

## Classification of Minerals by Anionic Species

(Anions are negative ions)

## Chemical Classification of Minerals

### Learning goals:

How are minerals classified by chemistry?  
Why is this useful?

- ### Anions are Negative Ions
- May be single species
    - $O^{2-}$ ,  $F^-$ ,  $Cl^-$ ,  $S^{2-}$
  - May be anionic group (polyanion):
    - $CO_3^{2-}$ ,  $SO_4^{2-}$ ,  $PO_4^{3-}$
  - Silicates are classified by polymerization of the silicate polyanion.
    - Isolated tetrahedra
    - Chains
    - Sheets
    - Frameworks

### Periodic Table

**Anions**

- Chalcogens
- Halogens
- Polyanions

- ### Native Elements (no anions)
- Pure elements that occur as minerals
    - Graphite, diamond (C)
    - Sulfur (S)
    - Gold (Au), Silver (Ag), Copper (Cu)
    - Iron (kamacite)
    - Nickel (taenite)
    - As, Te, Se, Pt, Ir, Os, Pd, Ru, Rh

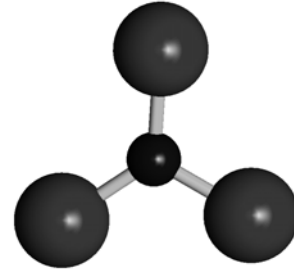
### Native Elements



*Hydroxides:  
anion is OH*

- *Brucite*  $Mg(OH)_2$
- *Gibbsite*  $Al(OH)_3$
- *Diaspore*  $AlOOH$  (*Bauxite*)
- *Goethite*  $FeOOH$

*Carbonates  
anion is  $(CO_3)^{2-}$*



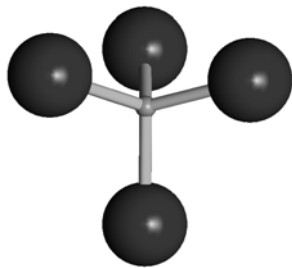
*Carbonates  
Anion is  $(CO_3)^{2-}$*

- *Calcite*  $CaCO_3$ , *Rhodochrosite*  $MnCO_3$
- *Siderite*  $FeCO_3$ , *Smithsonite*  $ZnCO_3$
- *Dolomite*  $CaMg(CO_3)_2$
- *Aragonite*  $CaCO_3$ , *Witherite*  $BaCO_3$
- *Strontianite*  $SrCO_3$ , *Cerussite*  $PbCO_3$
- *Malachite* and *Azurite*

Carbonate Minerals

																		Calcite Group			Aragonite Group			Other			He														
H																																									
Li	Be	B	C	N																							O	F	Ne												
Na	Mg	Al	Si	P																							S	Cl	Ar												
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																								
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																								
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn																								
Fr	Ra	Ac																																							
																		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu										
																		Th	Pa	U																					

*Sulfates and Phosphates:  
 $(SO_4)^{2-}$  and  $(PO_4)^{3-}$*



*Sulfates and Phosphates:  
 $(SO_4)^{2-}$  and  $(PO_4)^{3-}$*

- *Barite*  $(BaSO_4)$ , *Celestine*  $(SrSO_4)$
- *Gypsum*  $CaSO_4 \cdot 2H_2O$
- *Anhydrite*  $CaSO_4$
- *Apatite*  $Ca_5(PO_4)_3OH$
- *Turquoise*  $CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$

**Sulfate Minerals**

																		■	Gypsum/Anhydrite	He
																		■	Barite Group	O F Ne
																		■	Alunite	S Cl Ar
H	Li	Be	B	C	N													O	F	Ne
Na	Mg	Al	Si	P													S	Cl	Ar	
K	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	Xe				
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn			
Fr	Ra	Ac																		
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu							
Th	Pa	U																		

*Silicates are classified by polymerization*

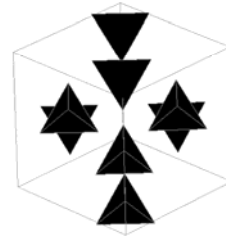
- Orthosilicates ( $SiO_4$ )<sup>4-</sup>: Isolated tetrahedra
- Sorosilicates ( $Si_2O_7$ )<sup>6-</sup> 'Bow-Ties'
- Chain silicates
  - ( $SiO_3$ )<sup>2-</sup>: Infinite single chains
  - ( $Si_4O_{11}$ )<sup>6-</sup>: Double Chains
- Sheet Silicates ( $Si_4O_{10}$ )<sup>4-</sup> sheets
- Framework Silicates ( $SiO_2$ ) framework

*Orthosilicates: ( $SiO_4$ )<sup>4-</sup>*

- Isolated  $SiO_4$  tetrahedra
- Olivine Group ( $Mg_2SiO_4$ )
- Garnet Group ( $Mg_3Al_2Si_3O_{12}$ )
- Aluminosilicate Group ( $Al_2SiO_5$ )
- Staurolite, Zircon, Titanite



*Orthosilicates: Isolated Tetrahedra*



*Sorosilicates and Cyclosilicates*

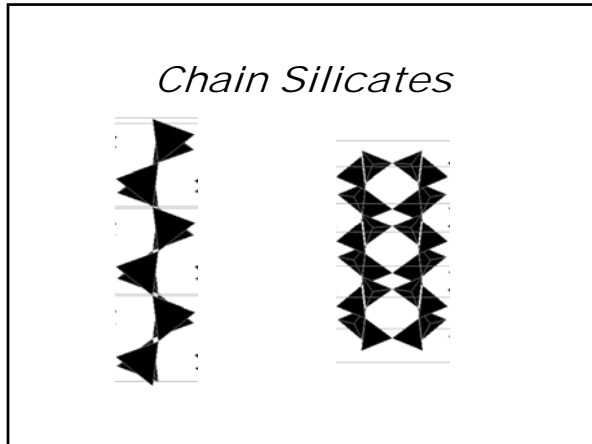
- Epidote Group  $Ca_2Al_2FeSi_3O_{12}(OH)$
- Tourmaline  $NaMg_3Al_5B_3Si_6O_{27}(OH)_4$
- Beryl  $Be_3Al_2Si_6O_{18}$
- Cordierite  $(Mg,Fe)_2Al(AlSi_5)O_{18} \cdot nH_2O$



*Chain Silicates*

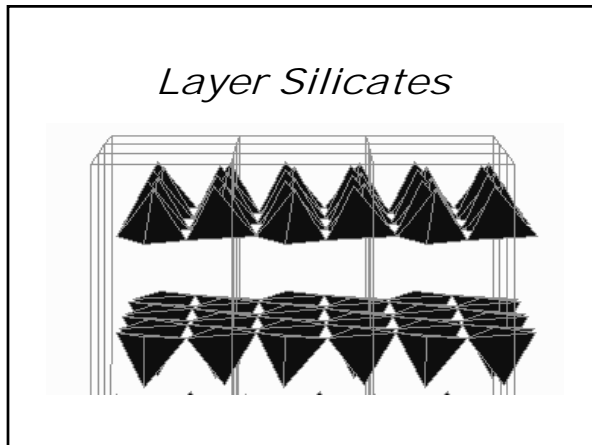
- Single Chains
  - Orthopyroxenes  $Mg_2Si_2O_6$
  - Clinopyroxenes  $CaMgSi_2O_6$
  - Pyroxenoids  $Ca_3Si_3O_9$
- Double Chains
  - Amphiboles  $(Mg,Fe)_7Si_8O_{22}(OH)_2$





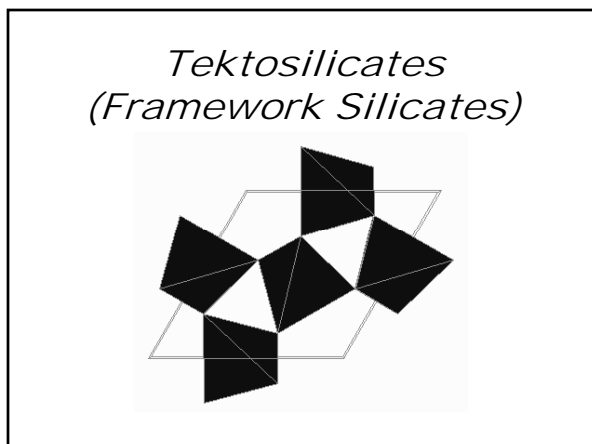
*Layer Silicates*

- Antigorite  $Mg_3Si_2O_5(OH)_4$
- Talc  $Mg_3Si_4O_{10}(OH)_2$
- Kaolinite  $Al_2Si_2O_5(OH)_4$
- Pyrophyllite  $Al_2Si_4O_{10}(OH)_2$
- Biotite  $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
- Muscovite  $KAl_2AlSi_3O_{10}(OH)_2$
- Chlorite  $(Mg,Fe)_6AlSi_3O_{10}(OH)_2$



*Framework Silicates  
(Tectosilicates)*

- Silica Group  $SiO_2$
- Alkali Feldspar  $(Na,K)AlSi_3O_8$
- Plagioclase  $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$
- Feldspathoids (Leucite, Kalsilite, etc)
- Zeolites (open hydrous frameworks)



*Chemical Classification of Minerals*

*Learning goals:*

*How (why) are minerals classified by chemistry?*

*Why is this useful?*

*Why not by cations?*

*How else might you classify minerals?*

*Hardness? Color?*

*Occurrence? Abundance?*

*Clicker Question:  
Give Chemical Classification  
of  
Kamacite (Fe)*

- A. Native Element*
- B. Sulfide*
- C. Metal*
- D. Extra-terrestrial*
- E. Oxide*

*Clicker Question:  
Give Class of  
Troilite (FeS)*

- A. Native Element*
- B. Sulfide*
- C. Sulfate*
- D. Phosphate*
- E. Oxide*

*Clicker Question:  
Give Class of  
Pyrite (FeS<sub>2</sub>)*

- A. Native Element*
- B. Sulfide*
- C. Sulfate*
- D. Phosphate*
- E. Oxide*

*Clicker Question:  
Give Chemical Classification  
of  
Barite (BaSO<sub>4</sub>)*

- A. Native Element*
- B. Sulfide*
- C. Sulfate*
- D. Phosphate*
- E. Oxide*

*Chemical Classification of  
Minerals  
Learning goals:*

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*Geochemical  
Classification of the  
Elements*

*Lithophile - Ionic*

*Siderophile - Metallic*

*Chalcophile - Covalent*

*Atmophile - Van der Waals*

## Geochemical Classification of the Elements

- How do the elements partition between coexisting fluid (melt) phases?
  - Gas Phase : *Atmophile* : Van der Waals
  - Oxide phase: *Lithophile* : Ionic
  - Sulfide Phase: *Chalcophile*: Covalent
  - Metal Phase: *Siderophile*: Metallic

## Geochemical Classification of the Elements

