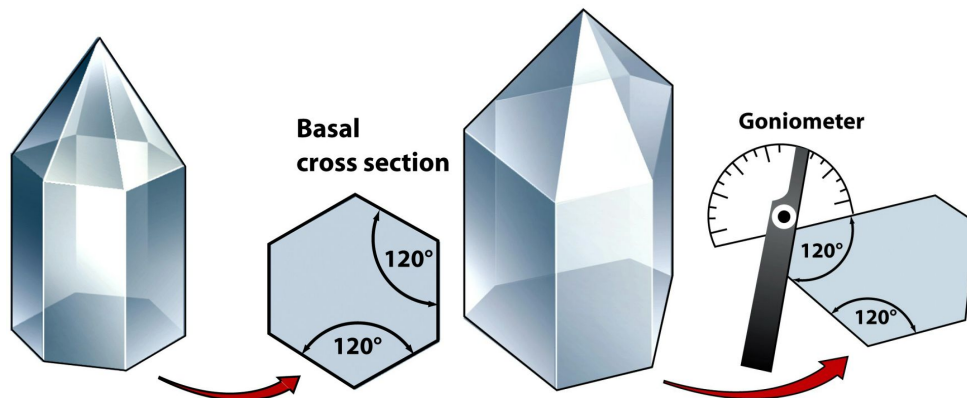


What is a crystal?

- A single, continuous piece of crystalline solid
- Typically bounded by flat surfaces (crystal faces)
- Crystal faces grow naturally as the mineral forms
- Constancy of interfacial angles: the same mineral has the same crystal faces; adjacent faces occur at the same angle to one another
- Faces and angles reflect crystalline structure - can have more than one critical angle



- Crystals come in a variety of shapes
- Many descriptive terms describe crystal shape (name describes shape)

X-Ray Diffraction

X-ray beam splits into numerous smaller beams. Interference of waves of different beams produces a diffraction pattern on a screen or film. The pattern indicates the spacing and arrangement of atoms.

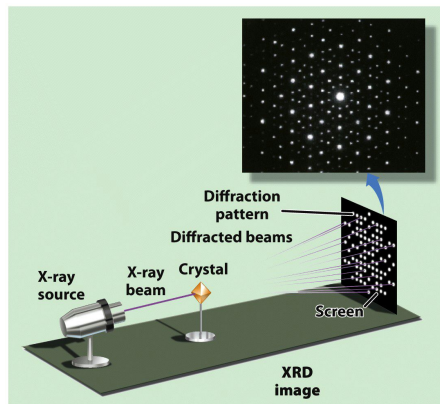


Figure 5-10b: Earth: Portrait of a Planet 3/e
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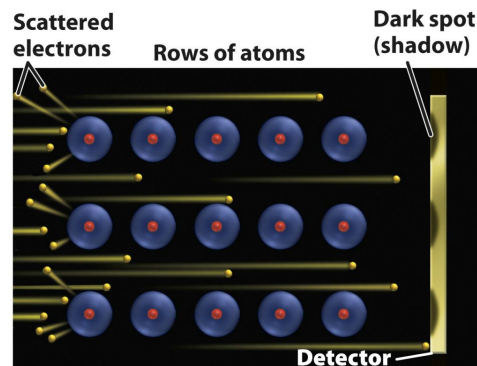
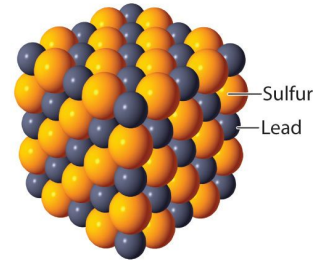


Figure 5-10c: Earth: Portrait of a Planet 3/e
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When you shoot an x-ray through a crystal - it turns out that the wavelength of x-rays is similar to the spacing of the atoms in the crystal. When you shoot an x-ray through a crystal, the beams of the x-ray get reflected and some pass through. So if you record on a screen the rays that went

through, a pattern of how the atoms are arranged is observed - thus indicating the structure of the crystal.

- Ordered atoms in crystals form spectacular patterns
- Atomic patterns repeat regularly in 3-dimensions: atomic arrangement is called a crystal lattice
- This 3-D internal pattern controls crystal shape



Looking inside Crystals

- Ordered atoms like tiny balls packed tightly together
- Held in place by chemical bonds
- The way atoms are packed (arranged) defines crystal structure
- Physical properties (hardness, shape) depend on: identity of atoms, arrangement of atoms, nature of atomic bonds
- e.g. Sodium Na⁺ and Chloride Cl⁻ ions are bonded in a cubic lattice by ionic bonds to form the mineral Halite, NaCl, known as salt

Ionic Bond - transfer of electrons

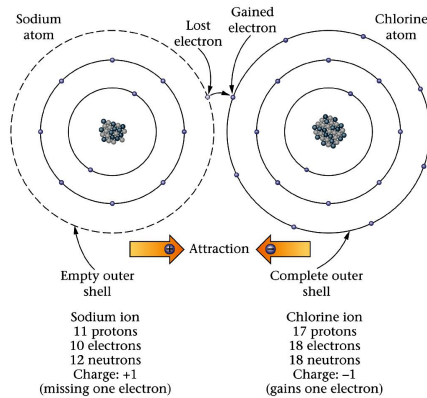


FIGURE a.9

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Covalent Bond - sharing of electrons

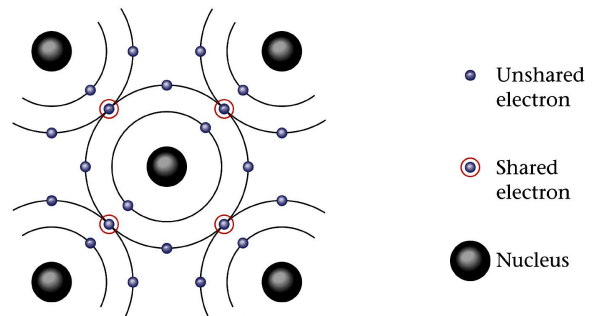


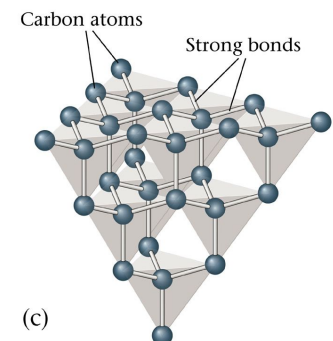
FIGURE a.10

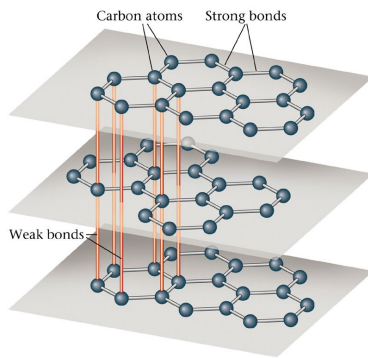
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- Typically ionic bonds are weaker bond when compared to a covalent bond
- The bonding properties of the atoms and can change the property of the mineral if given the same chemical formula, e.g. diamonds

Diamonds vs graphite (C-bonding)

In diamonds, each atom bonds to four neighbours arranged in the form of a tetrahedron. The bonds between carbon atoms are covalent, meaning they share electrons, i.e. their electron clouds overlap, and as a result, the bonds are very strong. Diamonds are the hardest mineral known to man.





(e)

In graphite (softest mineral), there is covalent bonding of 3 atoms within each sheet (within the sheets, carbon atoms share their electrons with 3 other carbon atoms through covalent bonding). Then there is ionic bonding between sheets. Strong sheets but weak interactions between the sheets.

More on Diamonds:

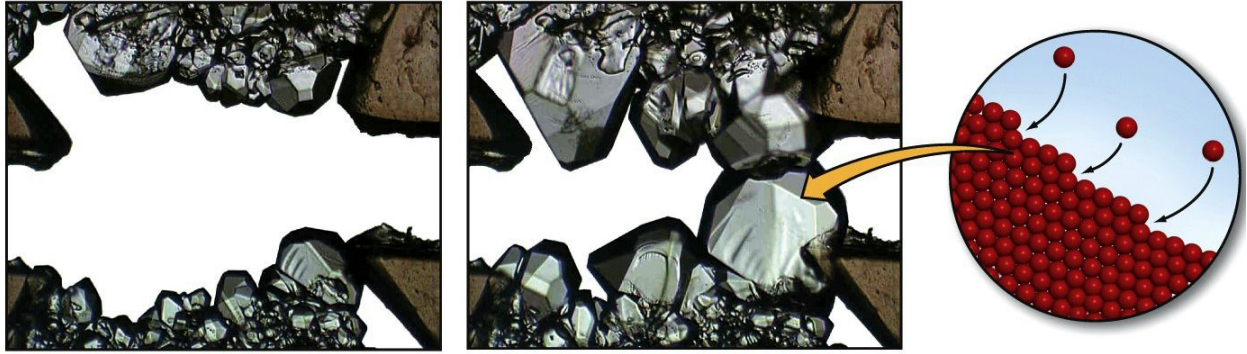
- Diamonds originate under extremely high pressure: ~150 km deep - in the upper mantle; pure carbon is compressed into the diamond structure
- Rifting causes deep-mantle rock to move upward, which is why we can find them on the surface today.
- Canada is the 4th largest producer worldwide of quality diamonds

Mineral Formation

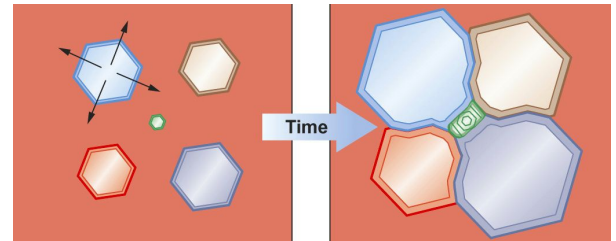
- Mineral crystals form when a melt solidifies. Quick cooling results in tiny crystals; slow cooling creates large crystals (more time to grow). Typically where there are volcanic eruptions.
- New crystals can form from an aqueous solution when dissolved solids become saturated (precipitate from solution), e.g. evaporation of water from saline solution.
- Also, crystals can form during chemical reactions at high T and P conditions which result in the genesis of new minerals at the expense of the old, through solid-state diffusion. e.g. as rocks are buried at great depths, new crystals form.
- Also, biomineralization forms new crystals - crystals form as a result of biological processes. e.g. our tooth enamel is mineral apatite.
- Lastly, mineral crystals can precipitate directly from a gas as it changes temperature rapidly. E.g. elemental sulphur grows at a geyser, the mouth of a volcanic vent (a solfatara) in Hawaii.

Mineral Formation Process

- A tiny crystal acts as a seed for further growth
- Atoms migrate to the seed and attach to the outer face (atoms are attracted)
- Growth moves faces outward from the center seed
- Unique shape reflects crystal's interior atomic order



- Outward crystal growth fills available space
- Resulting crystal shape is governed by surroundings: open space-good crystal faces grow; confined space - no crystal faces
- If there are multiple seeds growing, the fact the space is restricted will impact the resulting structure. e.g. green mineral is being restricted by the growth of the other 4 minerals. - Existing crystals may act as obstacles, restricting growth in one or more directions.



Mineral growth is often restricted by lack of space

- Anhedral - grown in tight space, no crystal faces - much more prevalent
- Euhedral - grown in open cavity, good crystal faces - grow into the open space in a geode (open cavity within a rock)

Mineral Destruction

Minerals can be destroyed by:

- Melting - heat breaks the bonds holding the atoms together
- Dissolving - solvents (mostly water) break atomic bonds - saline solution that is no longer crystallized
- Chemical reaction - reactive materials break bonds to form new ones

Physical Properties of Minerals

- Color
- Streak
- Luster
- Hardness
- Specific Gravity
- Crystal Habit
- Fracture or Cleavage

Color: The part of visible light that is not absorbed by a mineral (what is reflected), i.e., a mineral absorbs certain colors/wavelengths, so the color you see when looking at is the the wavelength that is reflected (not absorbed).

- Diagnostic for some minerals: Malachite is a distinctive green
- Some minerals exhibit a broad color range (not diagnostic), e.g. quartz: clear, white, rose, purple, gray, etc
- Color varieties often reflect trace impurities in the composition of the mineral

Streak: Color of the powder produced by crushing a mineral

- Obtained by scraping a mineral on unglazed porcelain (or any substance like metal)
- Streak color is less variable than crystal color

Luster: The way a mineral surface scatters light (shininess/texture)

Two subdivisions

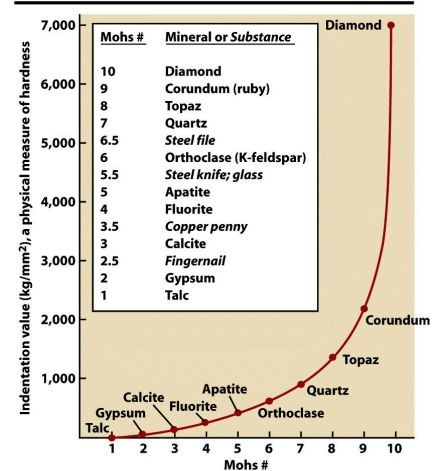
- Metallic - looks like a metal (reflective and shiny)
- Non-metallic: silky, glassy, satiny, resinous, pearly, earthy

Hardness: Scratching resistance of a mineral. Derives from the strength of the atomic bonds.

Hardness compared to the Mohs scale for hardness:

1. Talc, graphite
2. Gypsum (fingernail 2.5)
3. Calcite (copper penny 3.5)
4. Fluorite
5. Apatite (glass - steel 5.5)
6. Orthoclase (steel file 6.5)
7. Quartz
8. Topaz
9. Corundum
10. Diamond

TABLE 5.1 Mohs Hardness Scale



Specific Gravity: Represents the density of a mineral: mineral weight (mass?) over the weight (mass?) of an equal water volume - unitless value since mass/mass

- Specific gravity is “heft” - how heavy it feels. e.g. Galena - heavy (SG 7.60) and Quartz - light (SG 2.65). Galena feels heavier than quartz

Crystal Habit: A single crystal with well-formed faces (euhedral) or an aggregate of many well-formed crystals. The habit is the shape of a single crystal with well-formed (euhedral)

crystal faces, a macroscopic reflection of the internal arrangement of atoms in the crystal (i.e. outer structure reflects internal structure)

- Arrangement of faces reflects internal atomic structure
- Records variation in directional growth rates
 - Blocky or equant: equal growth rate in 3-dimension
 - Bladed: shaped like a knife - faster growth rate in 1 direction (vertical) versus the other direction (horizontal), 2-dimensional growth
 - Needle-like: rapid growth in 1-dimension, slow in others

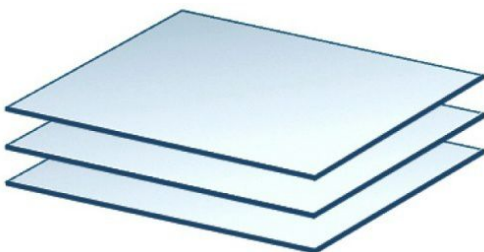
Special Physical Properties: There are many other less common physical properties that are useful for identifying minerals. E.g. Sulphur smells like rotten eggs. Halite tastes like salt (it is salt). Magnetite is magnetic.

- Effervescence—reactivity with acid, e.g. Calcite
- Magnetism—magnetic attraction, e.g. Magnetite
- Taste
- Smell
- Feel—tactile response
- Elasticity—response to bending
- Diaphaneity—relative transparency
- Piezoelectricity—electric charge when squeezed
- Pyroelectricity—electric charge when heated
- Refractive Index—degree of bending light
- Malleability—ability to be pounded into thin sheets
- Ductility—ability to be drawn into thin wires
- Sectility—ability to be shaved with a knife

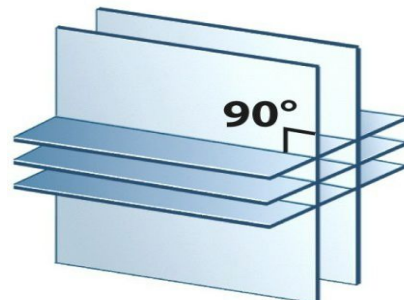
Fracture: Minerals break in ways that reflect atomic bonding. Different minerals fracture (break) in different ways, depending on the internal arrangement of their atoms. Cleavage forms in directions where the bonds holding the atoms together in the crystal are the weakest (van der Waals in graphite, biotite, and muscovite). Conchoidal fractures are smoothly curving, clamshell-shaped surfaces, they typically form in quartz and glass.

Cleavage creates flat, shiny (reflective) surfaces that may occur in steps. Cleavage can be distinguished from crystal faces because it is throughgoing; faces are on external crystal surfaces only. The number of cleavage planes and their angle to one another are diagnostic.

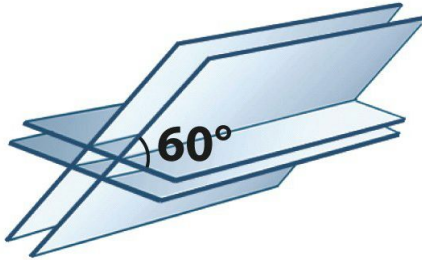
One direction:



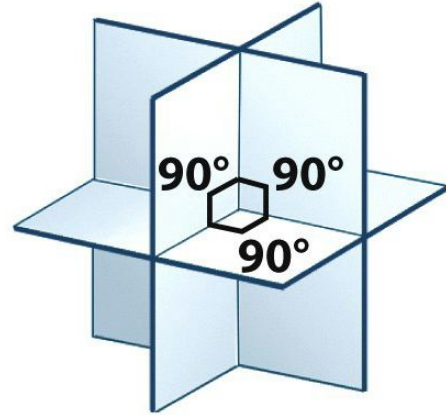
Two-directions at 90 degrees:



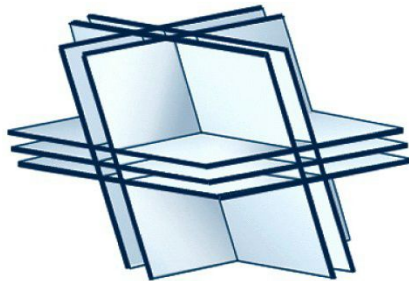
Two-directions NOT at 90 degrees:



Three-directions at 90 degrees, e.g. halite:



Three-directions NOT at 90 degrees, e.g. calcite



Practice Question: When we say that a material is “crystalline” we mean that internally....

Answer: Atoms are distributed in an orderly arrangement.

Practice Question: The chemical formula of quartz is SiO_2 . This means that if you analyze a piece of quartz, you will find that...

Answer: The piece contains one Si atoms for every 2 O atoms.

Practice Question: Take a moment to write down... What is covalent bonding? What is ionic bonding?

Covalent bonding is the sharing of valence electrons between 2 non-metal elements (e.g. CO_2). This sharing results in a neutral charge, Ionic bonding is the transfer of electrons between a metal element and non-metal element (NaCl). The more electronegative atom will “take” the electron from the less electronegative atom, therefore resulting in a positive and negative charge among the respective atoms.

Practice Question: What statement about the specific gravity of minerals is correct?

Answer: If a mineral has a specific gravity of 2, then a cubic cm of the mineral weighs twice as much as a cubic cm of water.

Practice Question: If a sample has good cleavage in 3 directions, and each cleavage direction is at right angles to the other 2, then...

Answer: When crystals break, little cube-shaped or brick-shaped fragments form

-Fracture is how it breaks, whereas cleavage are planes where breaks will occur along. In the case of a mineral, it will fracture along its cleavages'. E.g. Mica which has strong bonds along its surfaces and weak bonds between the surfaces, mica has a cleavage in 1 direction along that plane. Generally, cleavages are planes that have the weakest bonds.

Mineral Classification: Minerals can be classified by their principal anions (negative atom) or anionic groups (negative molecule). There are 8 principal classes.

Silicates (SiO_2^{4-}):

- The rock forming minerals - building blocks of lithosphere
- Constitute almost entire crust of the Earth
- They are the most common minerals
- E.g. Quartz SiO_2

Sulfides (S^{2-}):

- Metal cations (+) bonded to a sulfide anion (-)
- E.g. Pyrite (FeS_2), Galena (PbS), Sphalerite (ZnS)

Oxides (O^{2-}):

- Metal cations (Fe^{2+} , Fe^{3+} , Ti^{2+}) bonded to oxygen
- E.g. Magnetite (Fe_3O_4), Hematite (Fe_2O_3), Rutile (TiO_2)

Sulfates (SO_4^{2-}):

- Metal cation bonded to a sulfate anionic group
- Many sulfates form by evaporation of seawater
- E.g. Gypsum ($CaSO_4 \cdot H_2O$), Anhydrite ($CaSO_4$)

Halides (Cl^- or F^-) halogen ion:

E.g. Halite (NaCl - rock salt), Fluorite (CaF_2)

Carbonates (CO_3^{2-}) commonly referred to as limestone:

E.g. Calcite ($CaCO_3$), Dolomite ($(Ca, Mg)CO_3$).

Native Metals (Cu, Au, Ag)

- Pure masses of a single metal
- E.g. Copper (Cu), Gold (Au), Silver (Ag), Mercury (Hg)

Native Elements (C):

- Pure masses of a single element
- E.g. Diamond, graphite (C)

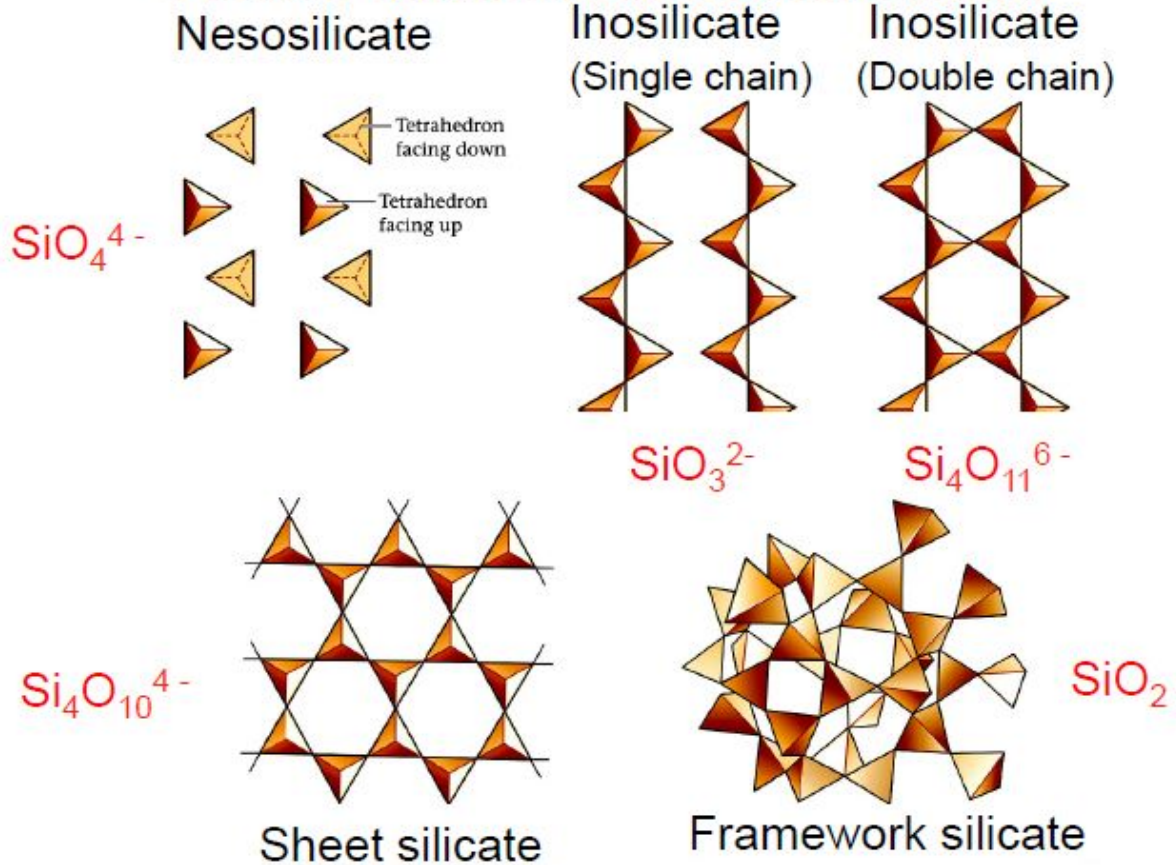
- Silicates [$(SiO_4)^{4-}$], like K-feldspar ($KAlSi_3O_8$)
- Oxides [O^{2-}], like hematite (Fe_2O_3), magnetite (Fe_3O_4)
- Sulfates [$(SO_4)^{2-}$], like gypsum ($CaSO_4 \cdot 2H_2O$)
- Halides [F^- , Cl^- , Br^- , I^-], like halite (NaCl), sylvite (KCl), fluorite (CaF_2)
- Carbonates [$(CO_3)^{2-}$], like calcite/aragonite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$)
- Sulfides [S^{2-}], like galena (PbS), pyrite (FeS_2)
- Native metals, like copper (Cu), gold (Au), silver (Ag)
- Native elements, like diamond and graphite (C)

Silicate Minerals:

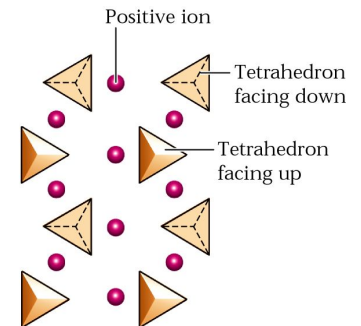
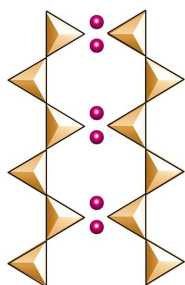
- Silicates are the most common minerals on Earth
- They dominate Earth's crust and mantle
- Made of oxygen and silicon with other atoms
- The SiO_4^{4-} anionic unit: the silicon-oxygen tetrahedron: 4 O atoms are bonded to a central Si atoms - define the corners of a 4-sided geometric figure
- The silica-tetrahedron is the building block of silicates

Silicate Structures

(distinguished on the basis of how many tetrahedrons are linked to each other or the number of oxygen atoms shared between tetrahedrons)

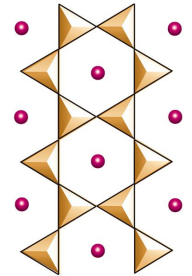


Nesosilicates: The tetrahedrons are independent and do not share any oxygen atoms. The negative charge of the tetrahedron is matched by the positive charge of metal cations. E.g. Olivine $(Fe, Mg)_2\text{SiO}_4$



Inosilicates: Single chain - sharing of 2 oxygen atoms. Typically have 2 cleavages at 90 degrees.
E.g. Pyroxene

Inosilicates: Double chain - sharing of 2 or 3 oxygen atoms. Typically have 2 cleavages at 60 degrees to each other. E.g. Amphibole.

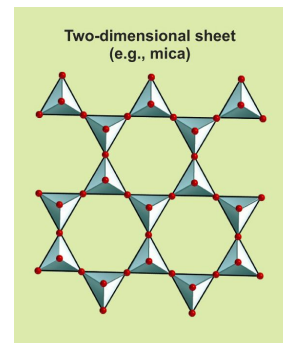


Chain Silicates:

- e.g. PYROXENES (SINGLE CHAIN) - cleavage at 90 degrees and AMPHIBOLES (DOUBLE CHAIN) - cleavage at 60 degrees
- Dark because of enrichment in Fe, Mg (ferromagnesian minerals).
- Cleavages allow you to tell these two groups apart.

Sheet Silicates:

- Silica tetrahedra share 3 oxygens
- Create 2-dimensional flat sheets of linked tetrahedra
- Characterized by one direction of perfect cleavage
- E.g. Micas, clays



Framework Silicates:

- All 4 oxygens in each silica tetrahedron are shared
- E.g. Feldspars - plagioclase and potassium feldspar
- Silica (quartz) group contains only Si and O

