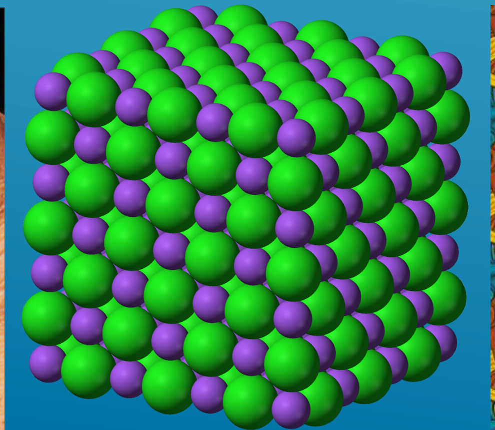
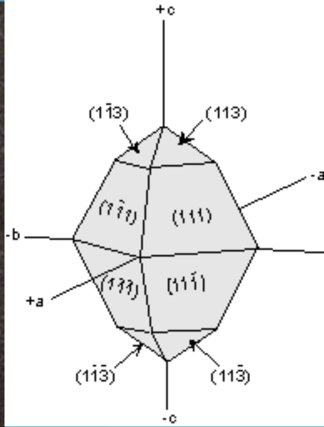
REVIEW: CHAPTERS 1 TO 5

Sarah Lambart

CHAPTER 1:
MINERAL PROPERTIES AND CLASSIFICATION

CHAP. 1: MINERAL PROPERTIES AND CLASSIFICATION

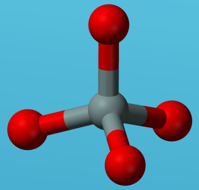
- **Mineral:**
  - naturally occurring (always)
  - a structure and a composition that give it defined macroscopic properties (always)
  - inorganic (always)
  - Solid (most of the time)
  - crystalline solid (most of the time)
  - Homogeneous (most of the time)

CHAP. 1: MINERAL PROPERTIES AND CLASSIFICATION

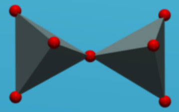
- **Classification (based on the dominant anion)**:
  - sulfates SO_4^{2-}
  - phosphates PO_4^{3-}
  - borates BO_3^{2-}
  - **silicates SiO_4^{2-}**
  - oxides O^{2-}
  - hydroxides OH^-
  - carbonates CO_3^{2-}
  - native (no anion)
  - sulfides S^{2-}
  - halides F^-, Br^-, Cl^- or I^-

CHAP. 1: MINERAL PROPERTIES AND CLASSIFICATION

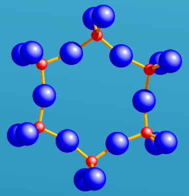
- **Silicate classification: (based on polymerization)**



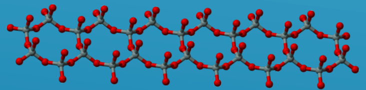
- orthosilicates: olivine (most common mnl on Earth), garnet



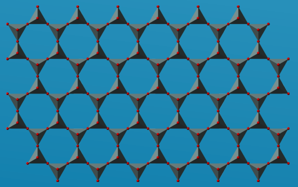
- sorosilicates: epidote



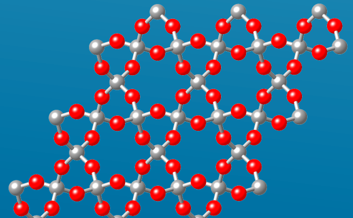
- cyclosilicates: tourmaline, cordierite



- chain silicates : amphiboles, pyroxenes



- sheet silicates: micas



- Framework silicates: quartz, feldspar (most common mnl in Earth's crust)

CHAP. 1: MINERAL PROPERTIES AND CLASSIFICATION

- **Physical properties:**

- Habit: euhedral, subhedral, anhedral
- Morphology: granular, tabular, prismatic
- Transparency: transparent, translucent, opaque
- Luster, Metallic, submetallic, adamantine, resinous, vitreous, earthy
- Color & Streak (color of powder on a porcelain plate)
- Tenacity: brittle, sectile, ductile
- Cleavage and fractures
- Density in g/cm^3 or specific gravity $(Wa/(Wa\text{-}Ww))$
- Hardness: Moh's scale: talc<gypsum<calcite<fluorite<apatite<orthoclase< quartz< topaz< corundum< diamond
- Others: taste, acid test, electric conductivity, radioactivity, magnetism, fluorescence, pleochroism

CHAPTER 2:
ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

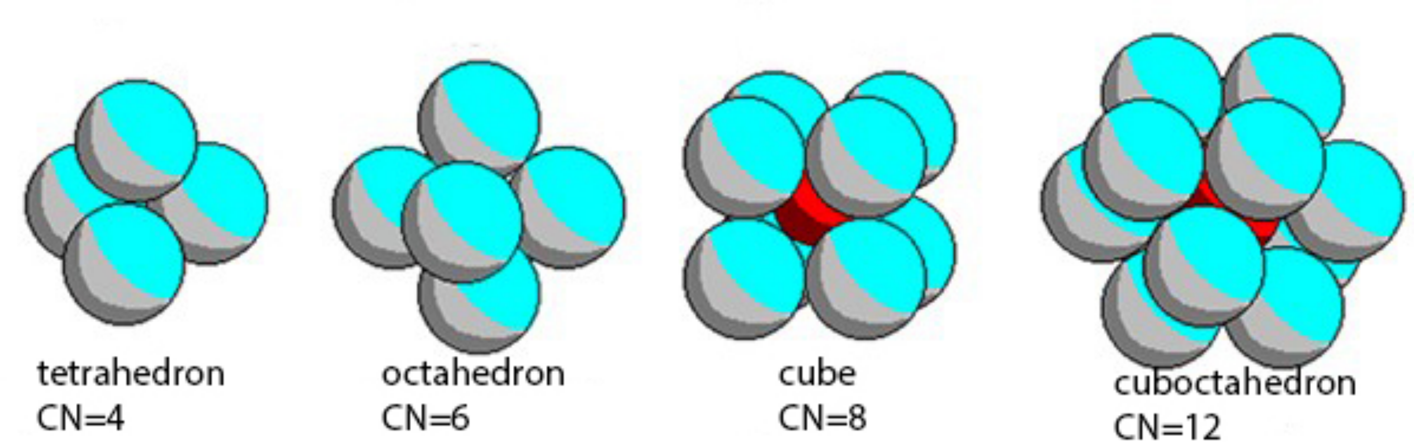
- **Close-packing:** Arrangement of atoms with the same size that minimizes void space.

- **2 different type of close packing**:
  - hcp: tetrahedral interstice (ABABA)
  - ccp: octahedral interstice (ABCABC)

CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

- Even if not ideally close-packed, anions form regular coordination polyhedra about cations

- **Definitions:** The coordination number or **CN** is the number of closest neighbors of opposite charge around an ion. It can range from 2 to 12 in ionic structures. These structures are called **coordination polyhedra.**



CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

- **Pauling's rule:**
- #1: the coordination polyhedron is defined by the ratio R_{cation}/R_{anion}

Rx/Rz	C.N.	Type
1.0	12	Hexagonal or Cubic Closest Packing
1.0 - 0.732	8	Cubic
0.732 - 0.414	6	Octahedral
0.414 - 0.225	4	Tetrahedral (ex.: SiO_4^{4-})
0.225 - 0.155	3	Triangular
<0.155	2	Linear

CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

- **Pauling's rule:**
- #2: The Electrostatic Valency (e.v.) Principle: ev = Z/CN

⇒ extremely useful in evaluating the nature of the crystal structure:

Stable structure ⇔ sum of electrostatic valences from cations exactly balance the charge of the anion.

CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

- **Pauling's rule:**
- #3: Shared edges and faces of coordination polyhedra decrease the stability of the crystal (because they reduced the distance cation-cation or anion-anion)
- #4: In crystal with different cations, those of high valency and small CN tend not to share polyhedral elements

CHAP. 2: ATOMIC ARRANGEMENTS AND MINERALOGICAL STRUCTURES

- **Pauling's rule:**
- #5: The principle of parsimony: the number of different kinds of constituents in a crystal tends to be small because there are only few types of different cations and anions sites.

⇒structures with complex chemical composition: different ions can occupy the same site ⇔ solid solutions

Ex: olivine: Mg^{2+} and Fe^{2+} can both occupy the octahedral sites while Si^{4+} occupies the tetrahedral sites

CHAPTER 3:
SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Definitions**
- **Lattice point (or node)**: random point in a crystal structure (usually chosen as the point of highest symmetry) that can be exactly reproduced by translation (and translation only)
  - **"Motif"**: The collection of atoms that can be reproduced by translation only.
  - **Crystal lattice:** constructed by connecting the lattice points

CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Primitive cell:**
  - **2D:** 4 connected lattice points forming a parallelogram
  - **3D:** 8 connected lattice points forming a parallelepiped

Contain one unique lattice point (or one motif)

CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Multiple cell: 2D**
  - **Centered:** One lattice point at each corner + one lattice point in the center. Contain **2 lattices points** (or 2 motifs)

CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Multiple cell: 3D**
  - **F: face-centered:** One lattice point at each corner + one lattice point in the middle of each faces. Contain **4 lattices points** (or 4 motifs)
  - **I: Body-centered:** One lattice point at each corner + one lattice point in the middle of the cell. Contain **2 lattices points**
  - **C: Side centered:** One lattice point at each corner + one lattice point in the middle of the bottom and the top faces. Contain **2 lattices points**

(each corner is shared with 8 other cells and each face is shared with 2 cells)

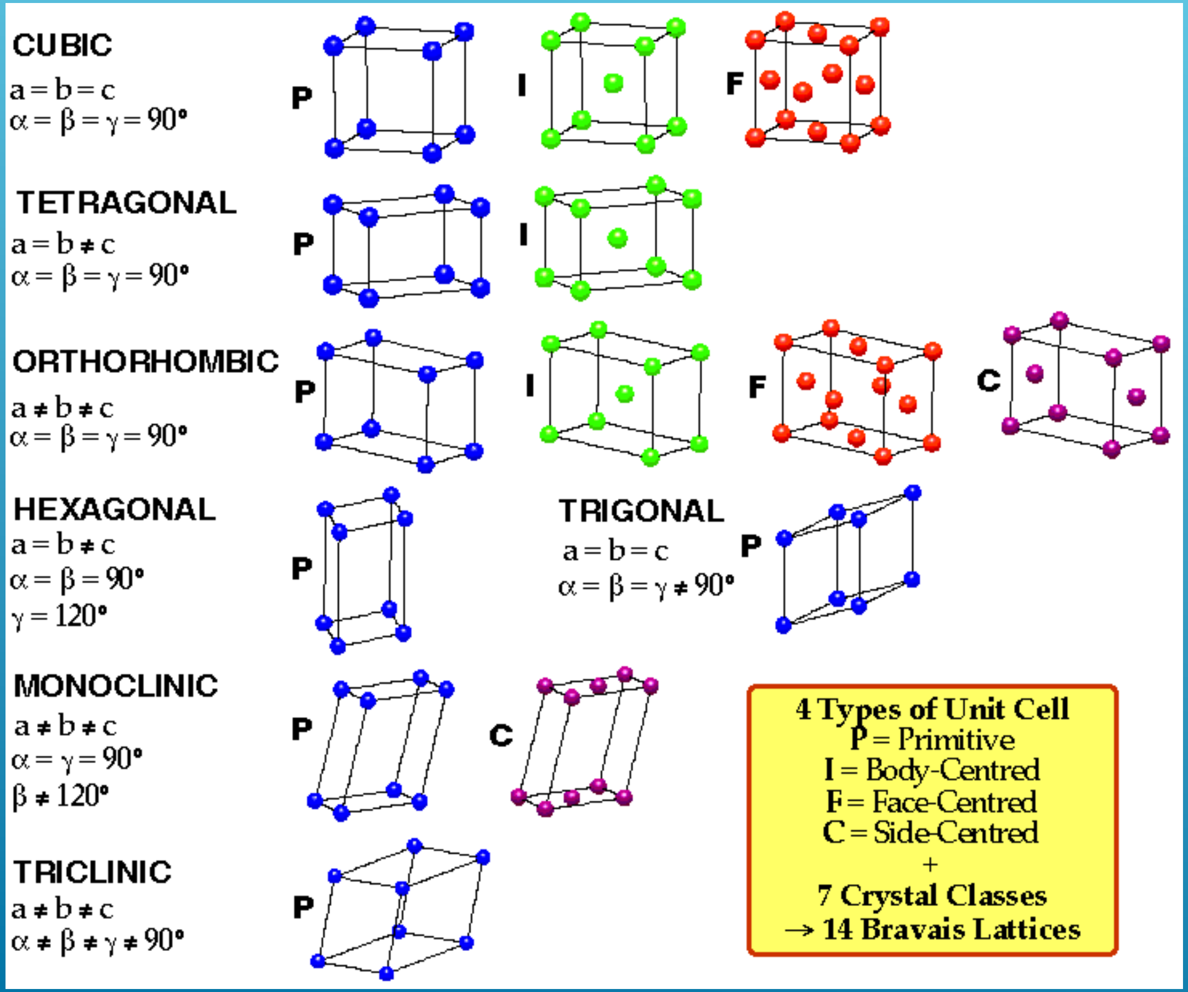
CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Unit cell**: the smallest divisible unit of a mineral that possesses the symmetry and properties of the mineral.

- Rules to choose a unit cell
  - Smallest repeatable unit
  - Highest possible symmetry (with the most 90° angles)

CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **7 Crystal systems & 14 Bravais lattice**



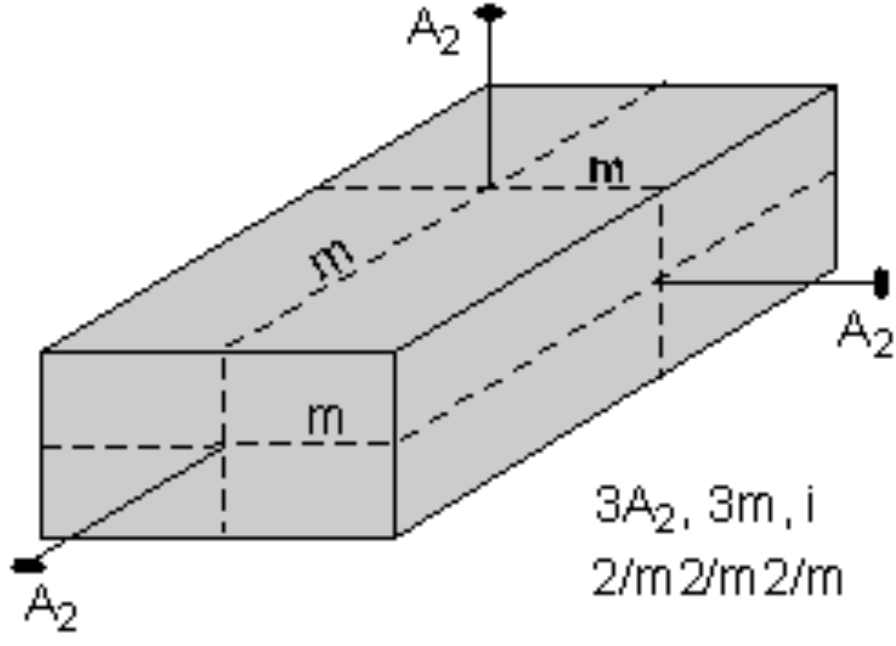
CHAP. 3: SYMMETRY AND GROUPS, AND CRYSTAL STRUCTURES

- **Elements of symmetry**
  - **Rotations:** 1 fold, 2 fold, 3 fold, 4 fold, 6 fold
  - **Mirror**
  - **Center of symmetry**
  - **Rotoinversions:**1 fold, 2 fold, 3 fold, 4 fold, 6 fold

CHAPTER 4:
THE 32 CRYSTAL CLASSES AND THE MILLER INDICES

CHAP.4: THE 32 CRYSTAL CLASSES AND THE MILLER INDICES

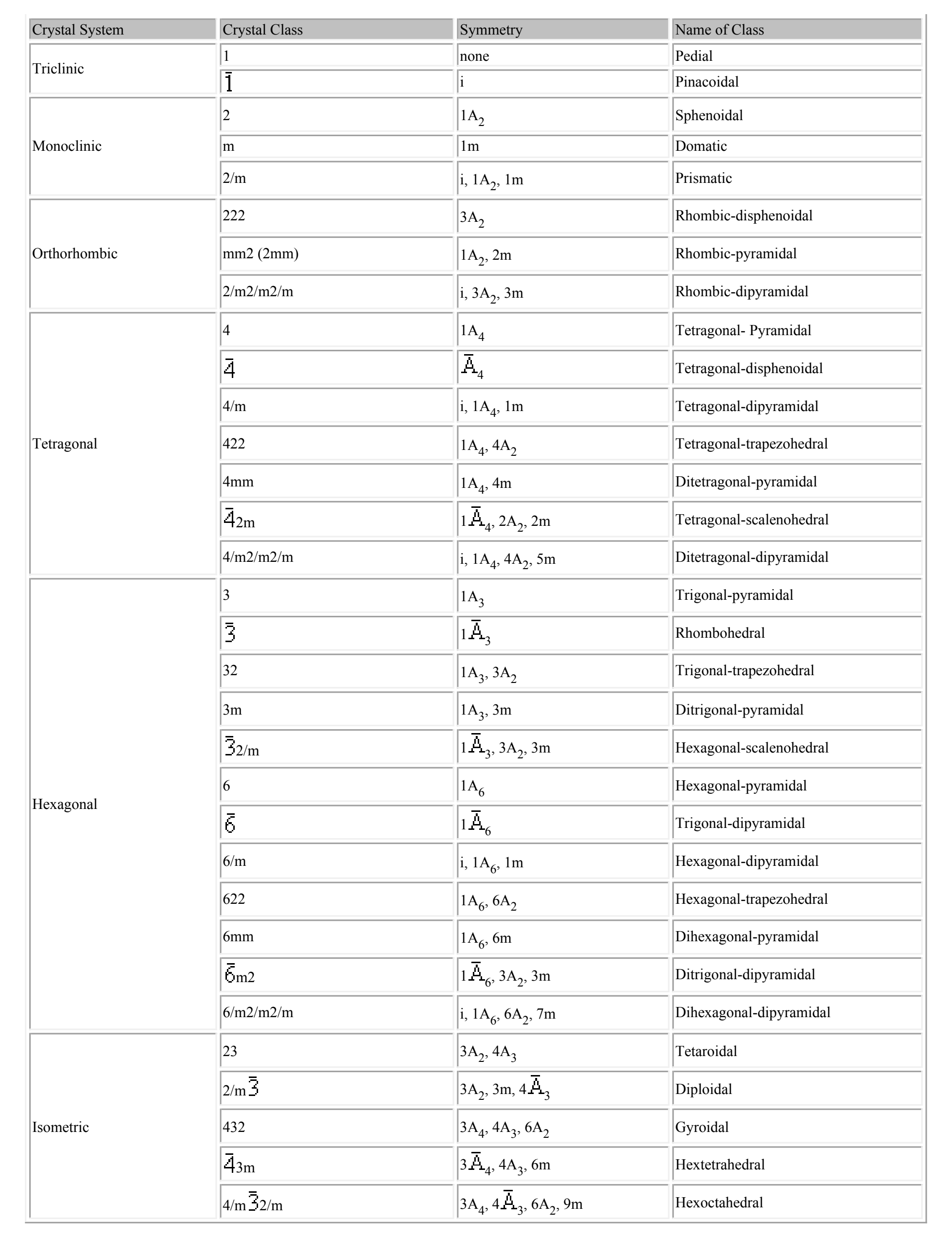
- **Hermann-Mauguin symbols**
- **Rules:**
  - **Write a number** representing **each of the unique rotation axes** present:
    2 2 2
  - Next we write an **"m" for each unique mirror plane.**
    2m 2m 2m
  - If any of the axes are perpendicular to a mirror plane we put / between the rotation axis and the mirror plane. 2/m2/m2/m



Rhombic-dipyramidal class

CHAP.4: THE 32 CRYSTAL CLASSES AND THE MILLER INDICES

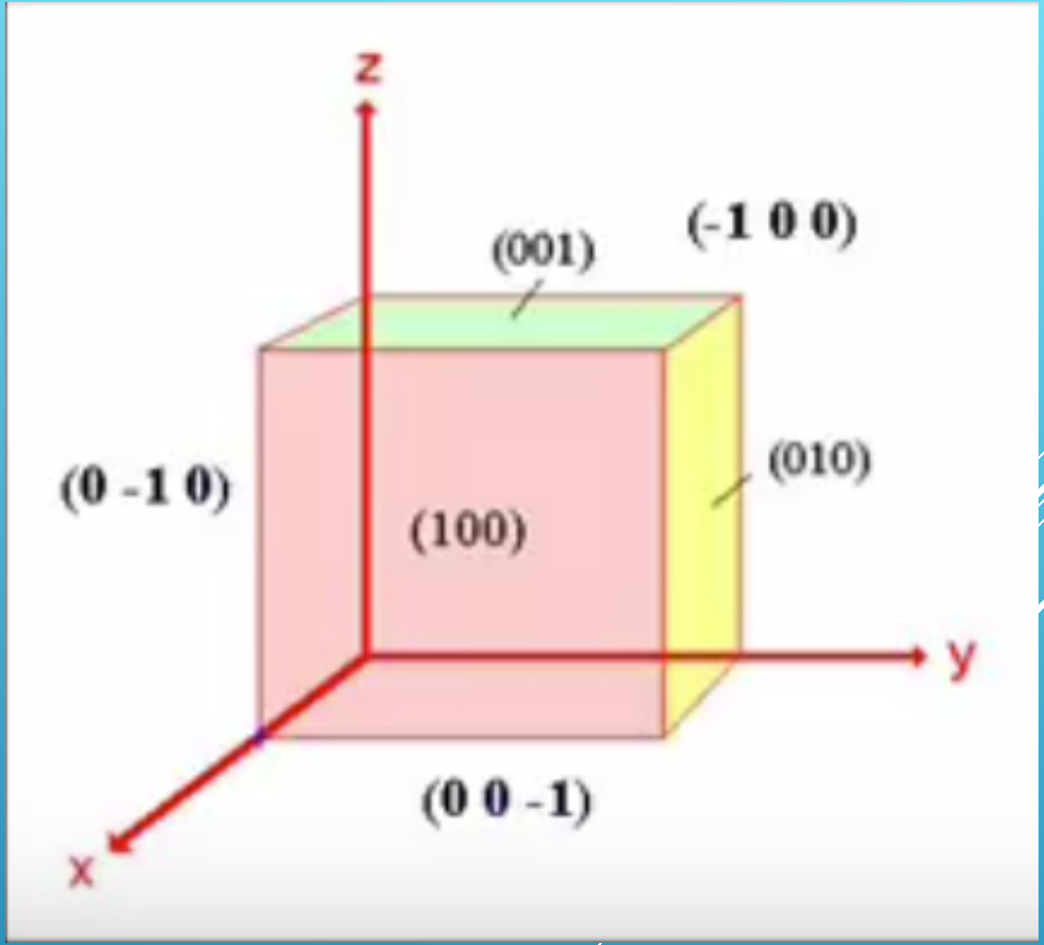
- **32 crystal classes or point groups**
- **Organized in 6 (+1) crystal systems:**
- Isometric: four A_3 or four $\overline{A_3}$
- Hexagonal: one A_6 or one $\overline{A_6}$
- Trigonal: one A_3 or one $\overline{A_3}$
- Tetragonal: one A_4 or one $\overline{A_4}$
- Orthorhombic: three A_2 or one A_2+two m
- Monoclinic: one A_2 or one m
- Triclinic: nothing or i



Crystal System	Crystal Class	Symmetry	Name of Class
Triclinic	1	none	Pedial
	$\bar{1}$	i	Pinacoidal
Monoclinic	2	$1A_2$	Sphenoidal
	m	1m	Domatic
	2/m	i, $1A_2$, 1m	Prismatic
Orthorhombic	222	$3A_2$	Rhombic-disphenoidal
	mm2 (2mm)	$1A_2$, 2m	Rhombic-pyramidal
	2/m2/m2/m	i, $3A_2$, 3m	Rhombic-dipyramidal
Tetragonal	4	$1A_4$	Tetragonal- Pyramidal
	$\bar{4}$	$\bar{A}_4$	Tetragonal-disphenoidal
	4/m	i, $1A_4$, 1m	Tetragonal-dipyramidal
	422	$1A_4$, $4A_2$	Tetragonal-trapezohedral
	4mm	$1A_4$, 4m	Ditetragonal-pyramidal
	$\bar{4}$2m	$1\bar{A}_4$, $2A_2$, 2m	Tetragonal-scalenohedral
	4/m2/m2/m	i, $1A_4$, $4A_2$, 5m	Ditetragonal-dipyramidal
Hexagonal	3	$1A_3$	Trigonal-pyramidal
	$\bar{3}$	$1\bar{A}_3$	Rhombohedral
	32	$1A_3$, $3A_2$	Trigonal-trapezohedral
	3m	$1A_3$, 3m	Ditrigonal-pyramidal
	$\bar{3}$2/m	$1\bar{A}_3$, $3A_2$, 3m	Hexagonal-scalenohedral
	6	$1A_6$	Hexagonal-pyramidal
	$\bar{6}$	$1\bar{A}_6$	Trigonal-dipyramidal
	6/m	i, $1A_6$, 1m	Hexagonal-dipyramidal
	622	$1A_6$, $6A_2$	Hexagonal-trapezohedral
	6mm	$1A_6$, 6m	Dihexagonal-pyramidal
	$\bar{6}$m2	$1\bar{A}_6$, $3A_2$, 3m	Ditrigonal-dipyramidal
	6/m2/m2/m	i, $1A_6$, $6A_2$, 7m	Dihexagonal-dipyramidal
Isometric	23	$3A_2$, $4A_3$	Tetaroidal
	2/m$\bar{3}$	$3A_2$, 3m, $4\bar{A}_3$	Diploidal
	432	$3A_4$, $4A_3$, $6A_2$	Gyroidal
	$\bar{4}$3m	$3\bar{A}_4$, $4A_3$, 6m	Hextetrahedral
	4/m$\bar{3}$2/m	$3A_4$, $4\bar{A}_3$, $6A_2$, 9m	Hexoctahedral

CHAP.4: THE 32 CRYSTAL CLASSES AND THE MILLER INDICES

- **Miller indices =** reciprocal of the parameters of each crystal face.
  - Between parentheses
  - No comma
  - No factions
  - Parallel faces indicated with opposite signs (negative or "bar")



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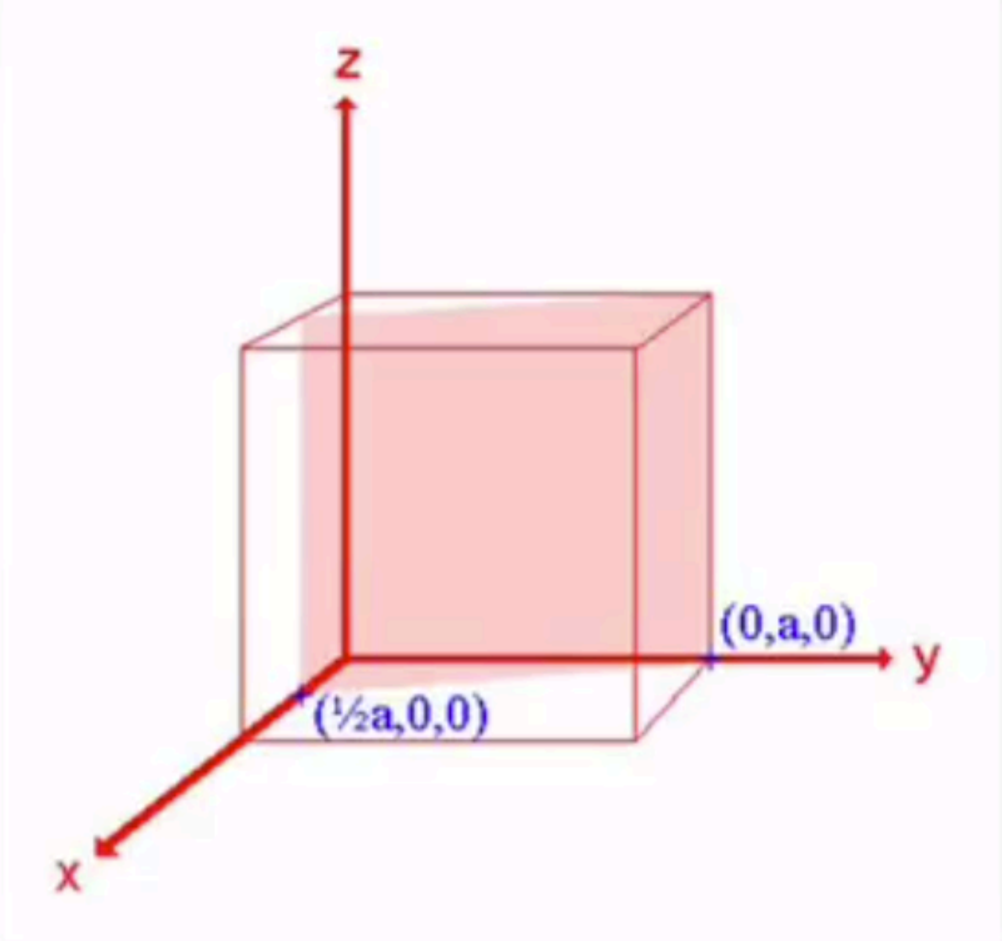


CHAP.4: THE 32 CRYSTAL CLASSES AND THE MILLER INDICES

- **48 crystal forms**
  - **15** crystal forms in the **isometric** system ⇔ closed forms
  - **33** nonisometric forms ⇔ open forms
    - Pedion
    - Dihedron
    - Pyramid
    - Trapezohedron
    - Rhombohedron
    - Pinacoid
    - Prism
    - Dipyramid
    - Scalenohedron
    - Tetrahedron

CHAPTER 5:
TWINNING,
CRYSTAL DEFECTS,
POLYMORPHISM VS ISOMORPHISM

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

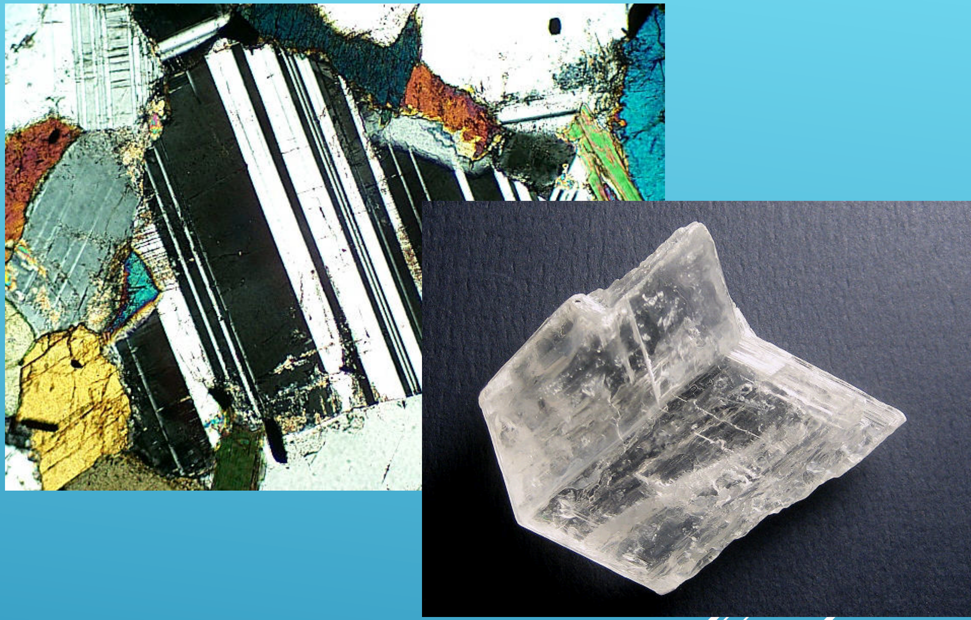
- **Twinning:** Addition of element of symmetry via the intergrowth of 2 or more crystals

- **Symmetry operations**:
  - Reflection across a mirror plan (twin plan) ⇒ contact twin
  - Rotation about a common axis (twin axis)
  - Inversion about a common point (twin point)

Penetration twin

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Most common twinning:**
  - Contact twin:
    - polysynthetic twinning – plagioclase
    - Swallow tail – gypsum
  - Penetration twin:
    - Carlsbad twinning – orthoclase
    - Iron cross – Pyrite



CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Cause of twinning:**
  - Transformation phase: related to the existence of polymorphs
  - Growth: presence of planar defect

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Crystal defects**
  - **Point defects:**
    - Interstitial atoms: require a lot of energy and significant deformation of the structure
    - Vacancy: promote diffusion
    - Frankel pair: interstitial + vacancy
    - Substitutions: solid solutions

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Crystal defects**
  - **Linear defects = dislocations**
    - Edge dislocation – addition of half of a plane
    - Screw dislocation: favors the crystal growth.
  - **Planar defects**
    - Stacking fault and twin boundary: perturbation in the packing order
  - **Inclusions (3D defects)**
    - Solid, fluid, or melt: used to reconstruct the history of the rock

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Polymorphism** = "many forms": a single chemical composition can exist with two or more different crystal structures.
- Change of structure = **polymorphic transformations:**
  - **Reconstructive** transformation: require energy – slow rates
  - **Displacive** transformation: instantaneous and reversible
  - **Order-disorder** transformation: due to the change of temperature

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Common polymorphs**
- **C (carbon):** diamond and graphite: reconstructive (explains the presence of metastable diamond at the surface of Earth)
- **Al_2SiO_5 (alumino-silicate):** andalusite – kyanite – sillimanite: reconstructive (indicate the metamorphism zone)
- **$CaCO_3$ (calcium- carbonate):** aragonite, calcite and vaterite: reconstructive
- **SiO_2 (silica):** Cristobalite, Tridymite, β-quartz (high), α-quartz (low), coesite and stishovite: reconstructive and displacive
- **KAl_2SiO_8 (potassium feldspar):** sanidine, orthoclase and microcline: order-disorder (presence of metastable polymorphs depends on the cooling rate)

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Pseudomorphism =** "false form": internal structure and chemical composition is changed but its external form is preserved.
  - 4 mechanisms:
    - **Substitution**: chemical constituent replaced by others
    - **Encrustation**: crust around a pre-exiting mineral
    - **Alteration**: partial replacement of the crystal
    - **Paramorphism**: polymorph (same compo) that kept the external shape of the initial mineral

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Isomorphism = solid solutions**: minerals with the same crystal structure in which specific sites can be occupied by two or more elements, ions, or radicals.
- Rules for substitutions:
  - Extent of substitution enhanced at higher T
  - Electrical neutrality has to be maintained
  - If difference in charge (Z) between substituting ions > 1: difficult substitution
  - The substitution should involve similar ion sizes (<15%)
  - If two ions are competing for the same site, the highest Z/r is favored.

CHAP. 5: TWINNING, CRYSTAL DEFECTS, AND POLYMORPHISM VS. ISOMORPHISM

- **Types of substitutions**
- Simple substitution (ex: olivine $(\underline{Fe,Mg})_2SiO_4$)
- Couple substitution (ex.: plagioclase $\underline{Na}AlSi_3O_8$ – $\underline{Ca}Al_2Si_2O_8$)
- Omission substitution (ex.: Pyrrhotite $Fe_{(x-1)}S$)
- Interstitial substitution (ex. Beryl $Al_2Be_3Si_6O_{18} \Rightarrow \underline{K}Al_3Be_3Si_5O_{18}$)