## Classification of Minerals by Anionic Species

(Anions are negative ions)

## How would you organize some 5000 species of minerals?

Color?

Hardness?

Occurrence environment?

Chemistry?

Positive ions? (cations)

Negative ions? (anions)

## Chemical Classification of Minerals Learning goals:

How are minerals classified by chemistry?

Why is this useful?

## Chemical Classification of Minerals Learning goals:

How are minerals classified by chemistry?

By anionic species.

## Chemical Classification of Minerals Learning goals:

Why is this useful?

Because there is very little substitution at anion sites

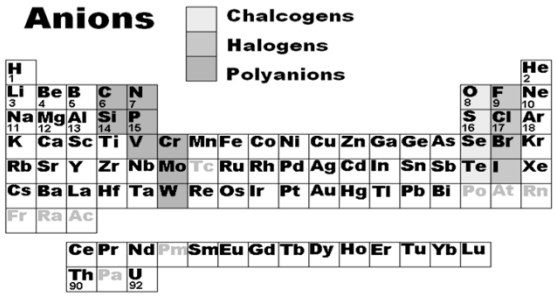
## Anions are Negative Ions

- 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

## Chemical Classification

- Native Elements (no anions)
- Halides (F, Cl, Br, I) (monovalent halogen)
- Sulfides & arsenides (S, Ar)
- Oxides (O)
- Hydroxides (OH)
- Sulfates & phosphates ($SO_4$, $PO_4$)
- Carbonates ($CO_3$)
- Silicates:
  - orthosilicates, sorosilicates, chain silicates, layer silicates, framework silicates

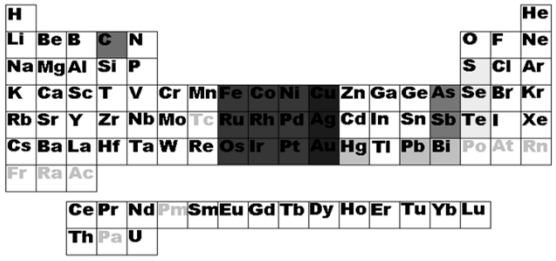
## Periodic Table




## 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

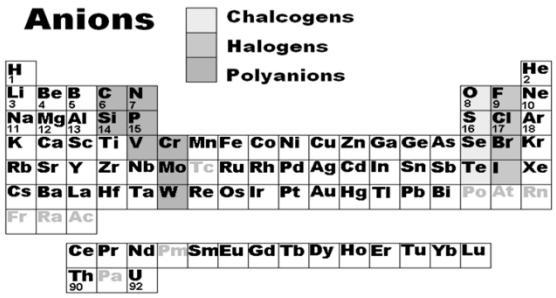
## Native Elements



## Halides: anion is F, Cl, Br, or I

- Halogens are the elements F, Cl, Br, I
- Halogens are monovalent anions
- Halite (NaCl), Sylvite (KCl)
- Fluorite ($CaF_2$)
- Cryolite $Na_3AlF_6$

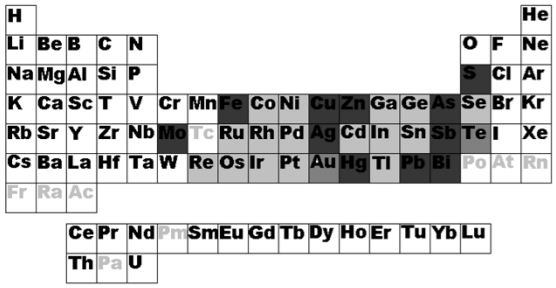
## Periodic Table



## Sulfides: anion is S

- Sulfur is "anion", but is more covalent than ionic (stoichiometry is less strict)
  - Pyrite, marcasite ($FeS_2$), chalcopyrite ($CuFeS_2$)
  - Sphalerite ZnS, galena (PbS)
  - Chalcocite $Cu_2S$, covellite (CuS), bornite ($Cu_5FeS_4$)
  - Realgar (AsS), orpiment ($As_2S_3$), cinnabar (HgS)
  - Stibnite ($Sb_2S_3$), molybdenite ($MoS_2$)
- Sulfide minerals typically have metallic luster, covalent bonding, and occur in hydrothermal veins.
- Only rarely do they occur at the surface.

## Elements in Sulfide Minerals



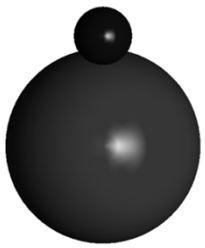

## Oxides (Single): anion is O (no polyanion)

- Hemi-oxide Cuprite ($Cu_2O$), Ice ($H_2O$)
- Monoxides
  - Periclase group MgO, FeO, CaO, MnO
  - Zincite ZnO, Bromellite BeO
- Sesquioxides
  - Corundum $Al_2O_3$, Hematite $Fe_2O_3$
- Dioxides
  - Rutile $TiO_2$, Cassiterite $SnO_2$, Pyrolusite $MnO_2$

## Oxides (Complex): anion is O

- Ilmenite $FeTiO_3$
- Spinel Group
  - Spinel $MgAl_2O_4$, Magnetite $Fe_3O_4$
- Perovskite $CaTiO_3$

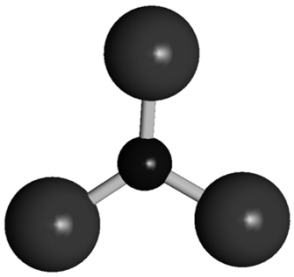
## Hydroxides: anion is $(OH)^-$



## Hydroxides: anion is OH

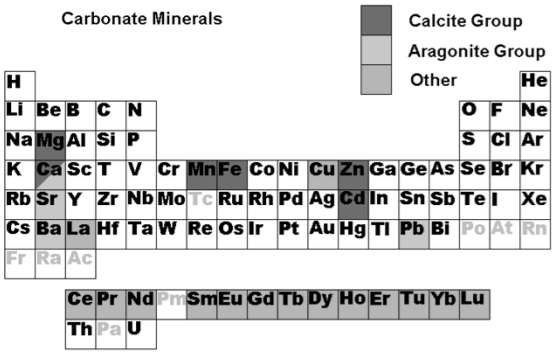
- Brucite $Mg(OH)_2$
- Gibbsite $Al(OH)_3$
- Diaspore AlOOH (Bauxite)
- Goethite FeOOH

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

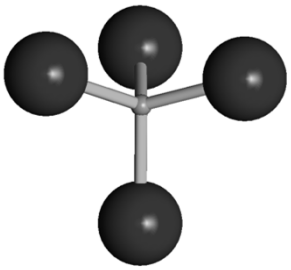


## Carbonates Anion is $(CO_3)^{2-}$

- *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*




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

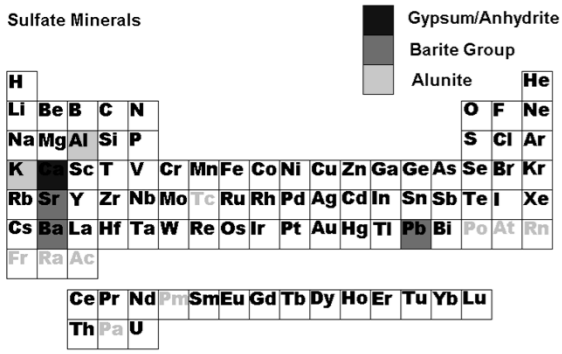


## Sulfates and Phosphates: $(SO_4)^{2-}$ and $(PO_4)^{3-}$

- *Sulfur is 6+*
- *Phosphorus is 5+*
- *Contrast sulfide ($S^{2-}$) and sulfate ($S^{6+}$).*
- *Phosphide ($P^{3-}$) and phosphate ($P^{5+}$).*
- *Sulfates and phosphates are oxidized!*

## 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 $CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$*



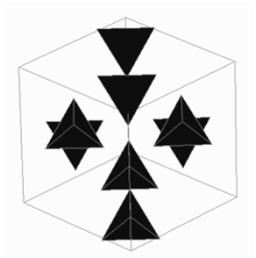

## *Silicates are classified by polymerization*

- *Orthosilicates $(SiO_4)^{4-}$: Isolated tetrahedral O / Si = 4.0*
- *Sorosilicates $(Si_2O_7)^{6-}$ 'Bow-Ties' 3.75*
- *Chain silicates*
  - *$(SiO_3)^{2-}$ : Infinite single chains 3.0*
  - *$(Si_4O_{11})^{6-}$ : Double Chains 2.75*
- *Sheet Silicates $(Si_4O_{10})^{4-}$ sheets 2.5*
- *Framework Silicates $(SiO_2)$ framework 2.0*

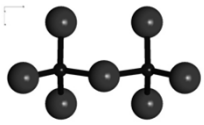
## *Orthosilicates: $(SiO_4)^{4-}$ Si/O: <~1/4 O / Si = 4*

- *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 Si/O: 1/3 ~ ¼ O / SI = 3 – 3.5*

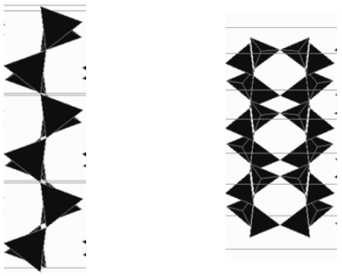


- *Epidote Group $Ca_2Al_2FeSi_3O_{12}(OH)$*
- *Tourmaline $NaMg_3Al_5B_3Si_6O_{27}(OH)_4$*
- *Beryl $Be_3Al_2Si_6O_{18}$*
- *Cordierite $(Mg,Fe)_2Al(AlSi_5)O_{18} \cdot nH_2O$*

## *Chain Silicates*

- *Single Chains Si/O ~ 1/3*
  - *O / Si = 3.0*
  - *Orthopyroxenes $Mg_2Si_2O_6$*
  - *Clinopyroxenes $CaMgSi_2O_6$*
  - *Pyroxenoids $Ca_3Si_3O_9$*
- *Double Chains Si/O 4:11*
  - *O / (Si+Al) = 2.75*
  - *Amphiboles $(Mg,Fe)_7Si_8O_{22}(OH)_2$*

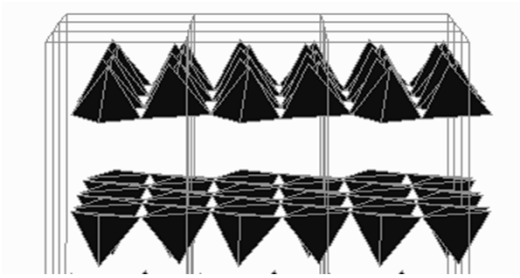
## Chain Silicates



## Layer Silicates
O / Si = 2.5

- 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 $KAl_2(AlSi_3)O_{10}(OH)_2$
- Chlorite $(Mg,Fe)_6AlSi_3O_{10}(OH)_2$

## Layer Silicates



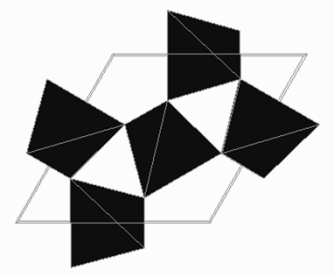
## Framework Silicates (Tektosilicates)
O / Si = 2

- 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)

## O / $(Al + Si)^{IV}$

- Framework Silicates = 2.0
- Sheet Silicates = 2.5
- Amphiboles = 2.75
- Chain Silicate = 3.0
- Sorosilicates = 3.5
- Orthosilicates = 4

## Tektosilicates (Framework Silicates)



## Chemical Classification

- Native Elements (no anions)
- Halides (F, Cl, Br, I)
- Sulfides & arsenides (S, Ar)
- Oxides (O)
- Hydroxides (OH)
- Sulfates & phosphates ($SO_4$, $PO_4$)
- Carbonates ($CO_3$)
- Silicates:
  - orthosilicates, sorosilicates, chain silicates, layer silicates, framework silicates

## 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?

## Give Chemical Classification of Kamacite (Fe)

A. Native Element

B. Sulfide

C. Metal

D. Extra-terrestrial

E. Oxide

## Give Chemical Classification of Kamacite (Fe)

A. <u>Native Element</u>

B. Sulfide

C. Metal

D. Extra-terrestrial

E. Oxide

## Give Classification of Troilite (FeS)

A. Native Element

B. Sulfide

C. Sulfate

D. Phosphate

E. Oxide

## Give Classification of Troilite (FeS)

A. Native Element

B. <u>Sulfide</u>

C. Sulfate

D. Phosphate

E. Oxide

*Give Classification of Pyrite ($FeS_2$)*

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

*Give Classification of Pyrite ($FeS_2$)*

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

*Give Chemical Classification of Barite ($BaSO_4$)*

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

*Give Chemical Classification of Barite ($BaSO_4$)*

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

*Give Chemical Classification of Fluorite ($CaF_2$)*

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

*Give Chemical Classification of Fluorite ($CaF_2$)*

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

## Give Chemical Classification of Apatite ($Ca_3(PO_4)_3F$)

A. Native Element
B. Sulfide
C. Sulfate
D. Phosphate
E. Halide

## Give Chemical Classification of Apatite ($Ca_3(PO_4)_3F$)

A. Native Element
B. Sulfide
C. Sulfate
D. Phosphate
E. Halide

## Homework 1

Due Tuesday

## Chemical Classification of Minerals Learning goals:

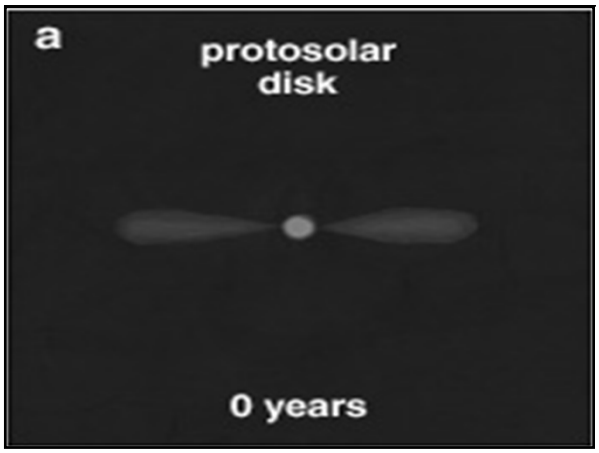
How (why) are minerals classified by chemistry?
Why is this useful?
Why not by cations?
How else might you classify minerals?
Hardness? Color?
Occurrence? Abundance?

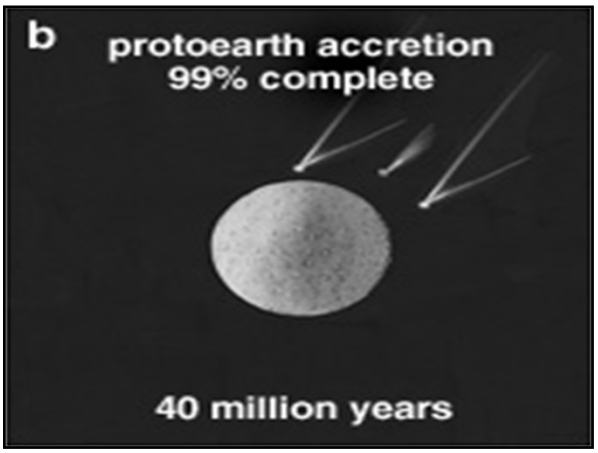
## Geochemical Classification of the Elements

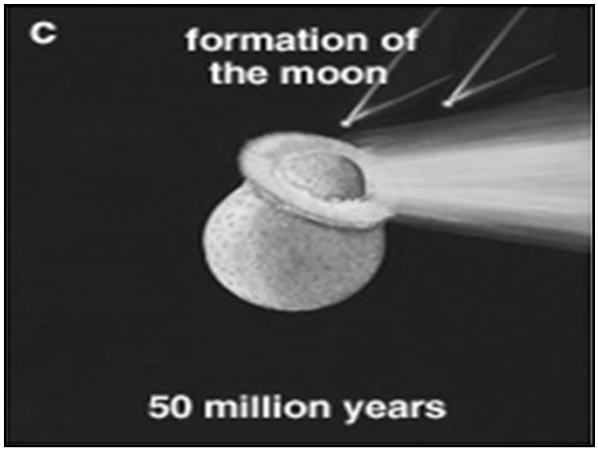
Lithophile - Ionic
Siderophile - Metallic
Chalcophile - Covalent
Atmophile - Van der Waals

## Geochemical Classification of the Elements

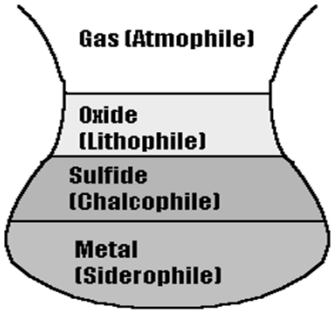
- How do the elements partition between coexisting fluid (melt) phases?
  - Gas Phase : Atmophile : Van der Waals
  - Oxide phase: Lithophile : Ionic
  - Sulfide Phase: Chalcophile: Covalent
  - Metal Phase: Siderophile: Metallic



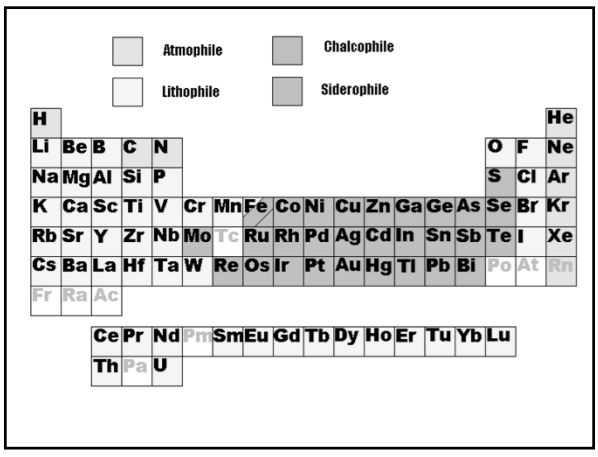




**Geochemical Classification of the Elements**




Elements partition among immiscible fluids by bond type (!!)

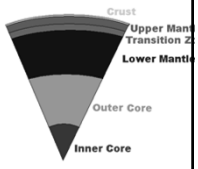



# *Geochemical Classification of the Elements*

*Atmophile - Van der Waals*
*Lithophile - Ionic*
*Chalcophile - Covalent*
*Siderophile - Metallic*

# Geochemical Classification of the Elements

*Atmophile - Van der Waals*
*Lithophile - Ionic*
*Chalcophile - Covalent*
*Siderophile - Metallic*




# Geochemical Classification of the Elements

*Atmophile - Van der Waals*
*Lithophile - Ionic*
*Siderophile - Metallic*
*Chalcophile - Covalent*