Geo 101
Physical Geology

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Review:

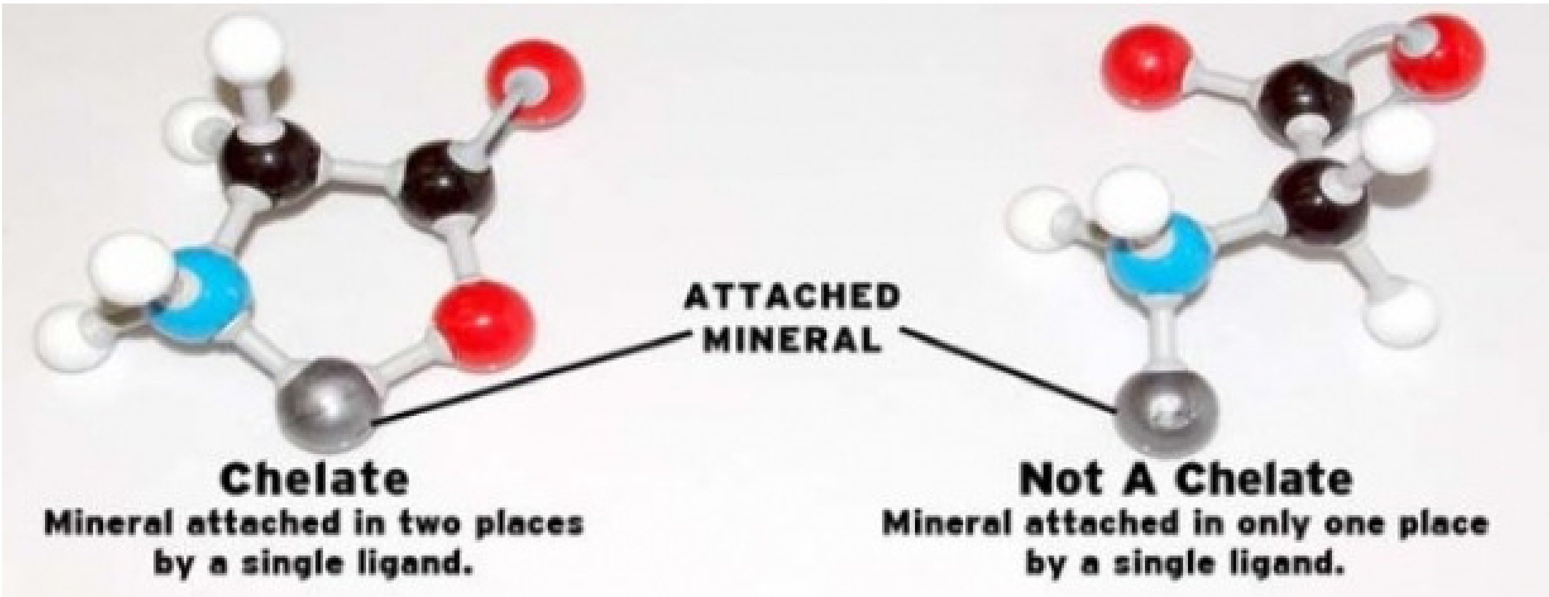
- Uniformitarianism and Catastrophism
- Rock and rock cycle
- Rock types
- Crystallization
- Lithification
- Formation of solar system
- Formation of Earth
- Geologic time

Q. What is a mineral?

A mineral is:

1. A naturally occurring substance.
2. Inorganic solid.
3. Have a chemical composition.
4. Has an ordered atomic structure (crystalline structure)

Chemical composition and crystalline structure are the two most important properties of a mineral: They distinguish any mineral from all others.



Q. Do we consider water as a mineral?

Answer:

Only ice (frozen water) is considered a mineral, whereas liquid water and water vapor do not.

The exception is mercury, which is found in its liquid form in nature.

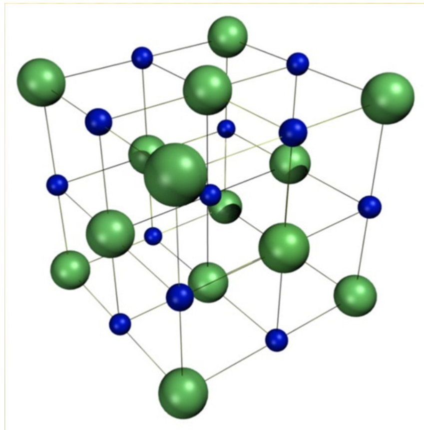
Q. Do we consider coal as a mineral?

Answer:

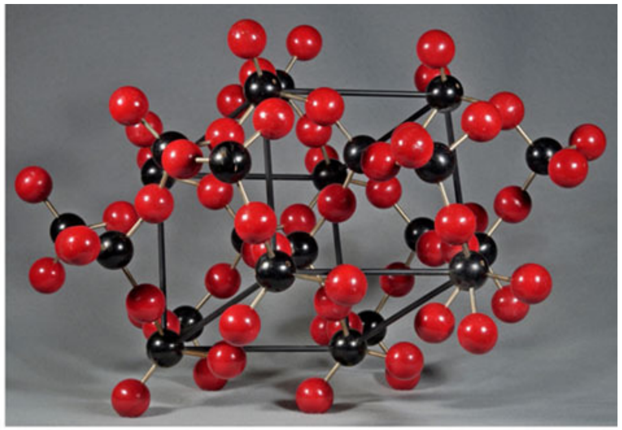
Coal is not a mineral because it contains organic carbon derived from plant remains.

Crystalline structure

- Minerals are crystalline substances, which means their atoms are arranged in an orderly, repetitive manner
- This orderly packing of atoms is reflected in the regularly shaped objects called crystals.
- To have a crystalline structure, a substance must be solid at Earth's surface temperature and not in the liquid or gaseous phase.



- Most minerals are chemical compounds having compositions that can be expressed by a chemical formula.
- For example, the common mineral quartz has the formula SiO2, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two.



Crystal Structure of Quartz

Q. What is the difference between rock and mineral?

- A rock is any solid mass of mineral, or mineral-like, that occurs naturally as part of our planet.
- Most rocks, like the common rock granite, occur as aggregates of several different minerals.
- A mineral is part of a rock. However, some rocks are composed almost entirely of one mineral. A common example is the sedimentary rock limestone, which consists of impure masses of the mineral calcite.

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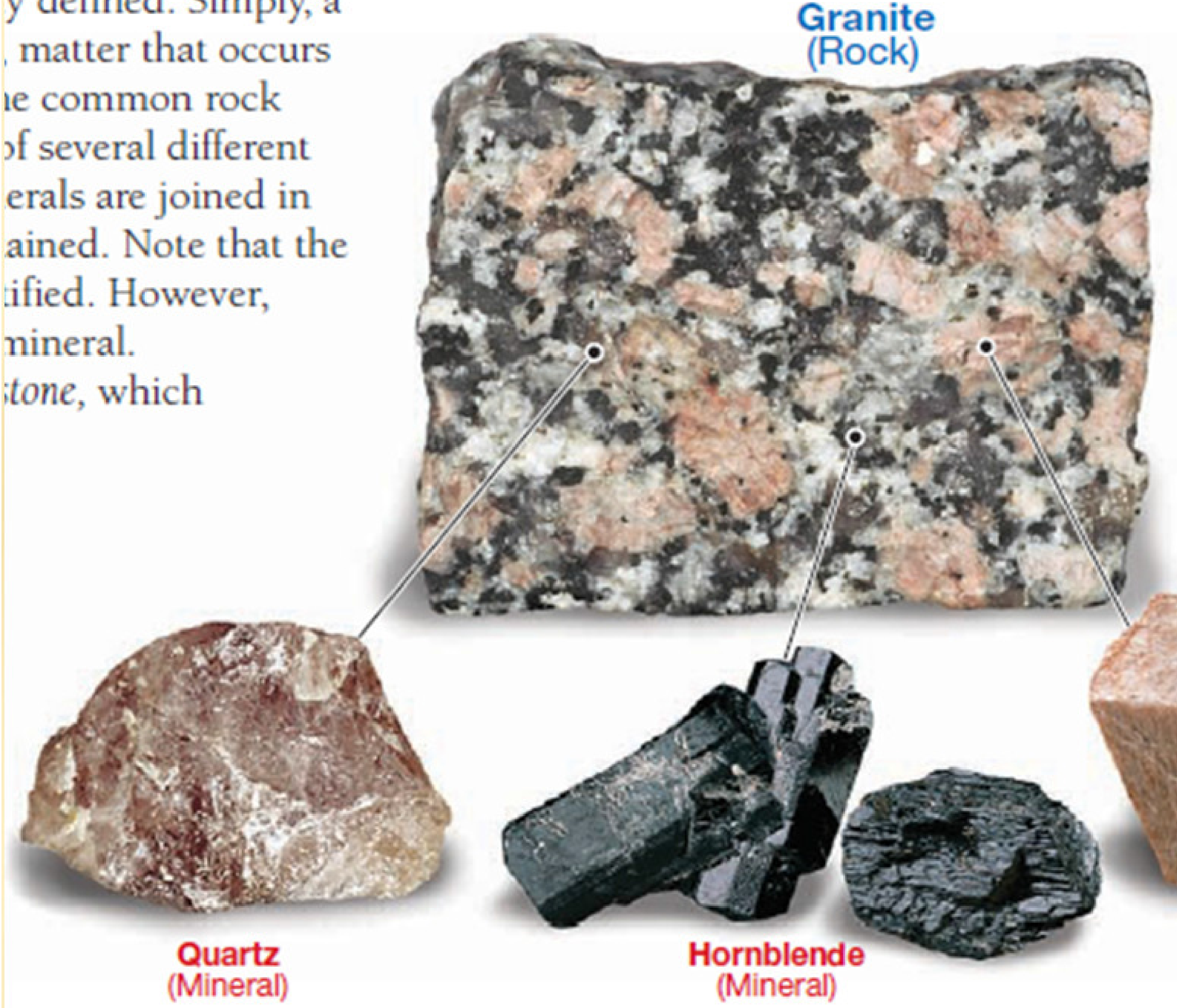
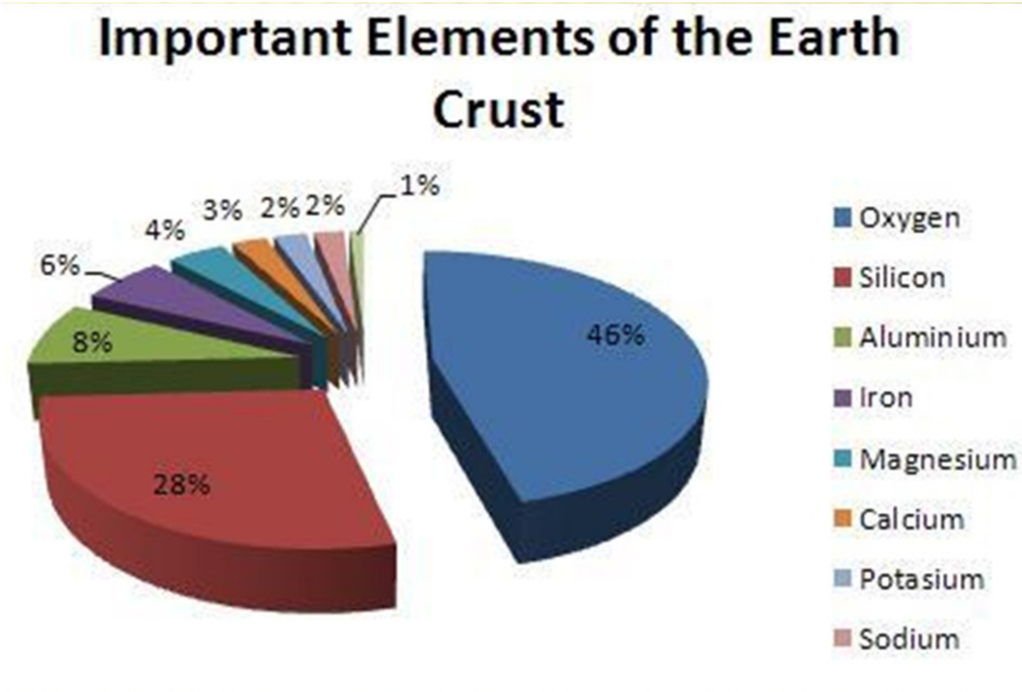


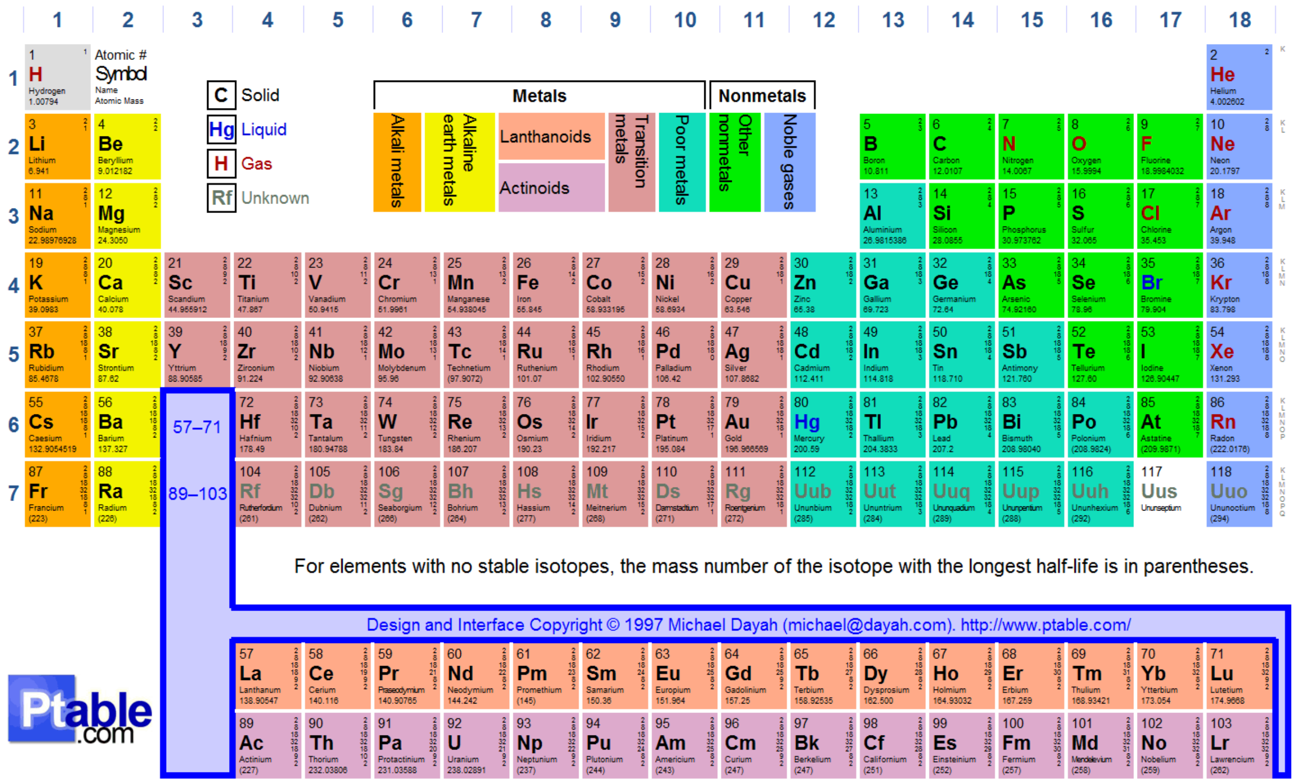
FIGURE 2.3 Most rocks are aggregates of two or more minerals. Shown here is a hand sample of the igneous rock granite and three of its major constituent minerals. *(Photos by E. J. Tarbuck)*

A total of 91 elements occur naturally in the Earth's crust. However, eight elements make up more than 98 percent of the earth's crust. These elements are:

- Oxygen
- Silicon
- Aluminum
- Iron
- Calcium
- Magnesium
- Potassium and
- Sodium



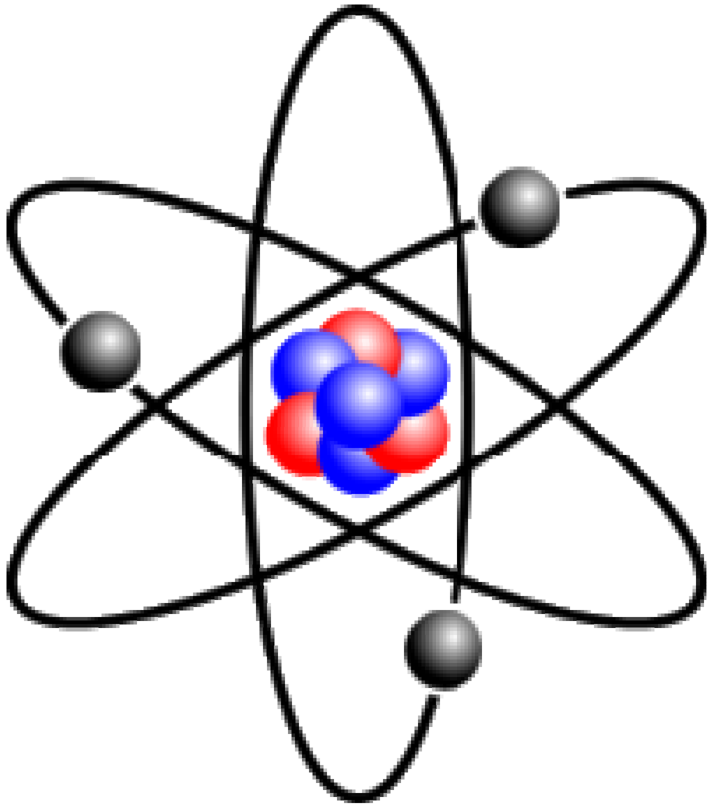
Periodic Table of Elements



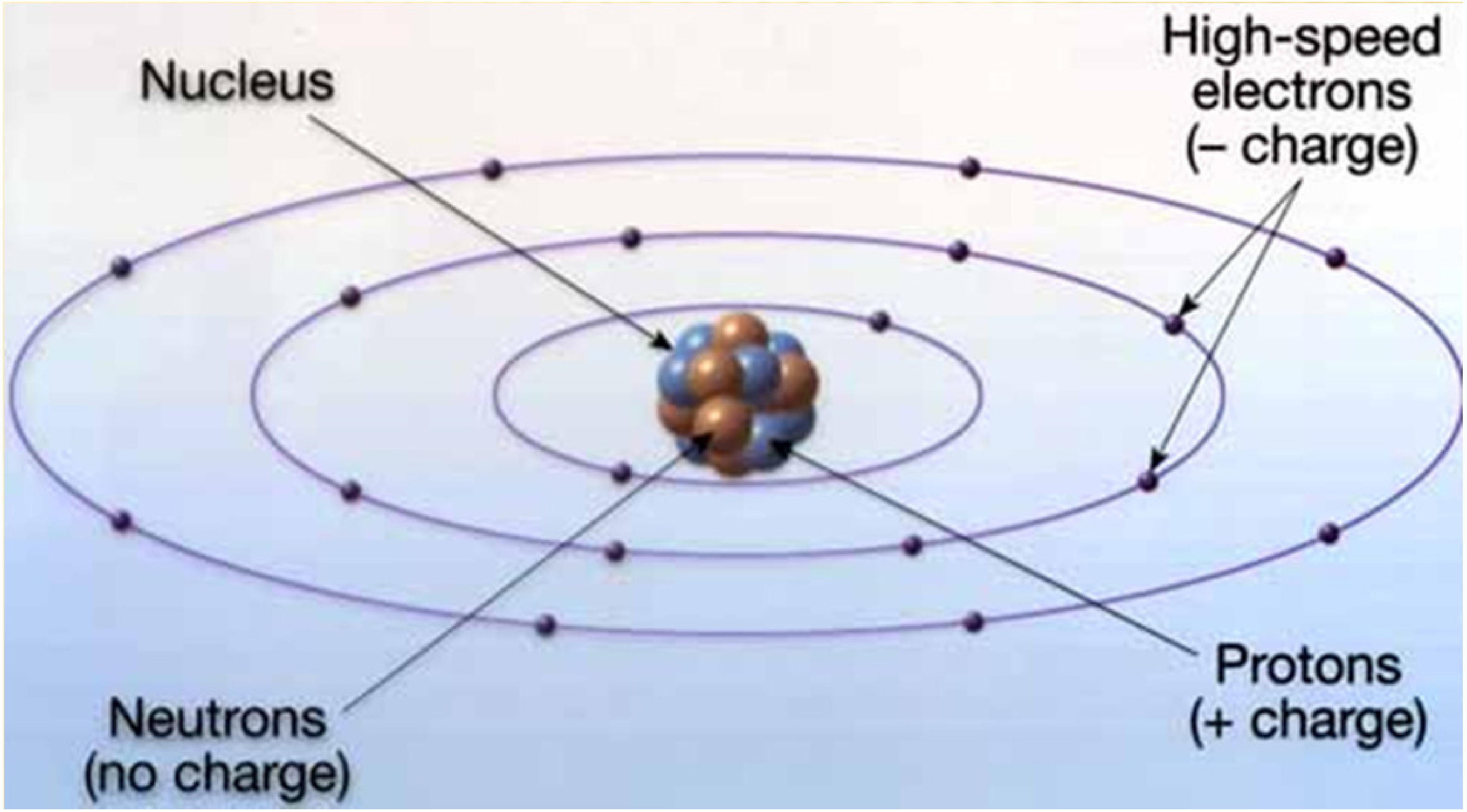
As of June 2011, the periodic table includes <u>118 chemical elements</u> whose discoveries have been confirmed. Of these, <u>91</u> are regularly occurring primordial or recurrently produced elements found naturally on the Earth.

Q. What is an atom?

An atom is the basic unit of an element. It is tiny; the diameter of the average atom is about 10^{-10} meters.



Q. What does an atom consist of?

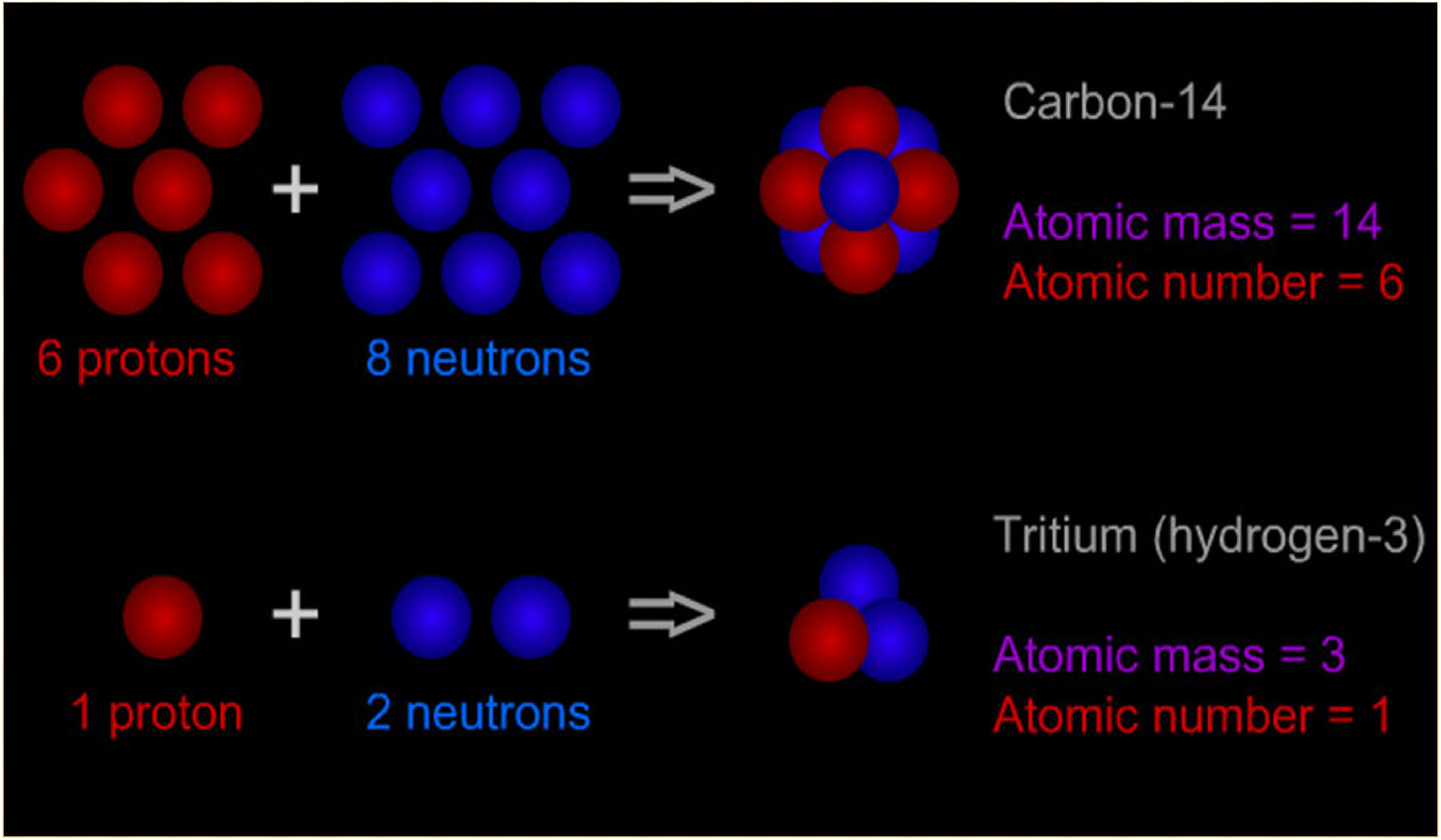


Nucleus: The central part of an atom.
Protons: Make up the nucleus and have positive electric charge.
Neutrons: Equally dense particles with neutral electric charges.
Electrons: Surround nucleus and negatively charges.

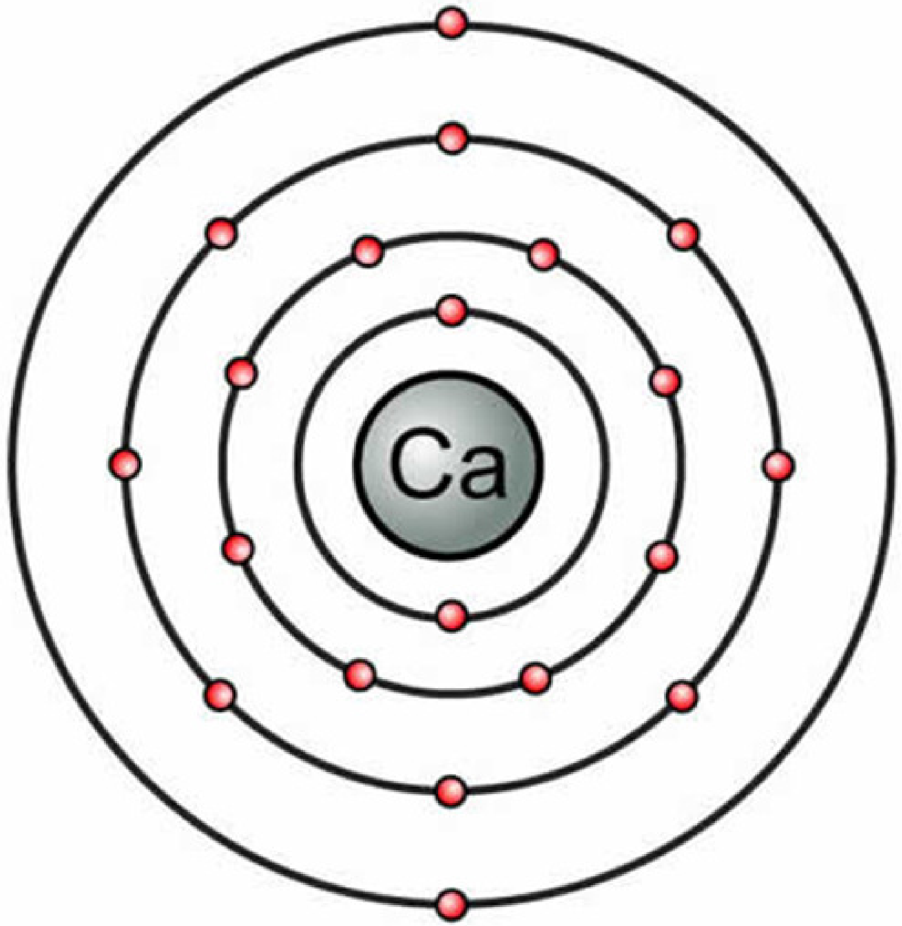
Q. What an atomic weight/mass? And atomic number?

- Atomic weight/mass is equal to the total number of Neutrons + Protons.

- Atomic number is equal to its number of Proton or Electron.


Carbon-14
Atomic mass = 14
Atomic number = 6
6 protons
8 neutrons
Tritium (hydrogen-3)
Atomic mass = 3
Atomic number = 1
1 proton
2 neutrons

- Electrons concentrate in spherical layers or shells around the nucleus.
- Each shell can hold a certain number of electrons.
- An atom is completely stable when its outermost shell is completely fill with electrons.

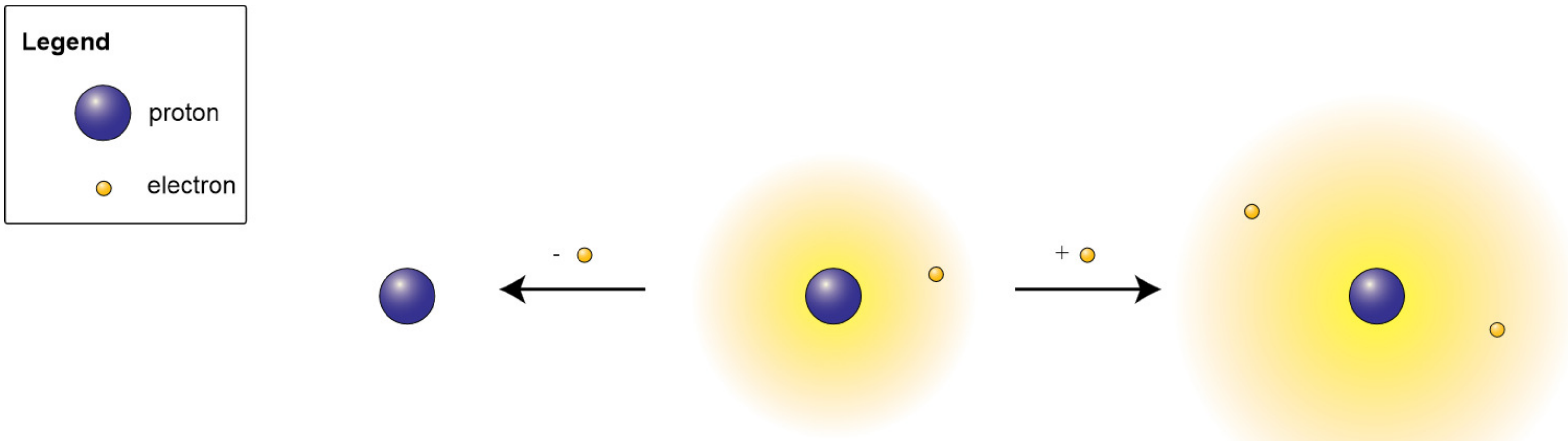


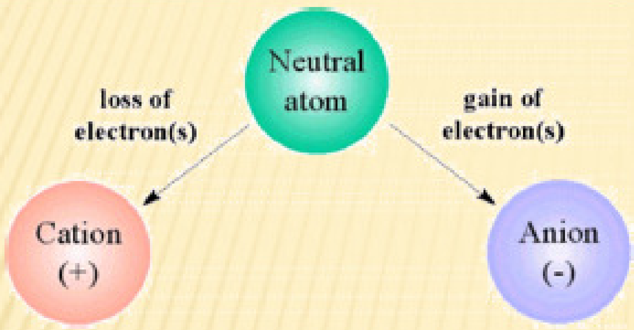
Q. What an ion?

The atoms can loose or gain an electron to make its outer shell complete.

When an atom loses one or more electrons, its protons outnumber its electrons and it develops a positive charge.

An ion is an atom which the total number of electrons is not equal to the total number of protons.





- A positively charged ion is a **Cation**. (Na^+).

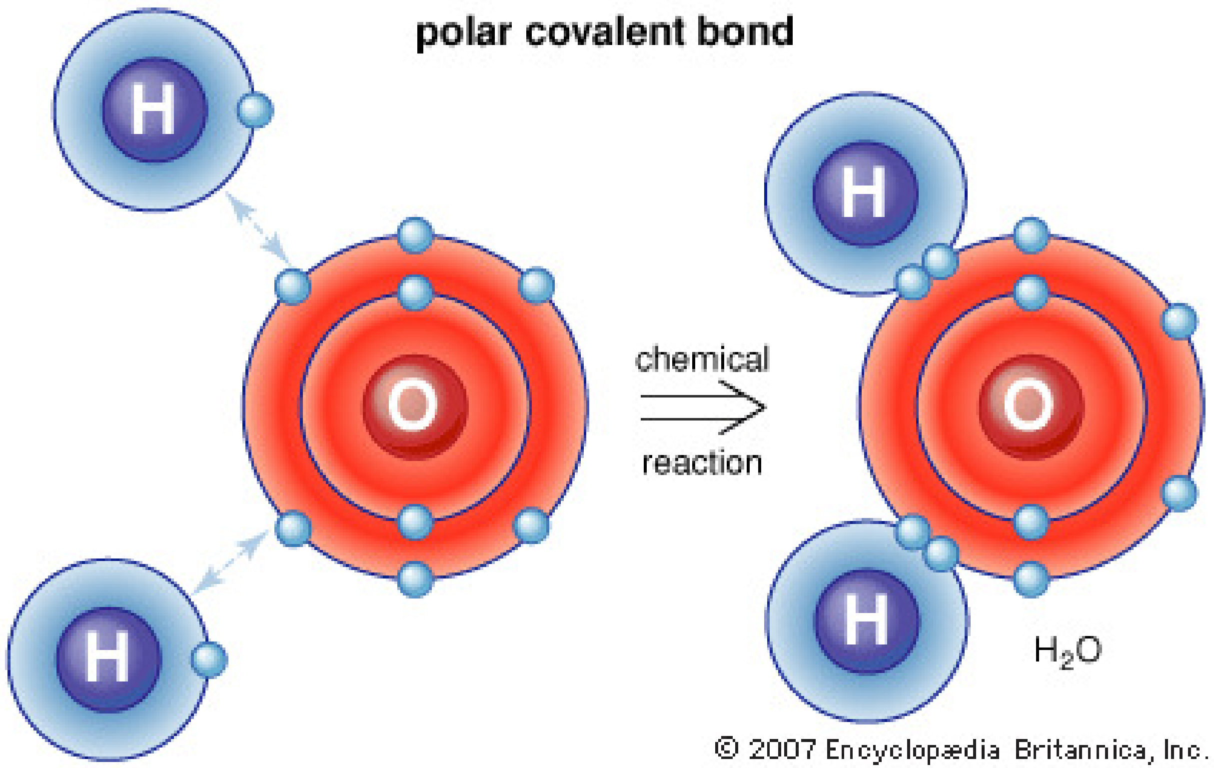
- Atom with a negative charge is called **Anion**, (Cl^-).

- Atoms and ions rarely exist independently. Instead, they unite to form **Compounds**. (NaCl).

- The forces that hold atoms and ions together to form compounds are called **chemical bonds**.

Q. What is a chemical bound?

A chemical bond is an attraction between atoms that allows the formation of chemical substances that contain two or more atoms.



Q. What are the types of chemical bounds?

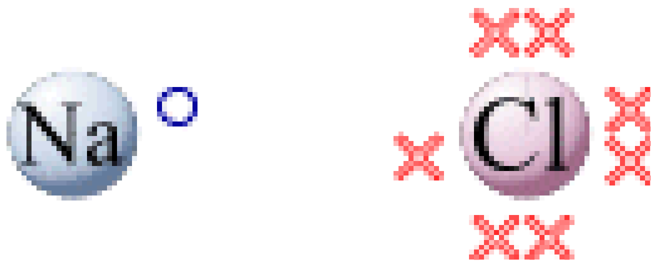
Types of chemical bonds:

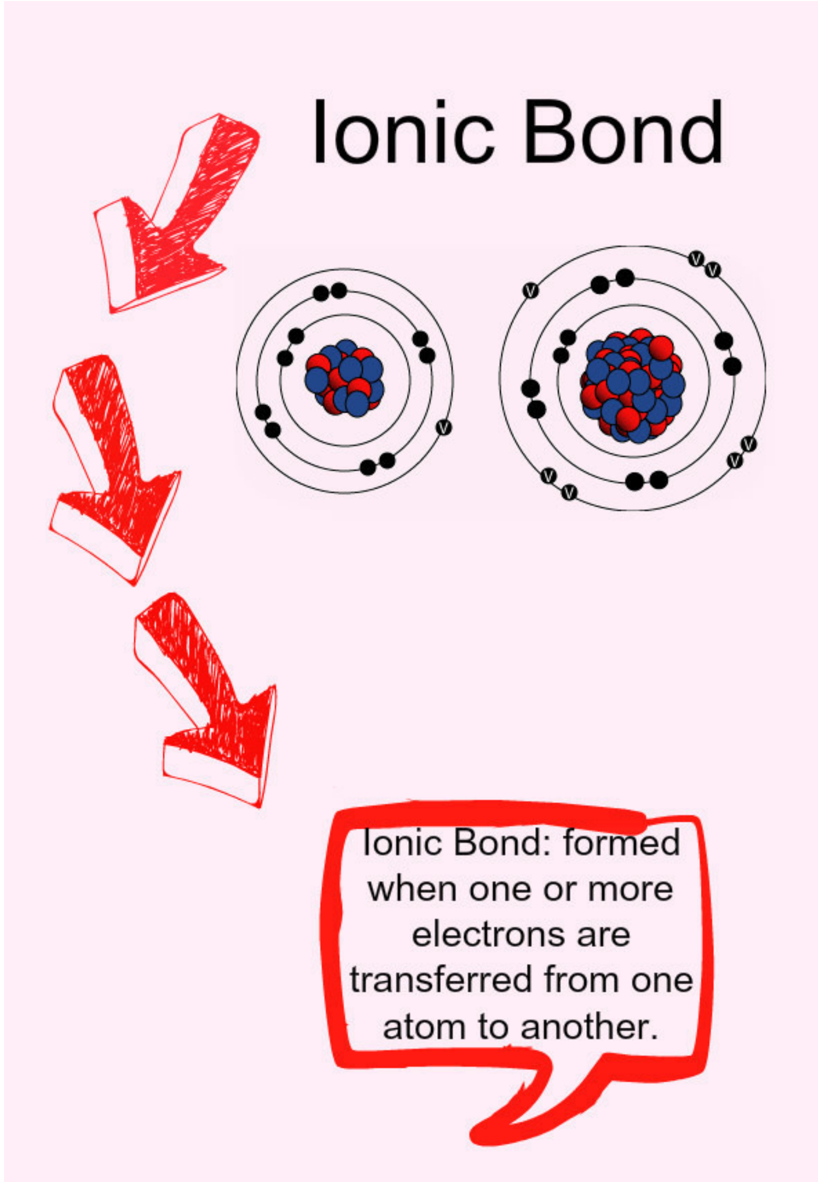
1. Ionic
2. Covalent
3. Metallic
4. Van der Waals forces

- An ionic compound (made up of two or more ions) is neutral because the positive and negative charges balance each other.

- For example, when sodium and chlorine form an ionic bond, the sodium atom loses one electron to become a cation and chlorine gains one to become an anion.

- When they combine, the +1 charge balances the -1 charge

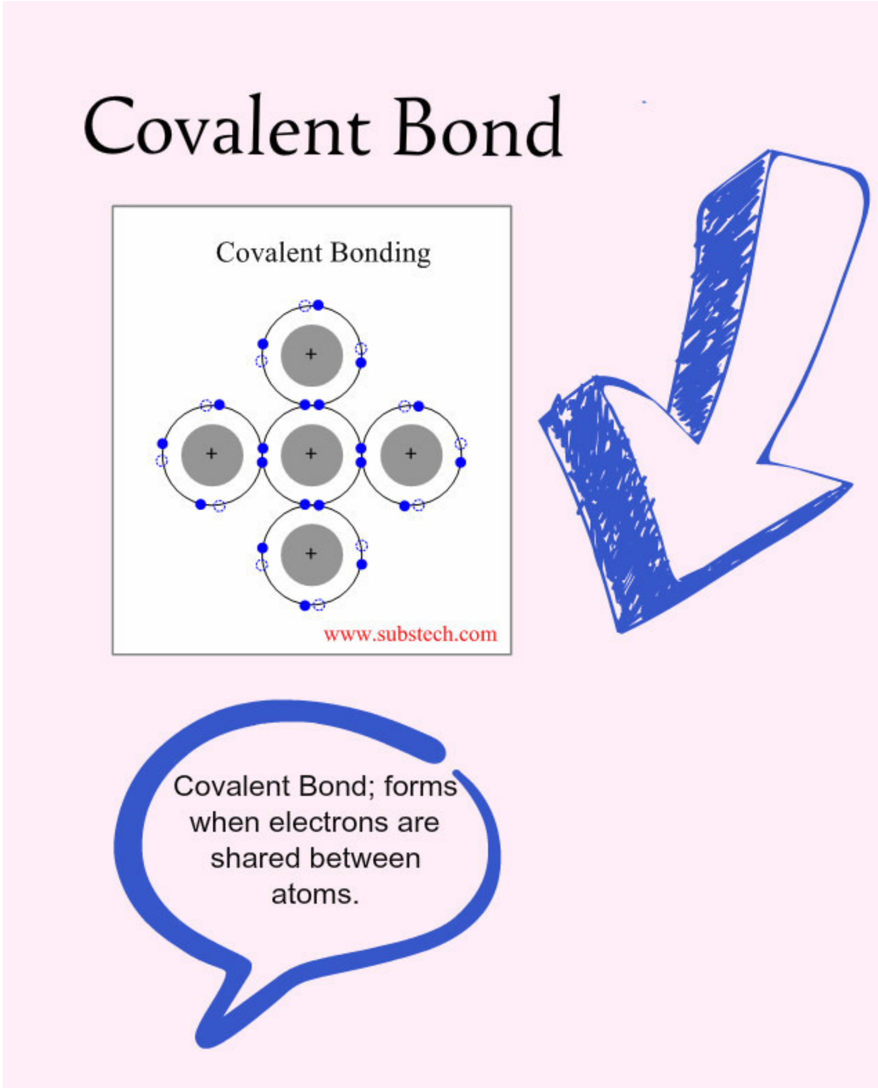


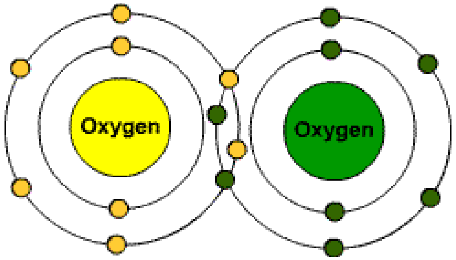


- Not all atoms combine by transferring electrons to form ions. Other atoms share electrons.

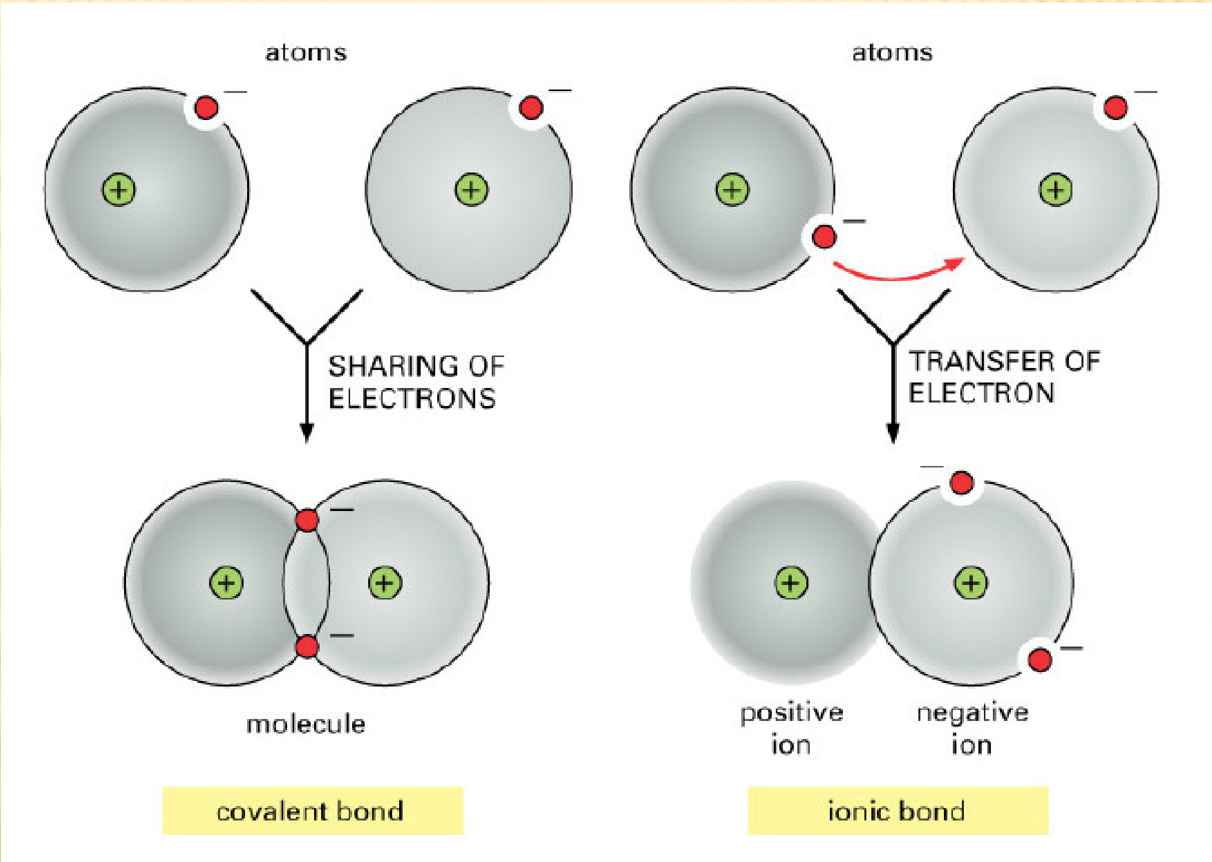
- A covalent bond develops when two or more atoms share their electrons to produce the effect of filled outer electron shells.

- For example the gaseous elements Oxygen, O_2; Hydrogen, H_2 and Chlorine, Cl_2 exist as stable molecules consisting of two atoms bonded together by sharing their valence electrons.



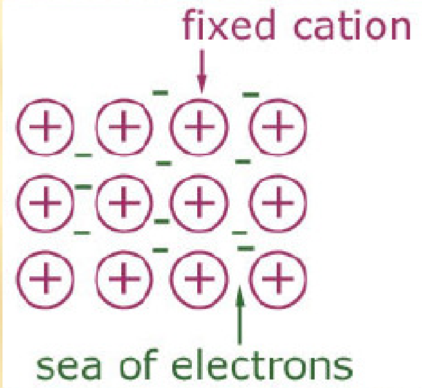


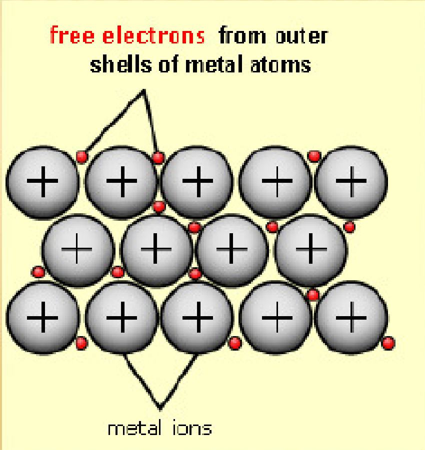
IONIC AND COVALENT BONDS



METALLIC BONDS

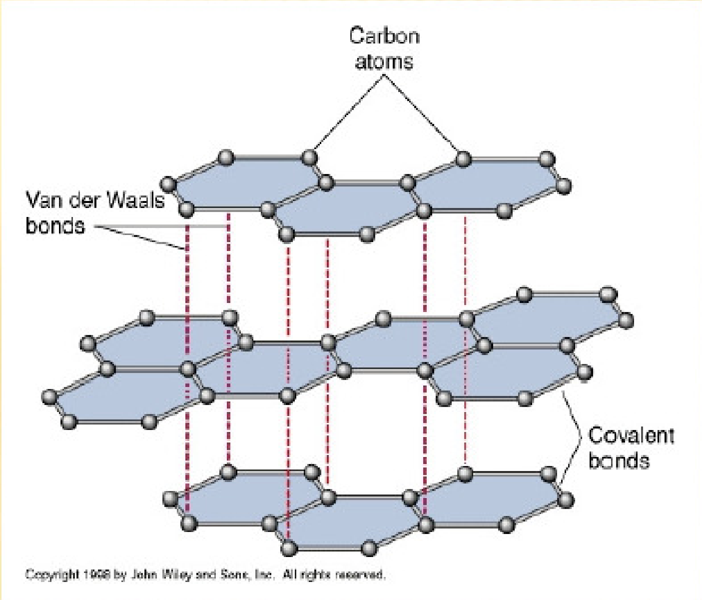
- IN A METALLIC BOND, THE OUTER ELECTRONS ARE LOOSE; THAT IS, THEY ARE NOT ASSOCIATED WITH PARTICULAR ATOMS.
- THIS ARRANGEMENT ALLOWS THE NUCLEI TO PACK TOGETHER AS CLOSELY AS POSSIBLE, RESULTING IN THE CHARACTERISTIC HIGH DENSITY OF METALS AND METALLIC MINERALS, SUCH AS PYRITE.
- BECAUSE THE ELECTRONS ARE FREE TO MOVE THROUGH THE ENTIRE CRYSTAL, METALLIC MINERALS ARE EXCELLENT CONDUCTORS OF ELECTRICITY AND HEAT.





VAN DER WAALS FORCES

- WEAK ELECTRICAL FORCES CALLED VAN DER WAALS FORCES ALSO BOND MOLECULES TOGETHER.
- THESE WEAK BONDS RESULT FROM AN UNEVEN DISTRIBUTION OF ELECTRONS AROUND INDIVIDUAL MOLECULES, SO THAT ONE PORTION OF A MOLECULE MAY HAVE A GREATER DENSITY OF NEGATIVE CHARGE WHILE ANOTHER PORTION HAS A PARTIAL POSITIVE CHARGE.
- BECAUSE VAN DER WAALS FORCES ARE WEAK, MINERALS IN WHICH THESE BONDS ARE IMPORTANT, SUCH AS TALC AND GRAPHITE, TEND TO BE SOFT AND CLEAVE EASILY ALONG PLANES OF VAN DER WAALS BONDS.



GRAPHITE

MATTER AND MINERALS

- MOST MINERALS ARE **COMPOUNDS.**
- WHEN IONS BOND TOGETHER TO FORM A MINERAL, THEY DO SO IN PROPORTIONS SO THAT THE TOTAL NUMBER OF NEGATIVE CHARGES EXACTLY BALANCES THE TOTAL NUMBER OF POSITIVE CHARGES.
- THUS, MINERALS ARE ALWAYS ELECTRICALLY **NEUTRAL.**

MATTER AND MINERALS

- THE COMPOSITION OF A MINERAL CAN BE EXPRESSED AS A CHEMICAL FORMULA, WHICH IS WRITTEN BY COMBINING THE SYMBOLS OF THE INDIVIDUAL ELEMENTS.

QUARTZ (SiO_2)

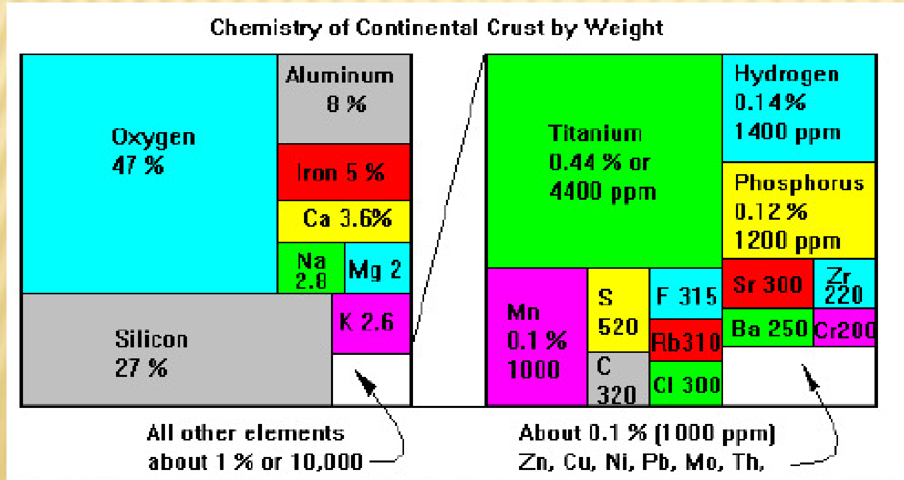
CALCITE (CACO3)

MATTER AND MINERALS

- A FEW MINERALS, SUCH AS GOLD AND SILVER, CONSIST OF ONLY A SINGLE ELEMENT. THEIR CHEMICAL FORMULAS, RESPECTIVELY, ARE AU (THE SYMBOL FOR GOLD) AND AG (THE SYMBOL FOR SILVER).
- MOST MINERALS, HOWEVER, ARE MADE UP OF **TWO TO FIVE ESSENTIAL ELEMENTS**.
- FOR EXAMPLE, THE FORMULA OF QUARTZ IS SiO_2: IT CONSISTS OF ONE ATOM OF SILICON (SI) FOR EVERY TWO OF OXYGEN (O). THE CHEMICAL COMPOSITION OF QUARTZ IS UNIFORM THROUGHOUT THE UNIVERSE AND THIS IS ONE OF THE MAIN CRITERIA FOR A SUBSTANCE TO BE CALLED AS A MINERAL.

MATTER AND MINERALS

- THE 91 ELEMENTS THAT OCCUR NATURALLY IN THE EARTH'S CRUST CAN COMBINE IN MANY WAYS TO FORM MANY DIFFERENT MINERALS.
-
- HOWEVER, THE EIGHT ABUNDANT ELEMENTS COMMONLY COMBINE IN ONLY A FEW WAYS.
- AS A RESULT, ONLY **NINE ROCK FORMING MINERALS** (OR MINERAL "GROUPS") MAKE UP MOST ROCKS OF THE EARTH'S CRUST.



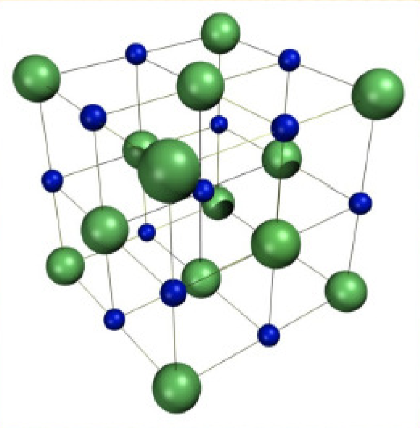
- THEY ARE

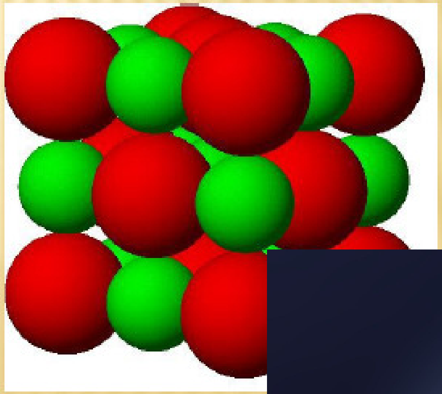
1. OLIVINE,
2. PYROXENE,
3. AMPHIBOLE,
4. MICA,
5. CLAYS,
6. QUARTZ,
7. FELDSPAR,
8. CALCITE, AND
9. DOLOMITE.

Q. What is a crystal?

CRYSTALS

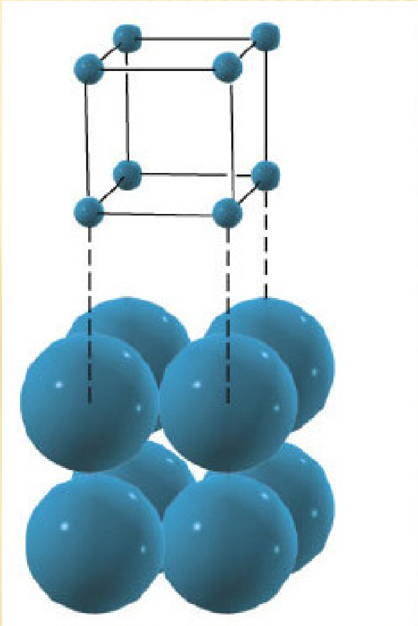
- A CRYSTAL IS ANY SUBSTANCE WHOSE ATOMS ARE ARRANGED IN A REGULAR, PERIODICALLY REPEATED PATTERN.
- ALL MINERALS ARE CRYSTALLINE.
- THE MINERAL HALITE (COMMON TABLE SALT) HAS THE COMPOSITION NACL: ONE SODIUM ION (NA+) FOR EVERY CHLORINE ION (CL-).

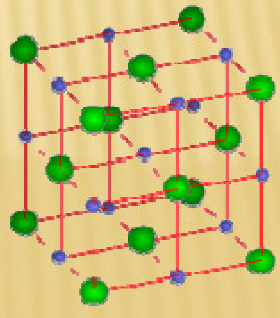




UNIT CELL

- THE SODIUM AND CHLORINE IONS ALTERNATE IN ORDERLY ROWS AND COLUMNS INTERSECTING AT RIGHT ANGLES.
- THIS ARRANGEMENT IS THE CRYSTALLINE STRUCTURE OF HALITE.
- IN EVERY CRYSTAL, A SMALL GROUP OF ATOMS, LIKE A SINGLE BRICK IN A WALL, REPEATS ITSELF OVER AND OVER. THIS SMALL GROUP OF ATOMS IS CALLED A UNIT CELL.





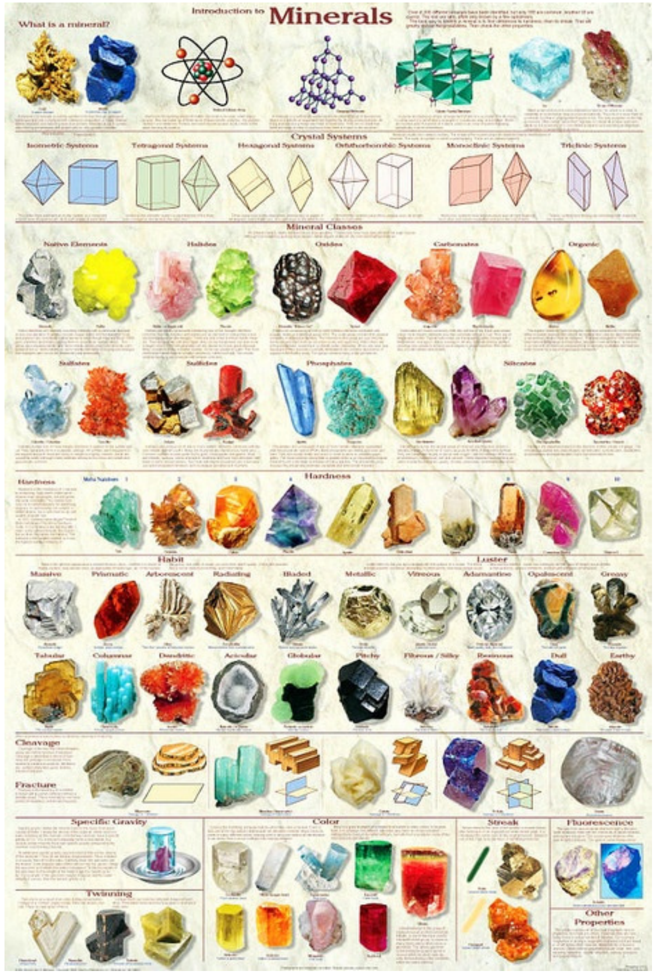
CRYSTAL FACE

- A **CRYSTAL FACE** IS A PLANAR SURFACE THAT DEVELOPS IF A CRYSTAL GROWS FREELY IN AN UNCROWDED ENVIRONMENT.
- IN NATURE, THE GROWTH OF CRYSTALS IS OFTEN IMPEDED BY ADJACENT MINERALS THAT ARE GROWING SIMULTANEOUSLY OR THAT HAVE FORMED PREVIOUSLY.
- FOR THIS REASON, MINERALS RARELY SHOW PERFECT DEVELOPMENT OF CRYSTAL FACES.

Q. What are the physical properties of minerals?

Physical properties of mineral:

1. Crystal habit
2. Cleavage
3. Fracture
4. Hardness
5. Specific gravity
6. Color
7. Streak
8. Luster



CRYSTAL HABIT

- Crystal habit is the characteristic shape of a mineral and the manner in which aggregates of crystals grow.

- If a crystal grows freely, it develops a characteristic shape controlled by the arrangement of its atoms, as in the cubes of halite. Some minerals such as Quartz occur in more than 1 different crystal habits.

- When crystal growth is obstructed by other crystals, a mineral cannot develop its characteristic habit. They form interlocking texture because some crystals grew around others as the magma solidified.

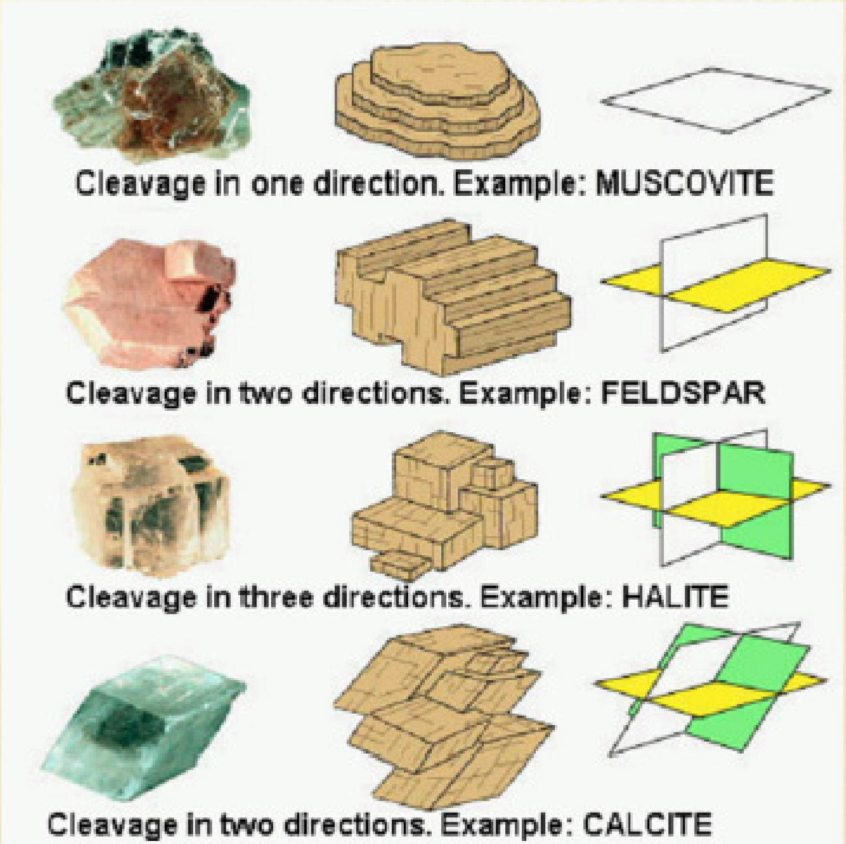
CLEAVAGE

- Cleavage is the tendency of some minerals to break along flat surfaces.

- The surfaces are planes of weak bonds in the crystal. Some minerals, such as mica and graphite, have one set of parallel cleavage planes. Others have two, three, or even four different sets.

- Many minerals have no cleavage at all because they have no planes of weak bonds.

- A flat surface created by a cleavage and a crystal face can appear identical as both are smooth and flat, however a cleavage plane is duplicated when the sample is broken whereas the crystal face is not.

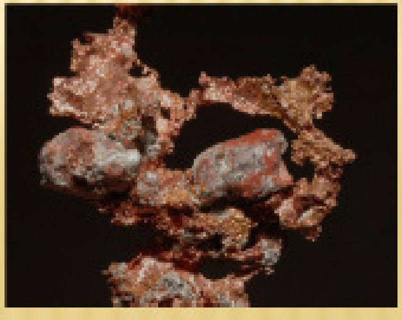


FRACTURE

- Fracture is the pattern in which a mineral breaks other than along planes of cleavage.
- Many minerals fracture into characteristic shapes.
- Conchoidal fracture creates smooth, curved surfaces. It is characteristic of quartz and olivine.
- Some minerals break into splintery or fibrous fragments.
- Most fracture into irregular shapes.

Conchoidal Fracture

Splintery Fracture



Jagged Fracture

SPECIFIC GRAVITY

- Specific gravity is the weight of a substance in air divided by the weight of an equal volume of water.
- If a mineral weighs 2.5 times as much as an equal volume of water, its specific gravity is 2.5.
- Most common minerals have specific gravities of about 2.7.
- Metals have much greater specific gravities; for example, gold has the highest specific gravity of all minerals, 19.3. Lead is 11.3, silver is 10.5, and copper is 8.9.

HARDNESS

- **Hardness** is the resistance of a mineral to scratching.
- It is easily measured and is a fundamental property of each mineral because it is controlled by bond strength between the atoms in the mineral.
- Geologists commonly use a knife or other object of known hardness.
- If the blade scratches the mineral, the mineral is softer than the knife. If the knife cannot scratch the mineral, the mineral is harder.

HARDNESS

- To measure hardness more accurately, geologists use a scale based on ten minerals, numbered 1 through 10.
- Each mineral is harder than those with lower numbers on the scale, so 10 (diamond) is the hardest and 1 (talc) is the softest.
- The scale is known as the Mohs hardness scale after F. Mohs, the Austrian mineralogist who developed it in the early nineteenth century.

COLOR

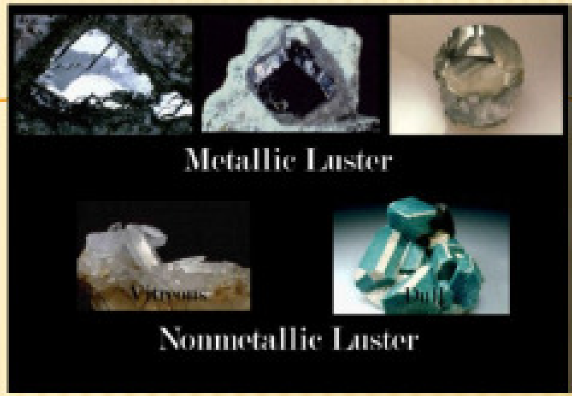
- Color is the most obvious property of a mineral, but it is commonly unreliable for identification.
- Color would be a reliable identification tool if all minerals were pure and had perfect crystal structures.
- However, both small amounts of chemical impurities and imperfections in crystal structure can dramatically alter color.

STREAK

- Streak is the color of a fine powder of a mineral.
- It is observed by rubbing the mineral across a piece of unglazed porcelain known as a streak plate.
- Many minerals leave a streak of powder with a diagnostic color on the plate.
- Streak is commonly more reliable than the color of the mineral itself for identification.

LUSTER

- **Luster** is the manner in which a mineral reflects light.
- A mineral with a metallic look, irrespective of color, has a metallic luster.
- The luster of nonmetallic minerals is usually described by self-explanatory words such as glassy, pearly, earthy, and resinous.



TYPES OF MINERALS

- Although about 3500 minerals are known to exist in the Earth's crust, only a small number – between 50 and 100 are important because they are common or valuable. These minerals can be grouped into 5 categories. They include
- Rock Forming Minerals
- Accessory minerals
- Gem
- Ore minerals
- Industrial Minerals

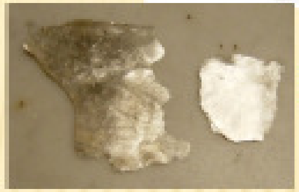
ROCK FORMING MINERALS

- Rock Forming Minerals make up the bulk of most rocks in the Earth's crust.
- They are important to geologists simply because they are the most common minerals. They include

1. olivine,
2. pyroxene,
3. amphibole,
4. mica,
5. the clay minerals,
6. feldspar,
7. quartz,
8. Calcite and
9. dolomite

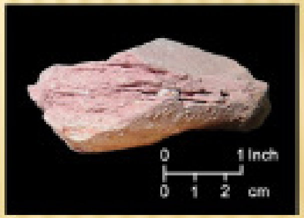

Olivine


Pyroxene

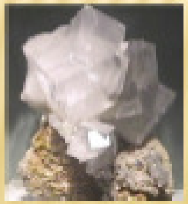

Mica


Amphibole


Quartz



Clay minerals


Dolomite


Feldspar


Calcite

ACCESSORY MINERALS

- **Accessory minerals** are minerals that are common but usually are found only in small amounts.

- Chlorite, garnet, hematite, limonite, magnetite, and pyrite are common accessory minerals.

Garnet

Chlorite

GEMS

- A gem is a mineral that is prized primarily for its beauty, although some gems, like diamonds, are also used industrially.

- Depending on its value, a gem can be either precious or semiprecious.

- Precious gems include diamond, emerald, ruby, and sapphire. Several varieties of quartz, including amethyst, agate, jasper, and tiger's eye, are semiprecious gems.

Diamond

Ruby

Sapphire

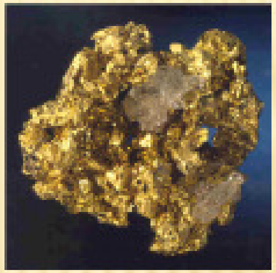
Emerald

ORE MINERALS

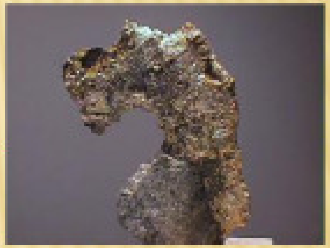
- **Ore minerals** are minerals from which metals or other elements can be profitably recovered. A few, such as native gold and native silver, are composed of a single element.

- However, most metals are chemically bonded to anions.

- Copper, lead, and zinc are commonly bonded to sulfur to form the important ore minerals chalcopyrite, galena.



Gold



Silver

Galena

Pyrite

Chalcopyrite

ORE MINERALS

- Argentite: Ag_2S for production of silver
- Barite: $BaSO_4$
- Bauxite Al_2O_3 for production of aluminium
- Beryl: $Be_3Al_2(SiO_3)_6$
- Bornite: Cu_5FeS_4
- Cassiterite: SnO_2
- Chalcocite: Cu_2S for production of copper
- Chalcopyrite: $CuFeS_2$
- Chromite: (Fe, Mg)Cr_2O_4 for production of chromium
- Cinnabar: HgS for production of mercury
- Cobaltite: (Co, Fe)AsS
- Columbite-Tantalite or Coltan: (Fe, Mn)(Nb, $Ta)_2O_6$
- Galena: PbS
- Gold: Au, typically associated with quartz or as placer deposits
- Hematite: Fe_2O_3
- Ilmenite: $FeTiO_3$
- Magnetite: Fe_3O_4
- Molybdenite: MoS_2
- Pentlandite:$(Fe, Ni)_9S_8$
- Pyrolusite:MnO_2
- Scheelite: $CaWO_4$
- Sphalerite: ZnS
- Uraninite (pitchblende): UO_2 for production of metallic uranium
- Wolframite: (Fe, Mn)WO_4

INDUSTRIAL MINERALS

- **Industrial Minerals** are industrially important, although they are not considered ore because they are mined for purposes other than the extraction of metals.
- Halite is mined for table salt, and gypsum is mined as the raw material for plaster and sheetrock.
- Apatite and other phosphorus minerals are sources of the phosphate fertilizers crucial to modern agriculture.
- Many limestones are made up of nearly pure calcite and are mined as the raw material of cement.

Apatite

Halite

Limestone

MINERAL CLASSIFICATION

- Minerals are classified according to their anions i.e. the negatively charged ions.

- Anions can be either simple or complex. A simple anion is a single negatively charged ion, such as O^{2-}.

- Alternatively, two or more atoms can bond firmly together and acquire a negative charge to form a complex anion. Two common examples are the silicate, $(SiO4)^{4-}$, and carbonate, $(CO3)^{2-}$.

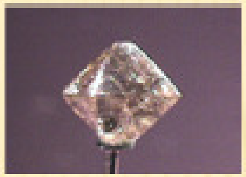
- Each mineral group (except the native elements) is named for its anion. For example, the oxides all contain O^{2-}, the silicates contain $(SiO4)^{4-}$, and the carbonates contain $(CO3)^{2-}$.

MAJOR MINERAL GROUPS

Mineral Classes	Chemical Makeup
Silicates	Contain silicon (Si) and oxygen (O) at least
Carbonates	CO_3 plus metal(s)
Sulfates	SO_4 plus metal(s)
Sulfides	S plus metal(s)
Oxides	O plus metal(s) without other nonmetals or metalloids (no Si, C, P, S, V, or W)
Hydroxides	OH plus metal(s) without other nonmetals or metalloids
Phosphates	PO_4 plus metal(s)
Halides	F, Cl, Br, or I plus metal(s) without other nonmetals or metalloids
Native elements	Occur in elemental form (one element only)

NATIVE ELEMENTS

- About 20 elements occur naturally in their native states as minerals.
- Fewer than ten, however, are common enough to be of economic importance.
- Gold, silver, platinum, and copper are all mined in their pure forms.
- Pure carbon occurs as both graphite and diamond.
- The minerals have identical compositions but different crystalline structures and are called **polymorphs**.
- Graphite is one of the softest minerals and is opaque and an electrical conductor.
- Diamond, the hardest mineral known, is transparent and an electrical insulator.

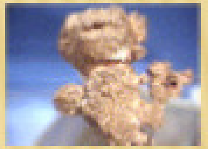


Diamond

Sulfur

Gold

Copper



Platinum

OXIDES

- The oxides are a large group of minerals in which oxygen is combined with one or more metals.
- Oxide minerals are the most important ores of iron, manganese, tin, chromium, uranium, titanium, and several other industrial metals.
- Hematite (iron oxide, Fe_2O_3) occurs widely in many types of rocks and is the most abundant ore of iron.
- Magnetite (Fe_3O_4), a naturally magnetic iron oxide, is another ore of iron.

Magnetite

Haematite

Rutile

SULFIDES

- Sulfide minerals consist of sulfur combined with one or more metals.
- Many sulfides are extremely important ore minerals.
- They are the world's major sources of copper, lead, zinc, molybdenum, silver, cobalt, mercury, nickel, and several other metals.
- The most common sulfides are pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), and sphalerite (ZnS).

Pyrite

Chalcopyrite

Galena

Sphalerite

SULFATES

- The sulfate minerals contain the sulfate complex anion $(SO_4)^{2-}$.

- Gypsum ($CaSO4.\ 2H_2O$) and anhydrite ($CaSO_4$) are two important industrial sulfates used to manufacture plaster and sheetrock.

- Both form by evaporation of seawater or salty lake water.

Gypsum

Anhydrite

PHOSPHATES

- Phosphate minerals contain the complex anion $(PO_4)^{3-}$
.
- Apatite, Ca_5 $(F,Cl,OH)(PO_4)^{3-}$, is the substance that makes up both teeth and bones. Phosphate is an essential fertilizer in modern agriculture.

Apatite

CARBONATES

- The complex carbonate anion $(CO_3)^{2-}$ is the basis of two common rock-forming minerals, calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$].

- Limestone is mined as a raw ingredient of cement.

- Aragonite is a polymorph of calcite that makes up the shells of many marine animals.

Limestone

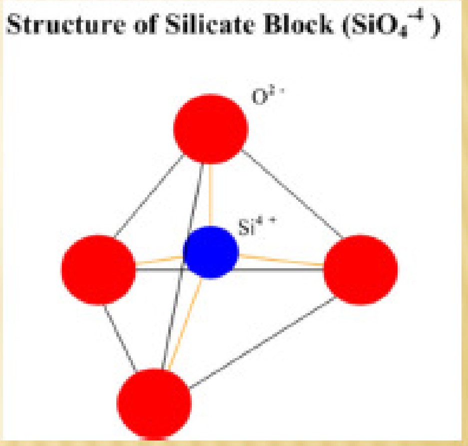
Dolomite

Aragonite

SILICATES

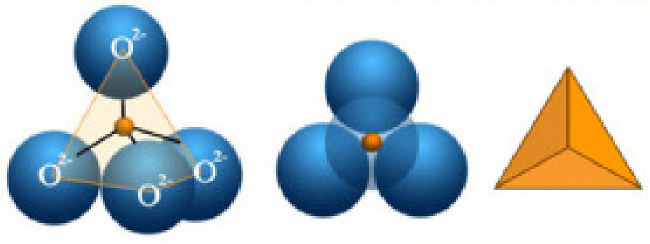
- The silicate minerals contain the $(SiO_4)^{4-}$ complex anion. Silicates make up about 95 percent of the Earth's crust.

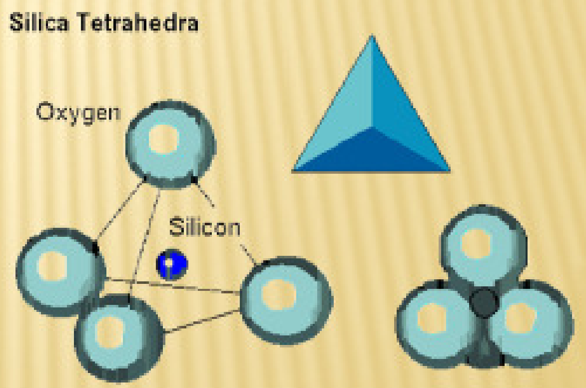
- They are abundant for two reasons.
  - First, silicon and oxygen are the two most abundant elements in the crust.
  - Second, silicon and oxygen combine readily.



SILICATE MINERALS

- Every silicon atom surrounds itself with four oxygens. The bonds between each silicon and its four oxygens are very strong.
- The silicon atom and its four oxygens form a pyramid-shaped structure called the silicate tetrahedron with silicon in the center and oxygens at the four corners.
- The silicate tetrahedron has a 4^- charge and forms the $(SiO_4)^{4-}$ complex anion. The silicate tetrahedron is the fundamental building block of all silicate minerals.
- To make silicate minerals electrically neutral, other cations must combine with the silicate tetrahedra to balance their negative charges.
- Silicate tetrahedra commonly link together by sharing oxygens. Thus, two tetrahedra may share a single oxygen, bonding the tetrahedra together.

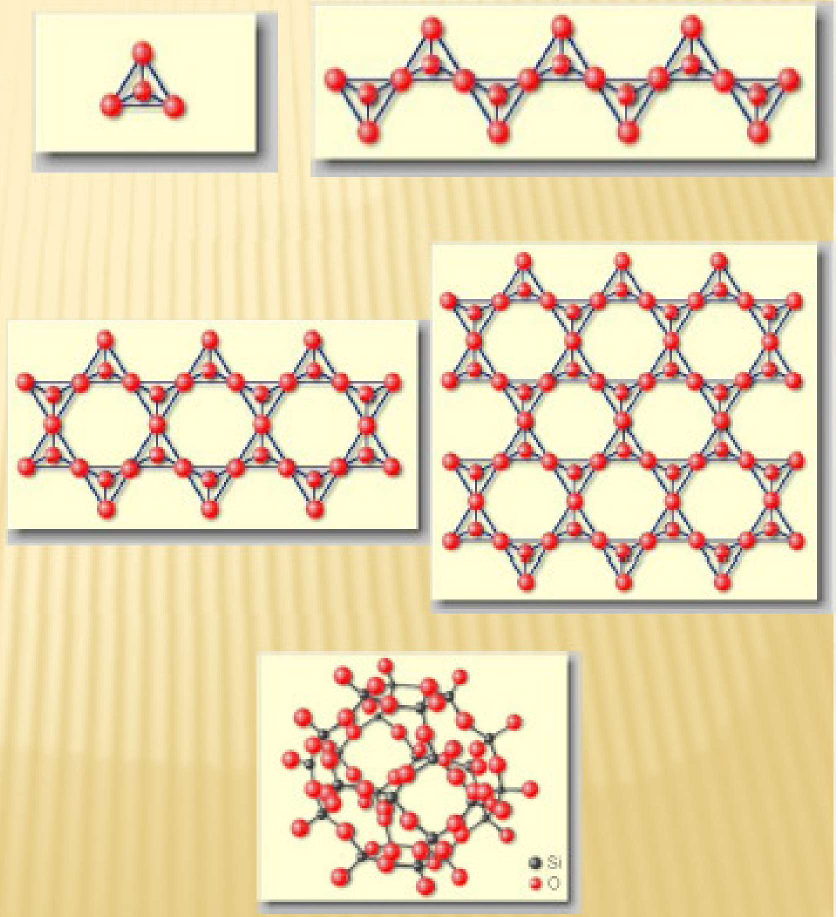




ROCK FORMING SILICATE MINERALS

- The rock-forming silicates (and most other silicate minerals) fall into five classes, based on five ways in which tetrahedra share oxygens.

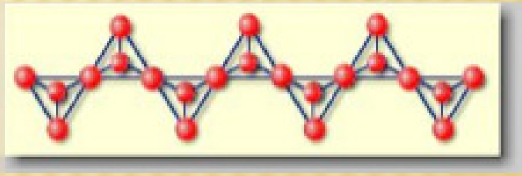
- Each class contains at least one of the rock-forming mineral groups.



SILICATE MINERALS

- In **independent tetrahedra** silicates, adjacent tetrahedral do not share oxygens.
- **Olivine** is an independent tetrahedra mineral that occurs in small quantities in basalt of both continental and oceanic crust .

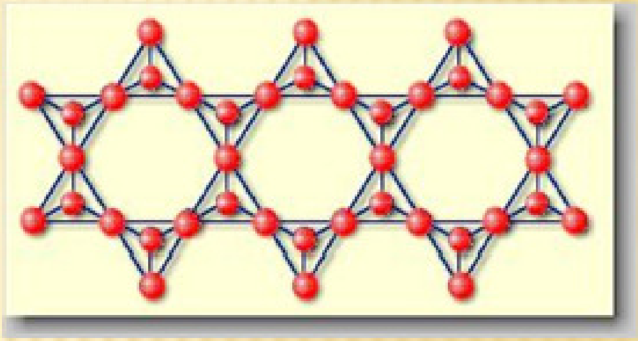
- Mantle is composed mainly of Olivine and Pyroxenes
- In the **single-chain silicates**, each tetrahedron links to two others by sharing oxygens, forming a continuous chain of tetrahedral.



- The **pyroxenes** are a group of similar minerals with single chain structures.
- Pyroxenes are a major component of both oceanic crust and the mantle and are also abundant in some continental rocks.

SILICATE STRUCTURE

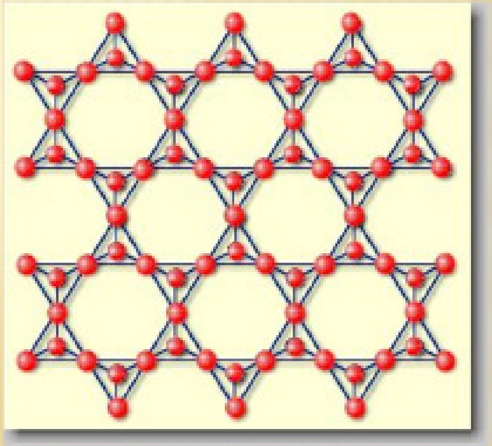
- The double-chain silicates consist of two single chains crosslinked by the sharing of additional oxygens between them.



- The amphiboles are a group of double-chain silicates with similar properties. They occur commonly in many continental rocks.

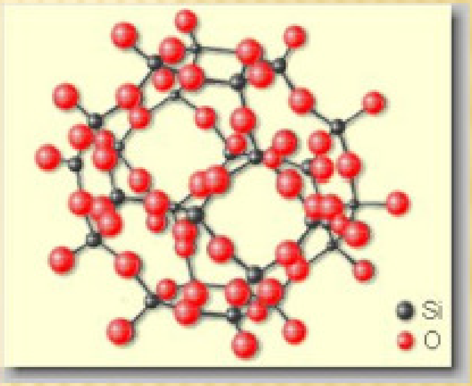
SILICATE MINERALS

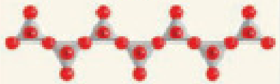
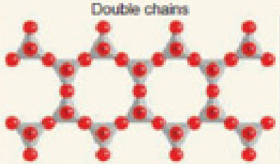
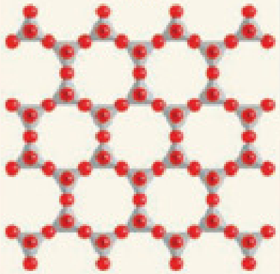
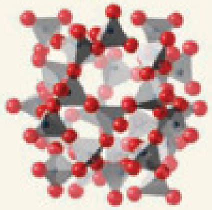
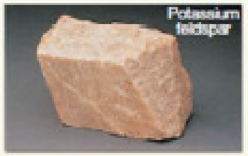
- In the **sheet silicates**, each tetrahedron shares oxygens with three others in the same plane, forming a continuous sheet.
- All of the atoms within each sheet are strongly bonded, but each sheet is only weakly bonded to those above and below. Therefore, sheet silicates have excellent cleavage.
- The **micas** are sheet silicates and typically grow as plate-shaped crystals, with flat surfaces.
- Mica is common in continental rocks.
- The **clay minerals** are similar to mica in structure, composition, and platy habit.
- Clay minerals are abundant near the Earth's surface and are an important component of soil and of sedimentary rocks.



SILICATE MINERALS

- In the **framework silicates**, each tetrahedron shares all four of its oxygens with adjacent tetrahedral.
- Because tetrahedra share oxygens in all directions, minerals with the framework structure tend to grow blocky crystals that have similar dimensions in all directions.
- **Feldspar** and **Quartz** have framework structures.
- Feldspars make up more than 50 percent of the earth's crust.
- Quartz is the only common silicate mineral that contains no cations other than silicon; it is pure SiO2



Mineral/Formula	Cleavage	Silicate Structure	Example
Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedron 	
Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains 	
Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	
Micas: **Biotite** $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 	
Micas: **Muscovite** $KAl_2(AlSi_3O_{10})(OH)_2$			
Feldspars: **Potassium feldspar (Orthoclase)** $KAlSi_3O_8$; **Plagioclase** $(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks 	
Quartz SiO_2	None