**Group 4A**

**Physical Properties**
- Group 4A elements are all solids at room temperature.
- The metallic properties of Group 4A elements increase from carbon to lead.
- Diamond, graphite, and buckminsterfullerene are three allotropes of carbon.

**Melting and Boiling Points**

<table>
<thead>
<tr>
<th>Element</th>
<th>mp (°C)</th>
<th>bp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>4827</td>
<td>3562*</td>
</tr>
<tr>
<td>Si</td>
<td>1420</td>
<td>2850</td>
</tr>
<tr>
<td>Ge</td>
<td>945</td>
<td>1751</td>
</tr>
<tr>
<td>Sn</td>
<td>232</td>
<td>327*</td>
</tr>
<tr>
<td>Pb</td>
<td>207.2</td>
<td>2.27*</td>
</tr>
</tbody>
</table>

*diamond

**Density**

<table>
<thead>
<tr>
<th>Element</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2.27*</td>
</tr>
<tr>
<td>Si</td>
<td>2.34*</td>
</tr>
<tr>
<td>Ge</td>
<td>5.32</td>
</tr>
<tr>
<td>Sn</td>
<td>7.26</td>
</tr>
<tr>
<td>Pb</td>
<td>11.34</td>
</tr>
</tbody>
</table>

*graphite

**Sources**
- Carbon is found in nature as an element, in Earth’s atmosphere as carbon dioxide, in Earth’s crust as carbonate minerals, and in organic compounds produced in cells.
- Silicon can be produced by the reduction of silicon dioxide (silica) with magnesium, carbon, or aluminum. Example: SiO₂(s) + 2Mg(s) → Si(s) + 2MgO(s)
- Tin is prepared by reduction of the mineral cassiterite, SnO₂. SnO₂(s) + 2C(s) → 2CO(g) + Sn(s)
- Lead is refined from the mineral galena, PbS. Galena is heated in air to form a mixture of PbO and PbSO₄. Lead is produced through further reaction of these compounds with PbS.

About 90% of the minerals in Earth’s crust are silica and silicates. In silicates, each silicon atom is surrounded by three or four oxygen atoms. These units can be linked together in chains, sheets, rings, or crystals.
Group 4A

**Atomic Properties**

- Group 4A elements have an electron configuration that ends in $ns^2np^2$.
- For Group 4A elements, the most common oxidation numbers are +4 and +2. For carbon, −4 is also common.
- Silicon and germanium are semiconductors.

**Important Compounds and Reactions**

- Group 4A elements are oxidized by halogens. Example:
  \[
  \text{Ge(s)} + 2\text{Cl}_2(g) \rightarrow \text{GeCl}_4(l)
  \]
- Group 4A elements combine with oxygen to form oxides. Example:
  \[
  \text{Sn(s)} + \text{O}_2(g) \rightarrow \text{SnO}_2(s)
  \]
- Complete combustion of hydrocarbons yields carbon dioxide and water. Example:
  \[
  \text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l)
  \]

**First Ionization Energy**

- Plants use carbon dioxide to produce carbohydrates and oxygen.
- Aqueous sodium silicate, Na$_2$SiO$_3$, is used as an adhesive for paper, as a binder in cement, and to stabilize shale during oil drilling.
- Acetylene is a fuel used for welding. It forms when calcium carbide and water react.
- Tungsten carbide, WC, is used on the cutting surfaces of drill bits and saw blades.
- Lead(IV) oxide, PbO$_2$, is used as electrodes in lead acid car batteries.
- Tin(II) fluoride, SnF$_2$, is used in toothpaste to prevent tooth decay.

**Silicon dioxide, SiO$_2$, is the sand on many beaches and is used to make glass.**
**C  Green Chemistry**

The term *green chemistry* was coined in 1992. It describes the effort to design chemical processes that don’t use or produce hazardous substances. The goal is to protect the environment and conserve resources. For example, if a catalyst is used to reduce the temperature at which a reaction occurs, the process requires less energy.

Carbon dioxide is at the center of a green chemistry success story. Organic solvents are used to dissolve substances that are insoluble in water. Many of these solvents are toxic. It can be difficult to remove all traces of the toxic solvent from reaction products and safely recycle or dispose of the solvent. Supercritical carbon dioxide can replace some organic solvents.

A gas becomes a supercritical fluid at a temperature and pressure called its critical point. For carbon dioxide, this occurs at 31.1°C and about 100 atmospheres. At its critical point, carbon dioxide is in a hybrid state. It has a high density (like a liquid) but it is easily compressed (like a gas). Many organic compounds dissolve in supercritical carbon dioxide. The solvent is easily separated from a reaction mixture because it evaporates at room temperature and pressure. It is also used to separate substances from mixtures. It can extract caffeine from coffee beans, dry-clean clothes, or clean circuit boards.

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**Si  Optical Glass**

Glass is a material with the structure of a liquid, but the hardness of a solid. In most solids, the particles are arranged in an orderly lattice. In solid glass, the molecules remain disordered, as in a liquid. The main ingredient in most glass is silica (SiO₂), which is one of the few substances that can cool without crystallizing.

The glass used in eyeglasses, microscopes, and telescopes is called optical glass. It is purer than window glass and transmits more light. Optical glass can be drawn into long fibers that are used like tiny periscopes to view tissues deep within the human body.

In an optical fiber, light travels through a thin glass center called the core. A second glass layer reflects light back into the core. An outer plastic layer protects the fiber from damage.

When the fibers are bundled into cables, they often replace electrical cables in computer networks. They are also used to transmit television signals and phone calls over long distances.
With a cellular phone, you can call your friends from almost any location. You can play a video game, read e-mails, or get the latest news. You may even be able to take and send digital photos. How can such a complex device be small enough to fit in your pocket? Semiconductor technology is responsible.

Silicon is a semiconductor. In its pure form, it conducts an electric current better than most nonmetals but not as well as metals. But its ability to conduct can be changed dramatically by doping, or adding traces of other elements, to the silicon crystal.

Doping with arsenic produces a donor, or n-type, semiconductor. Each arsenic atom has five valence electrons, compared with four for silicon. So there are extra electrons in the crystal. Doping with boron produces an acceptor, or p-type, semiconductor. Because boron has only three valence electrons, there is a positive “hole” in the crystal for every boron atom. The extra electrons or holes are free to move and conduct an electric current.

Combinations of n-type and p-type semiconductors are used to build tiny electronic components. An integrated circuit containing millions of components can fit on a semiconductor wafer that is smaller than a fingernail! The resulting “chip” can control a computer, portable CD player, calculator, or cellular phone.

Buckminsterfullerene ($C_{60}$) is one member of a family of fullerenes. These structures are closed-cage spherical or nearly spherical forms of elemental carbon. The cages are networks of 20 to 600 carbon atoms.

Scientists have verified the existence of nesting spheres of fullerenes. $C_{60}$ can be nested inside $C_{240}$, and this pair can be nested inside $C_{540}$. These nesting structures are sometimes called bucky-onions because they resemble the layers of an onion.

Dr. Sumio Iijima discovered a tubular fullerene, or carbon nanotube, in Japan in 1991.

One name for diamonds is "ice." A diamond can quickly draw heat from your hand when you touch it. Such a high thermal conductivity is unusual for a substance containing covalent bonds.
**C Greenhouse Gases**

There are gases in Earth’s atmosphere that are called greenhouse gases because they act like the glass in a greenhouse. Sunlight easily passes through these gases to Earth’s surface. Some of the solar energy is reflected off the surface as infrared radiation. This radiation is absorbed by greenhouse gases and radiated back to Earth. By trapping infrared radiation, the greenhouse gases keep Earth’s surface about 33°C warmer than it would be otherwise.

Carbon dioxide (CO$_2$) is the most abundant greenhouse gas. It is released into the air as a product of cellular respiration and removed from the air during photosynthesis. Such interactions normally keep the amount of atmospheric CO$_2$ in check. But the burning of fossil fuels releases more than 20 billion metric tons of CO$_2$ every year. Also, as forests are cleared for agriculture, the ability of plants to remove CO$_2$ from the atmosphere is reduced.

Scientists agree that a rise of only a few degrees in Earth’s temperature could cause problems. They disagree on how severe the problems could be. Could climates change so that farm-lands become deserts? Could the melting of ice caps cause sea levels to rise until coastal cities are under water?

**Si Composite Materials**

Most composites contain two distinctly different materials. The materials can be arranged in layers as when a sheet of plastic is sealed between panes of glass. Or a composite may consist of a matrix in which fibers of a second material are embedded. Often, the matrix is plastic. The fibers can be carbon. Polycrylonitrile (PAN) is used to make some carbon fibers. PAN fibers oxidize when they are heated in air. The chains of aromatic rings that result are then heated in the absence of air. The chains fuse into long thin ribbons of almost pure carbon, which pack together in stacked layers.

Composites reinforced with carbon fibers are stronger than steel, yet light in weight. These composites are used in sports equipment, such as hockey sticks and golf clubs. It is less tiring to swing a tennis racket made from a carbon-fiber composite than one made from wood or metal. Carbon-fiber baseball bats act more like wood bats than do aluminum bats.
**Carbon Monoxide**

It is hard to detect colorless, odorless carbon monoxide gas. When it is inhaled, its molecules bind to the hemoglobin in red blood cells. They bind about 200 times more effectively than oxygen molecules do. So less oxygen reaches body tissues. Headaches, dizziness, nausea, and drowsiness are symptoms of low-level carbon monoxide poisoning. Higher levels of carbon monoxide are fatal.

The incomplete combustion of fuel in gas furnaces and space heaters produces carbon monoxide. It also forms in internal combustion engines that are not well maintained. In the United States, cars have catalytic converters, which convert carbon monoxide to carbon dioxide. Cigarette smoke contains carbon monoxide. The carbon monoxide from one cigarette can remain in a smoker’s blood for several hours. Smoking increases the risk of heart attacks because the heart must pump harder to deliver oxygen to cells when the level of oxygen is reduced.

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**Recycling Plastics**

At about 2 kg of waste per person per day, the United States leads the world in the production of solid waste. Luckily, the United States is also a leader in recycling. It is important to recycle plastics because they are made from crude oil, a non-renewable resource. Also, some plastics release toxic gases, such as hydrogen cyanide (HCN) and hydrogen chloride (HCl), when they burn in an incinerator. Finally, plastics are used for packaging material because they do not decay when exposed to sunlight, water, or microorganisms. The downside of this resistance to decay is that plastics can remain unchanged in dumps and landfills for decades.

Plastics are usually sorted by type before they are melted and reprocessed. The plastics industry has a code to identify common types of plastics. The numeral 1 is assigned to polyethylene terephthalate (PET), which is used in soft-drink bottles. The numeral 2 refers to high-density polyethylene (HDPE), which is used in milk jugs and shampoo bottles. These are the two types in greatest demand. Carpets and clothing are made from recycled PET fibers. Recycled HDPE is used as a wood substitute for decks and benches.

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**Silicone Polymers**

If you have worn hard contact lenses or used shaving cream, you have used a silicone. Silicone polymers have chains in which silicon and oxygen alternate. The properties of silicones depend on the groups bonded to the silicon atoms and the length of the chains.

In silicone rubber and resins, there are cross-links between the chains. These silicones repel water and remain elastic, even at low temperatures. They are used in space suits, as gaskets in airplane windows, and as sealants that are squeezed into place and left to harden.

In polydimethylsiloxane, two methyl groups are bonded to each silicon atom in the chain. Polydimethylsiloxane is used as a lubricant in skin and suntan lotions.

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**Did You Know...**

Members of the Scott expedition to the South Pole in 1912 may have died because of tin. Their supply of paraffin fuel leaked out through tiny holes in the tin-soldered joints of the storage cans because tin slowly changes to a powder below 13°C.