology requires.

Semiconductors are made out of silicon for two fundamental reasons. Silicon has the properties needed to make semiconductors, and silicon is the second most abundant element on earth.

Glasses

Glass is another silicon derivate that is widely utilized by modern day society. If sand, a silica deposit, is mixed with sodium and calcium carbonate at temperatures near 1500 degrees Celsius, when the resulting product cools, glass forms. Glass is a particularly interesting state of silicon. Glass is unique because it represents a solid non-crystalline form of silicon. The tetrahedral silica elements bind together, but in no fundamental pattern behind the bonding. (see Figure 16)

Figure 16: Non-crystalline silica

The end result of this unique chemical structure is the often brittle typically optically transparent material known as glass. This silica complex can be found virtually anywhere human civilization is found.

Glass can be tainted by adding chemical impurities to the basal silica structure. (see Figure 17) The addition of even a little Fe₂O₃ to pure silica glass gives the resultant mixed glass a distinctive green color.
Fiber Optics

Modern fiber optic cables must relay data via undistorted light signals over vast distances. To undertake this task, fiber optic cables must be made of special ultra-high purity glass. The secret behind this ultra-high purity glass is ultra pure silica. To make fiber optic cables meet operational standards, the impurity levels in the silica of these fiber optic cables has been reduced to parts per billion. This level of purity allows for the vast communications network that our society has come to take for granted.

Ceramics

Silicon plays an integral role in the construction industry. Silicon, specifically silica, is a primary ingredient in building components such as bricks, cement, ceramics, and tiles.

Additionally, silicates, especially quartz, are very thermodynamically stable. This translates to silicon ceramics having high heat tolerance. This property makes silicon ceramics particularly useful from things ranging from space ship hulls to engine components. (see Figure 18)
Polymers

Silicone polymers represent another facet of silicon’s usefulness. Silicone polymers are generally characterized by their flexibility, resistance to chemical attack, impermeability to water, and their ability to retain their properties at both high and low temperatures. This array of properties makes silicone polymers very useful. Silicone polymers are used in insulation, cookware, high temperature lubricants, medical equipment, sealants, adhesives, and even as an alternative to plastic in toys.

Production

As silicon is not normally found in its pure state, silicon must be chemically extracted from its naturally occurring compounds. Silica is the most prevalent form of naturally occurring silicon. Silica is a strongly bonded compound and it requires a good deal of energy to extract the silicon out of the silica complex. The principal means of this extraction is via a chemical reaction at a very high temperature.

The synthesis of silicon is fundamentally a two step process. First, use a powerful furnace to heat up the silica to temperatures over 1900 degrees celsius, and second, add carbon. At temperatures over 1900 degrees celsius, carbon will reduce the silica compound to pure silicon.

Purification

For some silicon applications, the purity of freshly produced silicon is not satisfactory. To meet the demand for high purity silicon, techniques have been devised to further refine the purity of extracted silicon.

Purification of silicon essentially involves taking synthesized silicon, turning it into a silicon compound that can be easily distilled, and then breaking up this new formed silicon compound to yield an ultra pure silicon product. There are several distinct purification methods available, but most chemical forms of purification involve both silane and silicon halide complexes.

Trivia

- Silicon is the eighth most abundant element in the universe.
- Silicon was first identified in 1787 but first discovered as an element 1824.
- Silicon is an important element in the metabolism of plants, but not very important in the metabolism of animals.
- Silicon is harmless to ingest and inject into the body but it is harmful to inhale.
- Silicosis is the name of the disease associated with inhaling too much of the silicon compound silica. It primarily affects construction workers.
- Silica is a major chemical component of asbestos.

References

Problems

Highlight area next to "Ans" to see answer

How many oxides does Silicon have, and what are they?

Ans:

How does a silicate tetrahedral balance its charge if not bonded with another silicate?

Ans:

Carbon is to organic compounds as silica is to:

Ans:

How big is the largest silicon-hydrogen compound?

Ans:

Why is silicon important to computers?

Ans:

Contributors

• Thomas Bottyan (2010), Christina Rabago (2008)