INORGANIC MATERIALS

Properties of metals

A. Conductivity:

Metals are a vast array of cations, their electrons disengaged, swirling around them as if the cations are in a sea of electrons. Added electrical potential pushes on past the stationary cations.

Molten ionic liquids conduct electricity since ions and electrons are mobile.

Molecular compounds conduct electrons through conjugated π-bonds as in conducting organic polymers.

Superconductors are a still a working mystery to us.

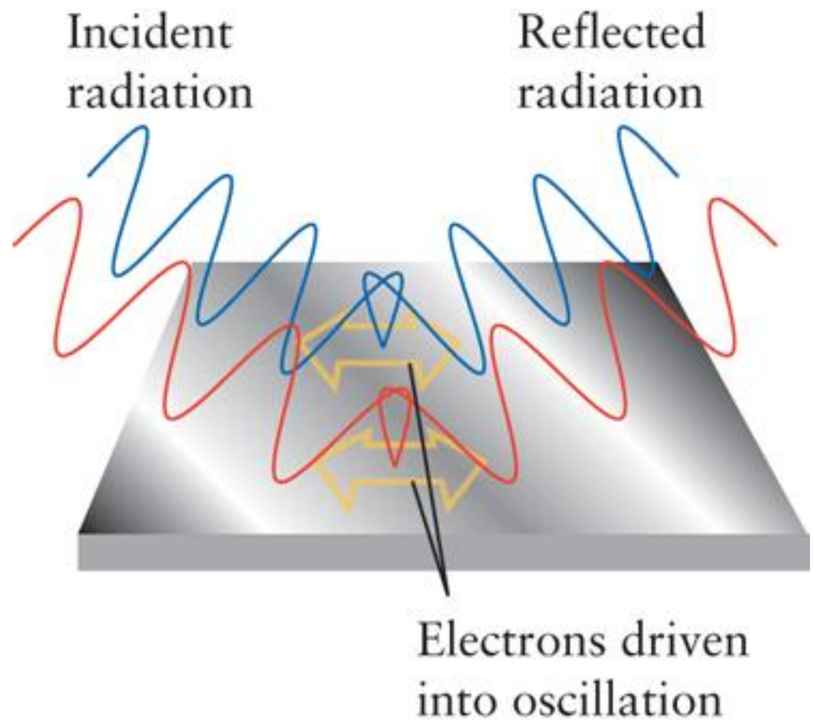
Properties of metals

B. Luster:

Metallic luster is a result of the mobile, sea of electrons.

The oscillating electromagnetic waves push the sea of electrons forward and backward.

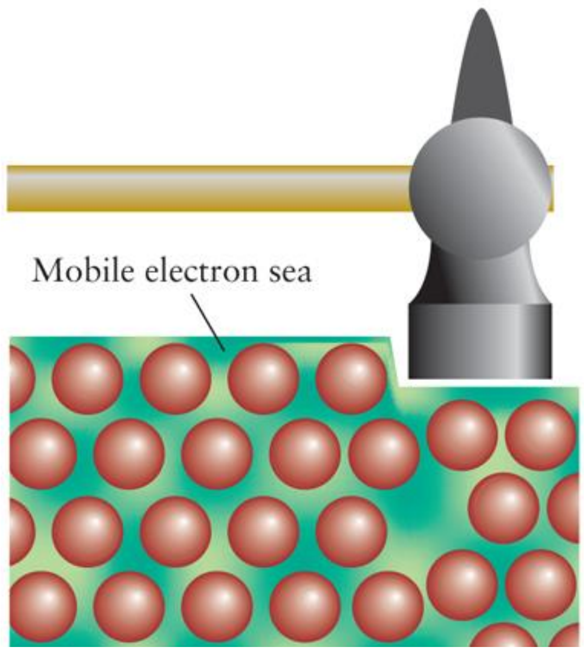
The result: light is re-emitted back to use, nearly perfectly in a mirror or luster appearance.

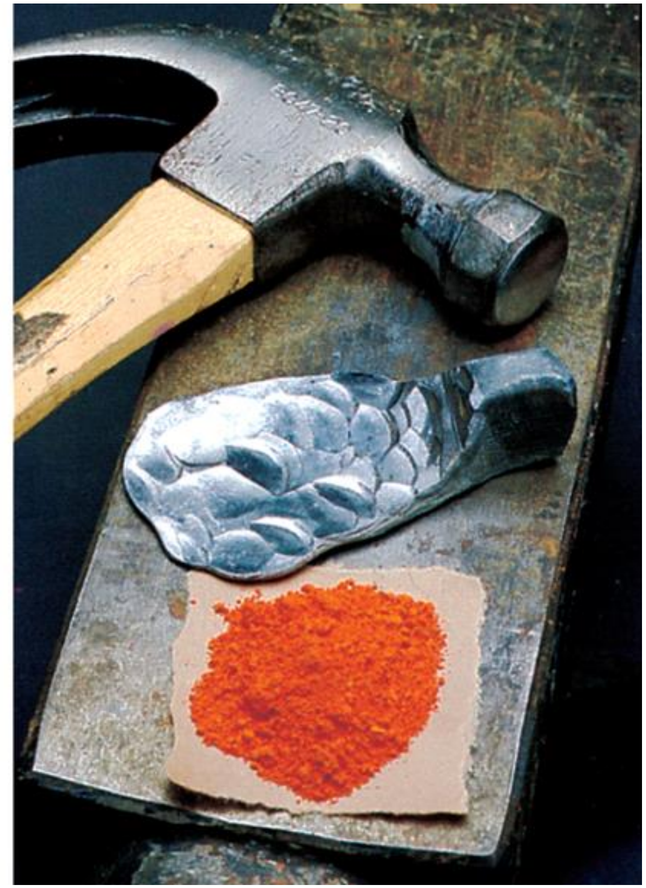


Properties of metals

C. Mobility:

When hammered, the cations in the sea of electrons, slip past one another, the electrons acting as a lubricant.





Groups of atoms slip at the same time, into a **slip plane**.

Alloys

Alloys are mixing two or more molten metals.

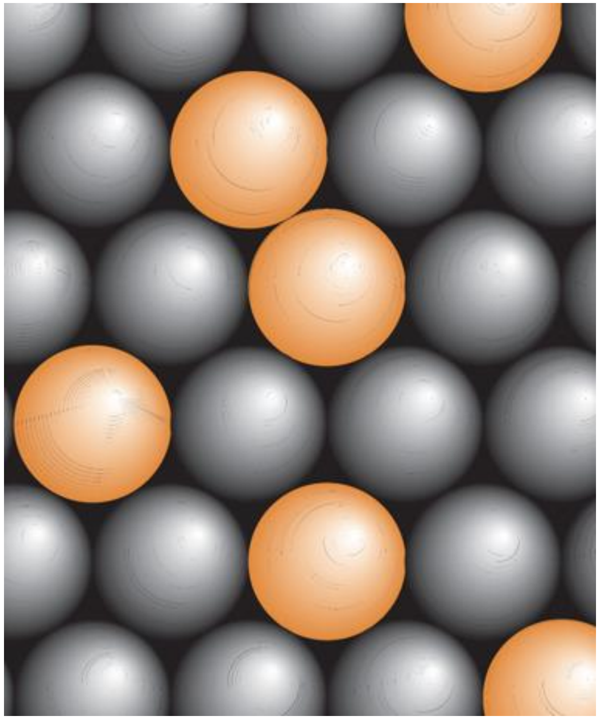
Homogeneous alloys, atoms of the different elements are distributed uniformly, like brass, bronze, and coinage alloys.

Heterogeneous alloys consist of a mixture of **crystalline phases** with different compositions, such as tin-lead solder and the mercury amalgam sometimes used to fill teeth.

d-block elements are **similar in size**, so an atom of one element takes the place of another.

Alloys

Substitutional alloys replaced an atom with another of the same size.



Copper-zinc alloy for some "copper" coins are an example.

Alloy	Mass percentage composition
brass	up to 40% zinc in copper
bronze	a metal other than zinc or nickel in copper (casting bronze: 10% Sn and 5% Pb)
cupronickel	nickel in copper (coinage cupronickel: 25% Ni)
pewter	6% antimony and 1.5% copper in tin
solder	tin and lead
stainless steel*	more than 12% chromium in iron

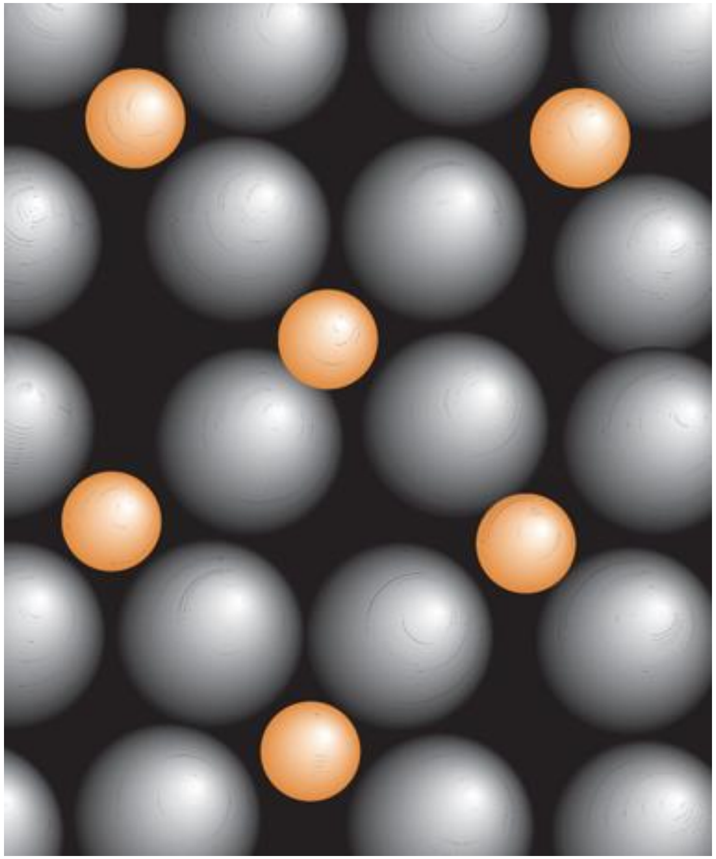
Alloys

Interstitial alloys have small atoms that fit between the bigger atoms into cavities or interstices (holes). Steel is an alloy of about 2% or less carbon in iron.

The atom going into the interstice, is usually about 60% smaller.

Electrical conductivity is effected by the atom in the hole.

However, the smaller atom is also harder adding strength to the alloy.



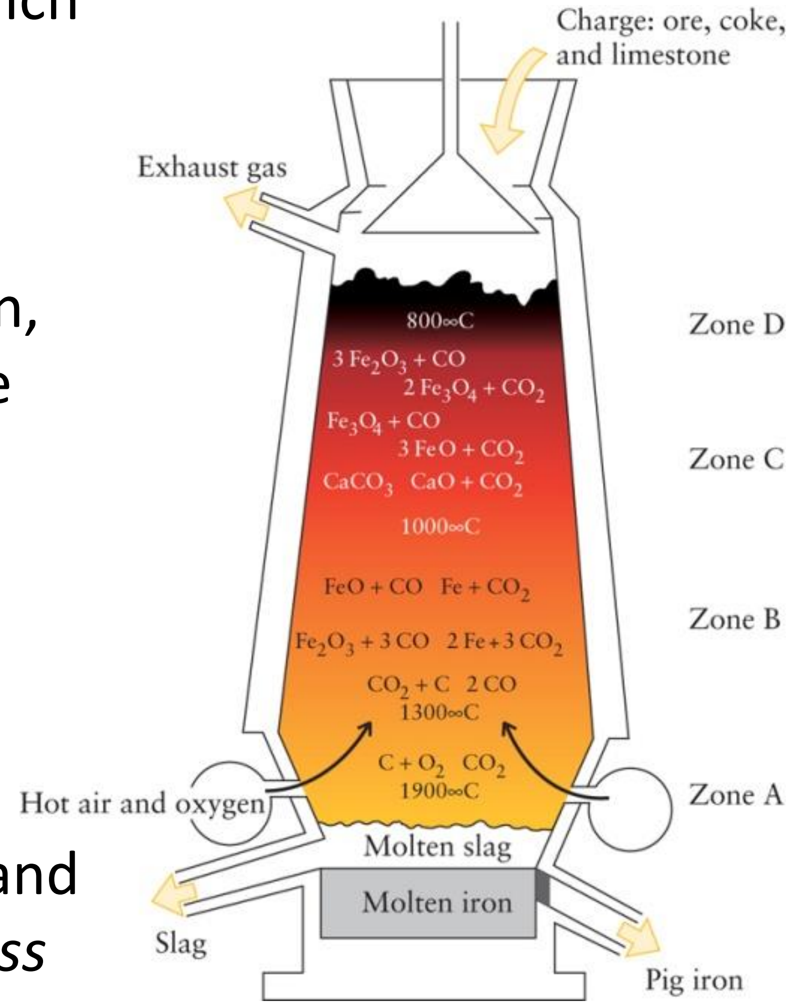
Steel

Iron is heated, in a charcoal fire from which the carbon came.

Pig iron: is produced in blast furnacces. Mainly iron, 3.5-4.5% carbon, ≈1% silicon, >1% manganese, and trace elements like sulfur and phosphorus.

To lower carbon content:

The ***basic oxygen process*** adds oxygen and powdered limestone. *This produces a less than 2% carbon content.*



Steel

To make steel, the carbon content is lowered, this is usually done with oxygen and oxidized minerals like lime, CaO, to make CO_2.

Next, ferroalloy metals are added like vanadium

Type of steel	Carbon content (%)	Properties and applications
low-carbon steel	< 0.15	ductility and low hardness, iron wire
mild-carbon steel	0.15 to 0.25	cables, nails, chains, and horseshoes
medium-carbon steel	0.20 to 0.60	nails, girders, rails, and structural purposes
high-carbon steel	0.61 to 1.5	knives, razors, cutting tools, drill bits

Stainless steel is highly **corrosion resistant** with about 15% by mass chromium. A thin veneer of chromium (III) oxide forms on the surface that repels water

Nonferrous Alloys

Nonferrous alloys are either homogenous or heterogeneous.

Both are heated and poured into a mold.

Sintering is pressing finely divided powdered metals into a mold. These tend to be **more porous**. In the case of bronze, bronze ball bearings are preferred since they absorb lubricant better.

Homogeneous alloys, preplacing atoms of **similar sized**, distort the local electronic structure. This distortion **lowers the electrical and thermal conductivity** of the host metal, but it also **increases hardness and strength**.

Nonferrous Alloys

Bronze the oldest known alloy (used in Turkey and Syria), where tin was melted with copper.

Tin (232°C m.p.) and Copper (1083°C m.p.) form a stronger alloy then individually. Harder than both and more resistant to corrosion.

Nonferrous Alloys

Alnico is an alloy of aluminum, nickel and cobalt has a wide thermal range of stability and corrosion resistant.

Hard Materials

Hard materials withstand strong deforming forces.

This includes cement, concrete, ceramics and steel.

These materials give buildings the ability to be built tall and weapons stronger and lighter.

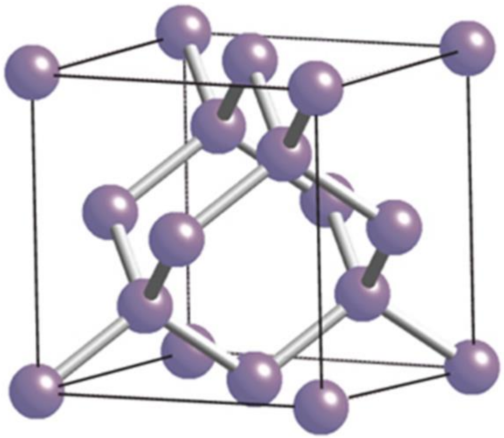



Diamond & Graphite

Network solids are very hard, rigid materials with high melting and boiling points.

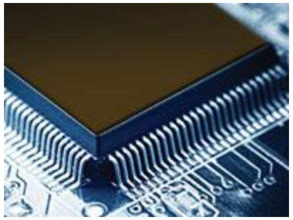
Diamond and graphite are allotropes of carbon, differing in the way in the atoms are linked.

Diamond:



Each carbon is sp^3, covalently bonded through a σ –bond to four neighbors.

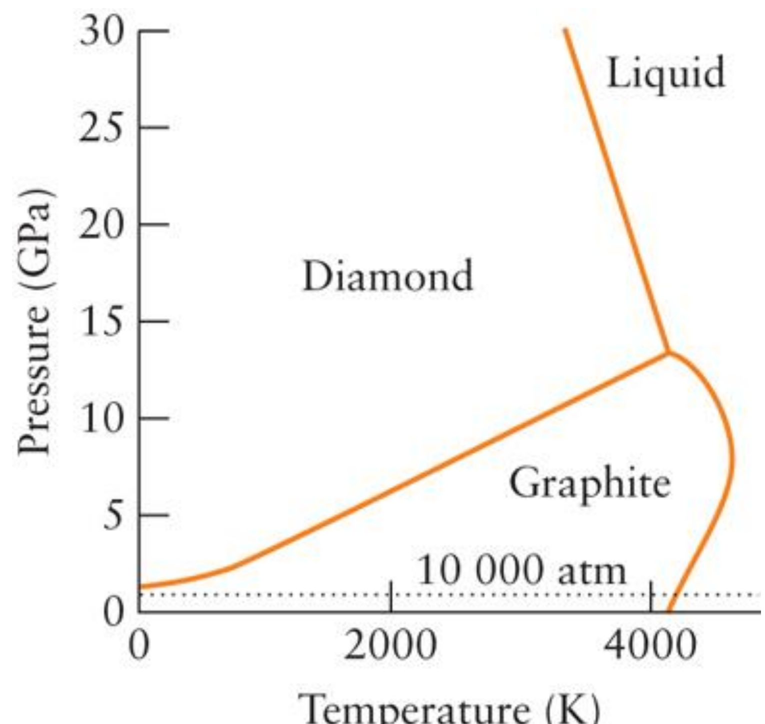
It's the hardest substance known and best conductor of heat and used for a protective coating on drills and heat conducting films.



Diamond & Graphite

Diamonds are found deep within the Earth in rock known as kimberlite. Diamonds are formed in the lab by subjecting graphite to high pressure, 80 kbar at 1500°C, often chromium (III) is added.

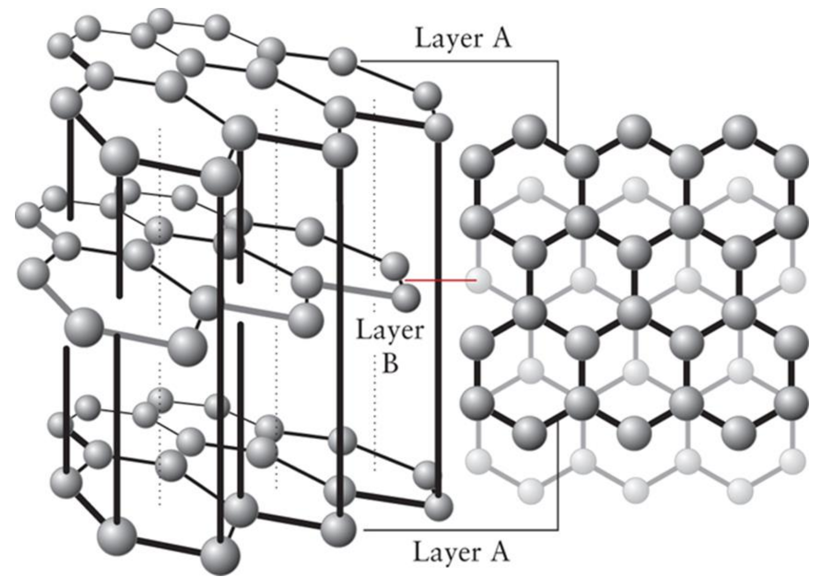
Regions of stability for diamond and graphite.



Diamond & Graphite

In graphite flat sheets are sp^2 hybridized carbon atoms are σ and π-bonded covalently into hexagons like chicken wire.

The sheets are held together by weak London forces.



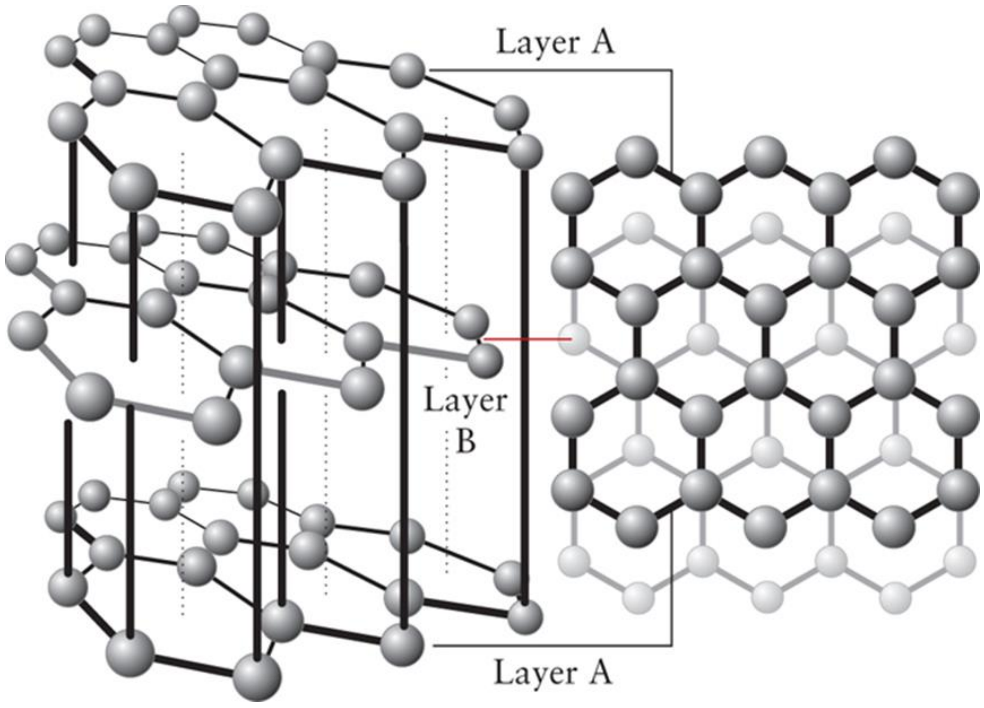
Electrons mobilize through the π–bonds between each carbon so account for graphite's luster, and conductivity.

However no electrons mobility is seen between sheets.

Diamond & Graphite

Each sheet of graphite is called graphene. Currently sheets are separated by pulling one layer away from another with tape; breaking the weaker London Forces between layers.

Graphene conducts electricity so if any gas absorbs to the surface the conductivity changes making graphene a very good gas sensor.



Calcium Carbonate

Calcium carbonate, $CaCO_3$, a 2+ cation and 2- anion has a very high lattice energy.

Found naturally as lightly compresses chalk and limestone. Marble is dense calcium carbonate and so polishes easily. Honeycombed colors are due to iron impurities.

The most common forms **pure calcium carbonate** are calcite and aragonite. Aragonite is denser and more rare.

Acid rain degrades marble in building material reverting calcium carbonate back to carbon dioxide and water.

Concrete & Cement

Lime, is a *broad class* of ***calcium*** containing inorganic compounds such as carbonates, oxides, hydroxides.

Calcium hydroxide, is known as **slaked lime** because the thirst of lime for water was quenched (slaked).

$$\mathbf{Ca(OH)_2}(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

Calcium carbonate decomposes to make **quicklime** when heated:

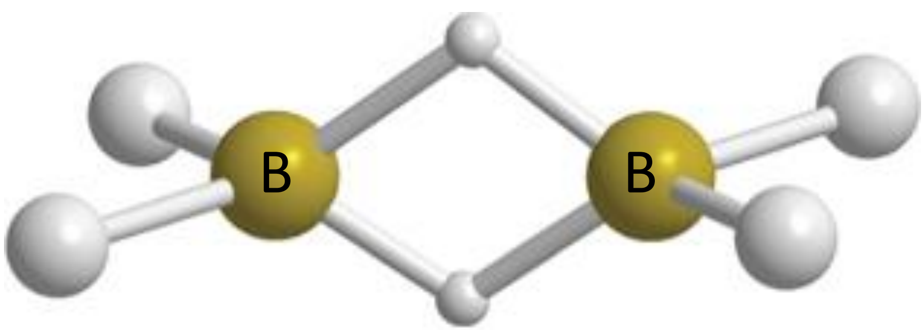
$$CaCO_3(s) \xrightarrow{\Delta} \mathbf{CaO}(s) + CO_2(g)$$

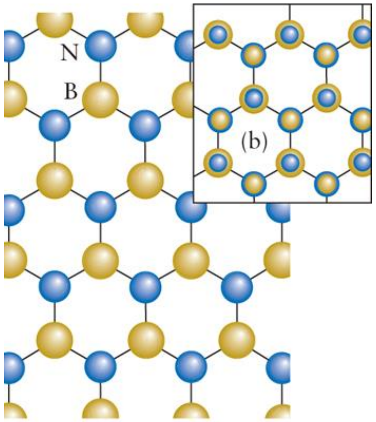
Calcium oxide is called quicklime *because* it reacts so exothermically and rapidly with water.

Borides, Carbides, and Nitrides

Metal borides are typically unrelated to their location in the periodic table and include AlB_2, CaB_6, $B_{13}C_2$, $B_{12}S_2$, Ti_3B_4, TiB, and TiB_2 . Boron is often the central atom in these clusters.

Covalent boron atoms form extended structures such as zigzag chains, branched chains, or networks of hexagonal rings of boron atoms.





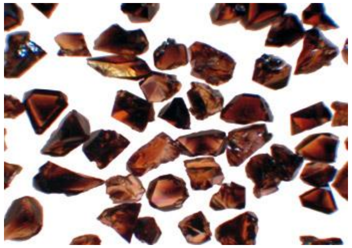
(a)

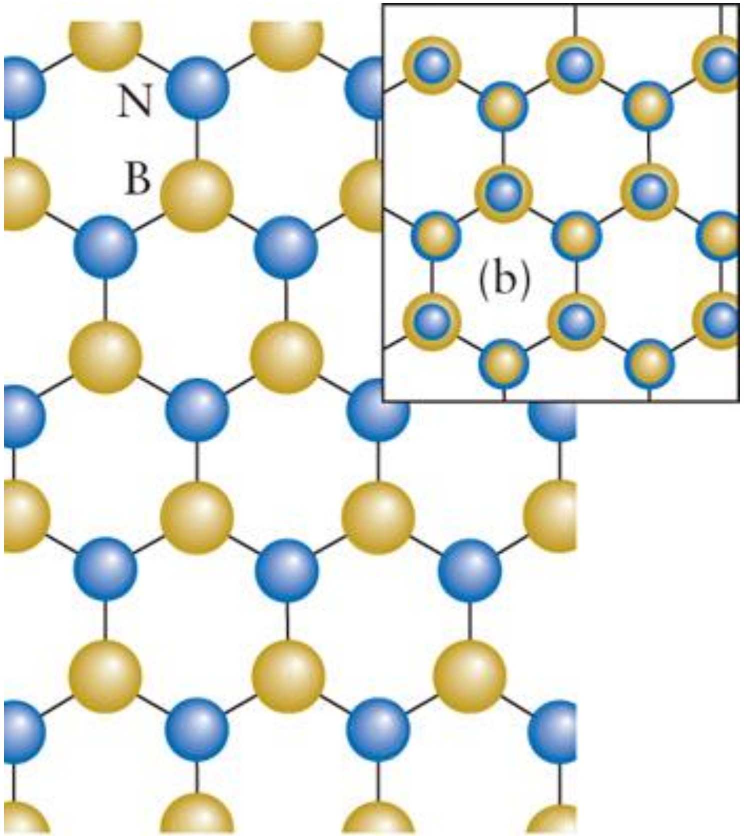
Borides, Carbides, and Nitrides

When heated to *white hot* in *ammonia*, boron nitride, BN, forms a fluffy, slippery powder resembling graphite:

$$2\,B(s) + 2\,NH_3(g) \xrightarrow{\Delta} 2\,BN(s) + 3\,H_2(g)$$

Under high pressure, boron nitride become very hard, diamondlike crystalline solids called Borazon (a proprietary name) with *similar* hardness and electrical properties to carbon including the formation of boron nitride nanotubes.





(a)

Borides, Carbides, and Nitrides

Covalent carbides include silicon carbide, SiC, which is sold as carborundum: $SiO_2(s) + 3\ C(s) \xrightarrow{2000℃} SiC(s) + 2\ CO(g)$

Carborundum is an excellent abrasive, very hard, with sharp edges.

Oxide of Silicon: Silicates

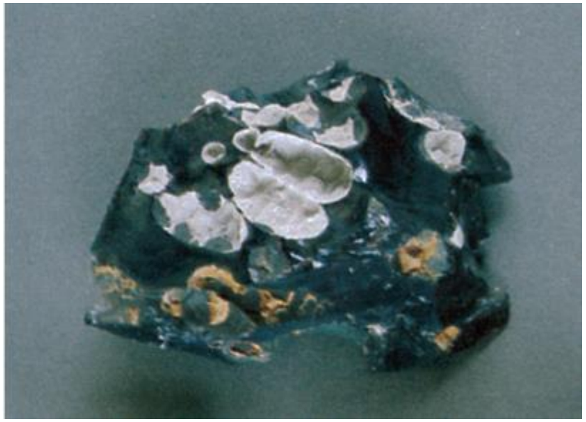
Silica, SiO_2, are hard, rigid network solids, insoluble in water and occur naturally in quarts.

Three common forms of silica:

quarts

quartzite

cristobalite



Sand is commonly formed from small pieces of quarts.

Glasses & Ceramics

Glasses and ceramics are two advanced materials that will have a big impact on your future life-style.

Optical fibers-which are already playing a major role in communication-will control our computers, and our automobiles will be much lighter and more economical.

Glasses - Making

To make glass, silica (sand) is heated to about 1600°C. Then metal oxides (M^+) are added to the heated silica.

At high temperatures Si-O bonds break allowing metal oxide $-Si-O^-M^+$ to form.

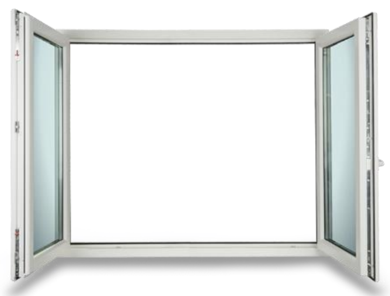
Silicate glasses are generally transparent and durable and can be formed in flat sheets, blown into bottles, or molded.

Optical fibers are made by drawing a thin fiber of optically pure glass. The fiber is then coated with plastic.

Glasses - Impurities

90% of all manufactured glass combines sodium and calcium oxides with silica to form **soda-lime glass**.

This glass, which is used for windows and bottles, is about 12% Na_2O.



Reducing the amount of soda and lime and adding 16% B_2O_3 produces a borosilicate glass, or Pyrex. ***Borosilicate*** glasses do not expand much when heated or cooled so are oven and laboratory friendly.

Glasses - Impervious

Glass is resistant to attack by most chemicals except with strong Lewis base F^- from hydrofluoric acid:

$$SiO_2(s) + 6\,HF(aq) \rightarrow SiF_6^-\,(aq) + 2\,H_3O^+\,(aq)$$

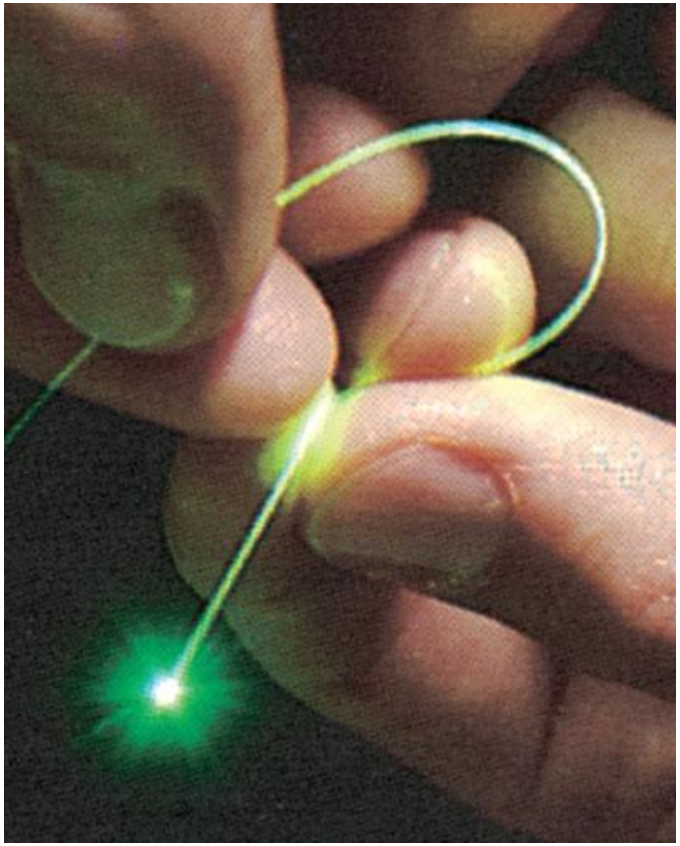
The process by which silica is removed from glass by the ions F^- (from HF), OH^-, and CO_3^{2-} is called etching.

Hot, molten sodium hydroxide and sodium carbonate also attacks glass:

$$SiO_2(s) + Na_2CO_3(l) \xrightarrow{1400°C} Na_2SiO_3(s) + CO_2(g)$$

Optical Fibers

Optical fibers provide wideband to telecommunications networks.



A glass is an ionic solid with an amorphous structure resembling that of a liquid.

Glass has a network structure of a nonmetal oxide, usually silica, SiO_2, melted with a metal oxides acting as "network modifiers," which alter the arrangement of bonds in the solid.

Ceramics

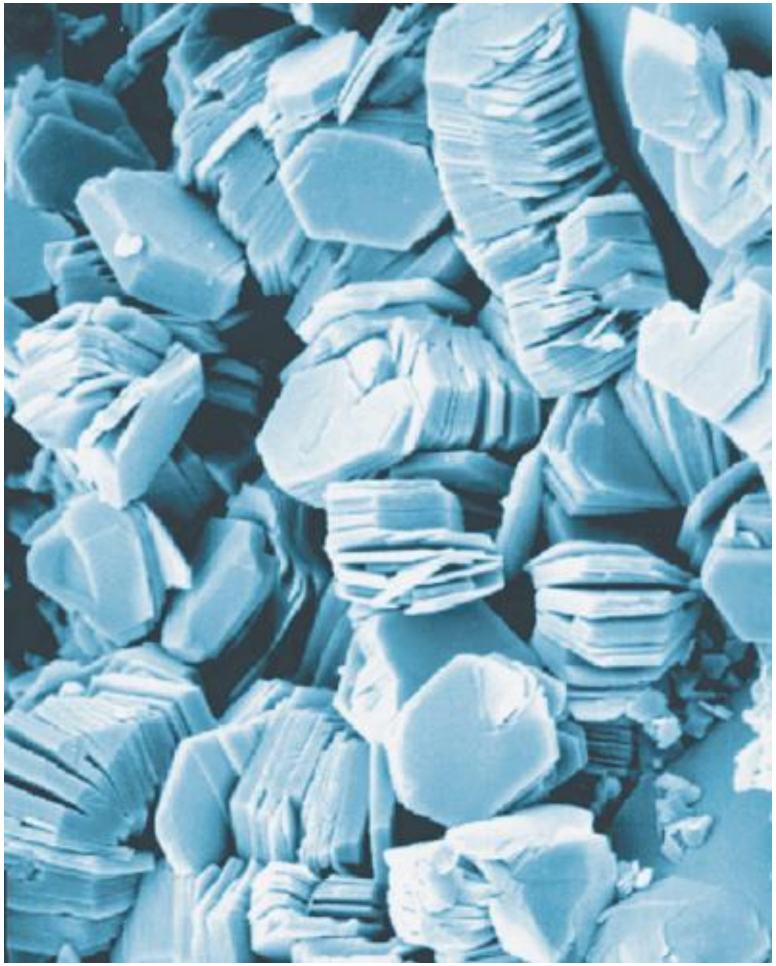
Most advanced technologies are made from one of the oldest known materials, common clay.

Most **clays** are oxides of silicon, aluminum, and magnesium with iron oxides impurities that cause the orange color of terra cotta tiles and flower pots.

China clay contains primarily kaolinite, a form of aluminum aluminosilicate that is reasonably free of the iron impurities that make many clays look reddish brown, and so it is white.

Ceramics

The internal structure of clay is Flaked, something like untidy stack of papers.



Sheets of tetrahedral silicate or octahedral units of aluminum or magnesium oxides are separated by *layers of water molecules* that **bind** the flakes together.

Heating clay drives the water out and <u>strong chemical bonds form</u> between the flakes.

Ceramics

Ceramic are inorganic material, hardened by heating to a high temperature.

Aluminum oxide, makes up about 80% of the advanced ceramics due to its:

- Hardness and rigidity,
- thermal conductivity,
- stability at high temperatures, and
- electrical insulating ability for microchips.

Large single-crystals of *aluminum oxide* are sapphires. Their color comes from **iron** and **titanium** impurities.

Ceramics

Sol-gel process is using **silicon dioxide ceramics** which are flexible, not brittle.

Organic silicon compounds polymerize into a network of cross-linked structures.

Removing the solvent produces high temperatures and low pressures, aerogel with a density about the same as that of air and is also a good insulator.

Conductors **resistance** changes with **temperature**.

Metallic conductors conductivity ***decreases*** as temperature increases.

Semiconductor conductivity ***increases*** as the temperature increases.

Insulators do not conduct electricity.

Superconductors have zero resistance. Some metals become superconductors at about 20K or less, and some compounds also show superconductivity around 70K.

Solid electrolyte is an ionic conductor.

Composite Material

Composite material consists of at least two materials which solidify together.

Bones have low density, where crystals of phosphate salts are embedded in fibers of a natural polymer called collagen that hold them together.

Lightweight composites, like graphite, can have three times the strength-to-density ratio of steel, and are found in tennis rackets and the body of the space shuttle.

Composite Material

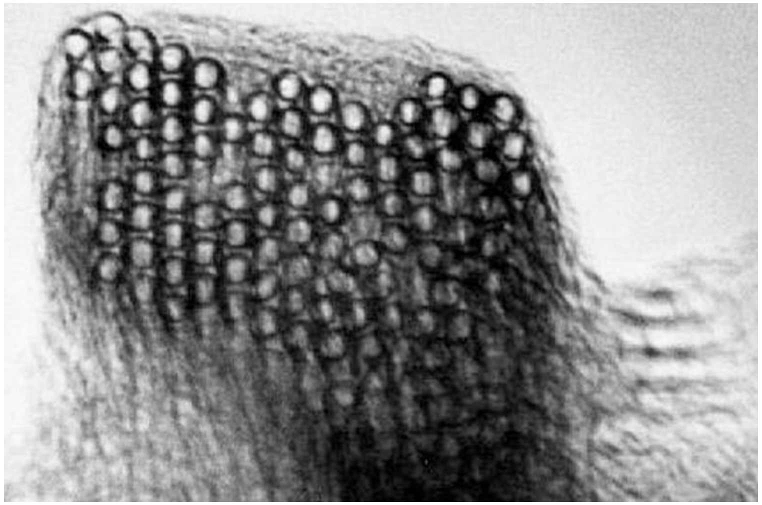
High temperature composites are found throughout cars including automobile engines, spark plugs, pressure and vibration sensors, brake linings, catalytic converters, and thermal and electrical insulation.

Nanomaterial

Nanoscience is the study of materials that are larger than single atoms, but too small to exhibit most bulk properties.

Nanoparticles range in size from about **1 to 100 nm** and can be manufactured and manipulated at the molecular level.

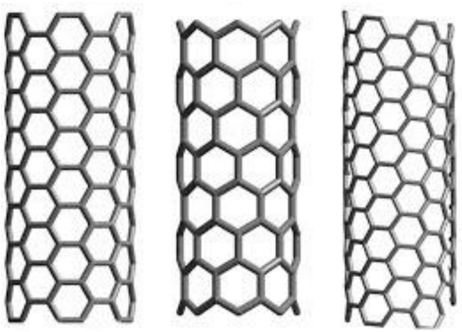
Nanotubes are nanometer wide tubes small enough to inject drugs into cells, or form tiny wires to conduct light and electrons.



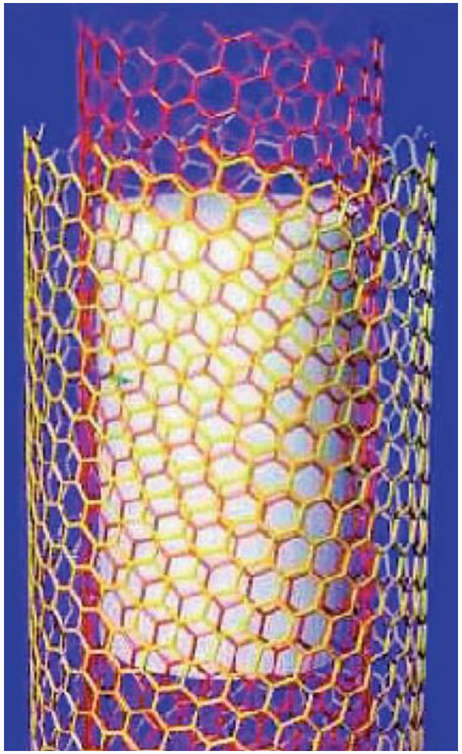
Nanomaterial

Carbon nanotubes conduct electricity in their extended network of delocalized π-bonds running from end to end.

They have low densities and are 40-times stronger than steel, yet are flexible enough to roll into even stronger structures.



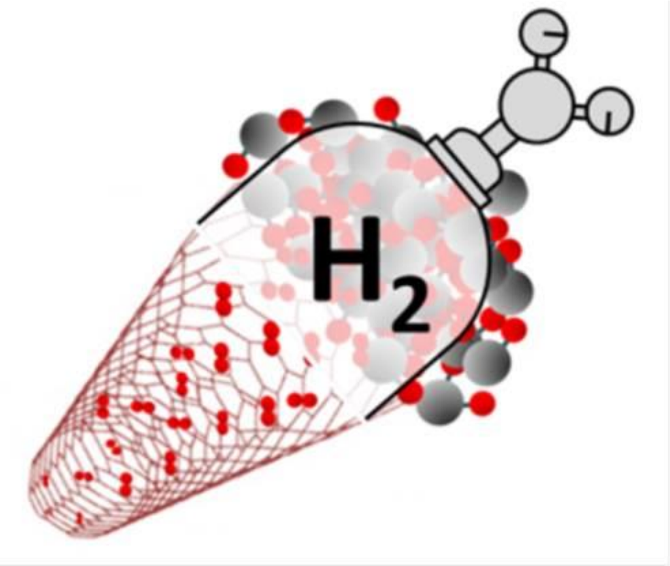
Single-walled



Double-walled

Nanomaterial

In carbon nanotubes the tubes are also a high density hydrogen storage device for possible use in automobiles.



In medicine

In electronic

Nanomaterial

"Nanobots," nanoscale robotic machines, have even been proposed to carry out medical repairs within the body.