



Democratic and People's Republic of Algeria

Ministry of Higher Education and Scientific Research



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Faculty Natural and life sciences
Department: Science of the Earth and the Universe

Mineralogy course

2nd year LMD Applied geology



The mineralogy course focuses on the study of minerals, the basic components of the earth's crust.

Students will be introduced to fundamental concepts of mineralogy, including the atomic structure of minerals, the geological and chemical processes that lead to their formation, the techniques used to identify them, and the study of their different groups.

2024-2025

CHAPTER I : CONCEPT OF CRYSTALCHEMISTRY

I.1 Reminders of the structure of the atom and chemical bonds

I.1.1 Reminders of the structure of the atom

I.1.1.1 The atom: The main constituents of atoms are:

- The nucleus is made up of a proton and the electron gravitates around the nucleus while rotating on itself.
- The atom is electrically neutral and the mass of the atom is concentrated in the nucleus (the mass of the electron is negligible compared to that of the nucleus)
(Atomic radii: $R_a = 5.10^{-2}$ nm and nucleus $R_n = 5.10^{-7}$ nm)
- The electron does not move on a fixed and determined trajectory (probability presence of occupying a given region): it is the electronic cloud, which represents all the positions likely to be occupied by the electron.

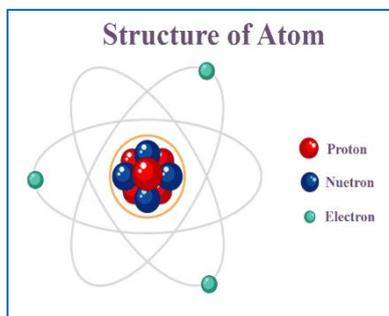


Figure 01: Structure of atom

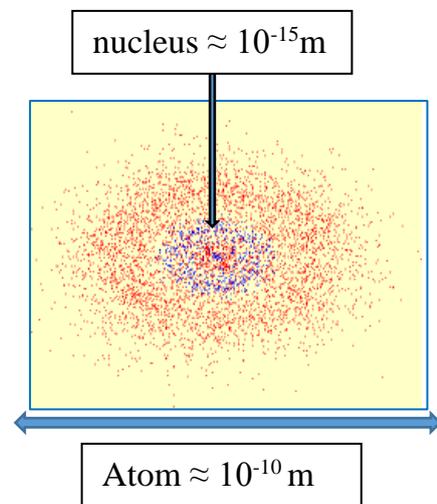
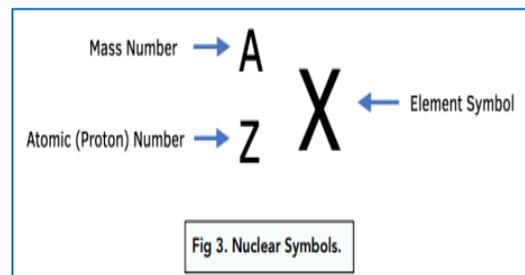


Figure 02: Cross section of an atom

I.1.1.2 Symbolic representation of the atom

An atom X can be represented symbolically by: A_ZX



The difference **A-Z** therefore gives the number of neutrons in the nucleus and Z also gives the number of electrons in the atom.

Example:

1 - The carbon atom is represented by ${}^{12}_6C$, that is to say:

- $Z = 6 \rightarrow$ 6 protons in the nucleus therefore 6 electrons.
 $A = 12 \rightarrow$ 12 nucleons therefore $12 - 6 = 6$ neutrons in the nucleus.

2 - The sodium atom is represented by ${}^{23}_{11}Na$, that is to say:

- $Z = 11 \rightarrow 11$ protons in the nucleus therefore 11 electrons.
 $A = 23 \rightarrow 23$ nucleons therefore $23 - 11 = 12$ neutrons in the nucleus.

I.1.1.2 Characteristic mass of the atom

- **Mass of nucleus**

The nucleus of an atom is made up of nucleons of two types: Neutrons and protons so to calculate its mass, simply add the masses of the particles which constitute it using the following values:

$$m_{\text{nucleus}} = m_p \times (\text{number of protons}) + m_n \times (\text{number of neutrons})$$

$$m_{\text{nucleus}} (\text{Fe}) = m_p \times (Z) + m_n \times (A - Z)$$

$$m_{\text{nucleus}} (\text{Fe}) = 1,673.10^{-27} \times (26) + 1,675.10^{-27} \times (30) = 9,375.10^{-26} \text{ kg}$$

- **Mass of electrons**

Electrons have a mass 2000 times lower than that of nucleons:

- **Mass of the atom**

We notice that the mass of an electron is very small compared to that of nucleons so the mass of the atom is concentrated in its nucleus.

The masses of protons and neutrons are almost identical too, if we neglect the mass of electrons:

$$m_{\text{nucleus}} \approx A \times m_p$$

I-1-2 Reminder of chemical bonds in minerals

I-1-2-1 General

These bonds correspond to bond energies of the order of 50 k.cal/mole.

They bring bonded atoms together at distances of 1 to 2 \AA .

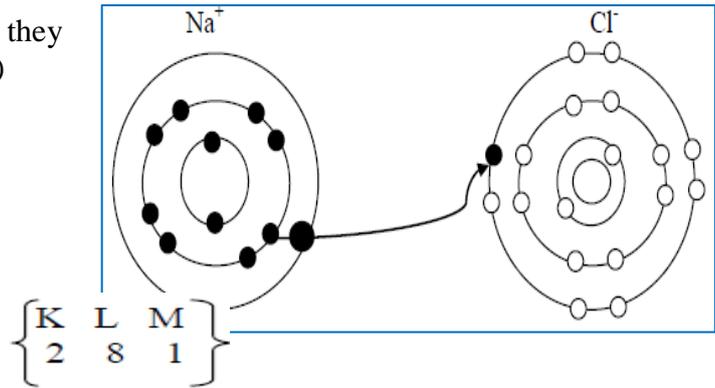
$$1\text{\AA} = 0.1\text{nm} = 10^{-10}\text{m}$$

There are (03) types of connections are as follows:

- Ionic bond
- Covalent bond
- Metallic bond

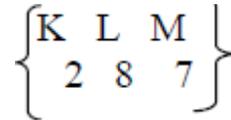
I.1.2.2 Ionic bond

They are hetero-polar bonds, that is to say, they have opposite signs (Example: Na⁺ and Cl⁻)



Na (Sodium) has an electronic structure

Easily loses the electron from its M shell to give 1 cation, (chlorine) has an electronic structure



Easily (easily) grabs an electron which completes its M shell by giving an anion.

Generally, positively charged atoms are monovalent (Na⁺, K⁺, ...), divalent (Fe²⁺, Ca²⁺, Mg²⁺, ...) and trivalent (Fe³⁺, ...) cations, while negatively charged atoms are monovalent anions (Cl⁻, Br⁻, F⁻, ...) or divalent (O²⁻, S²⁻, Te²⁻, ...).

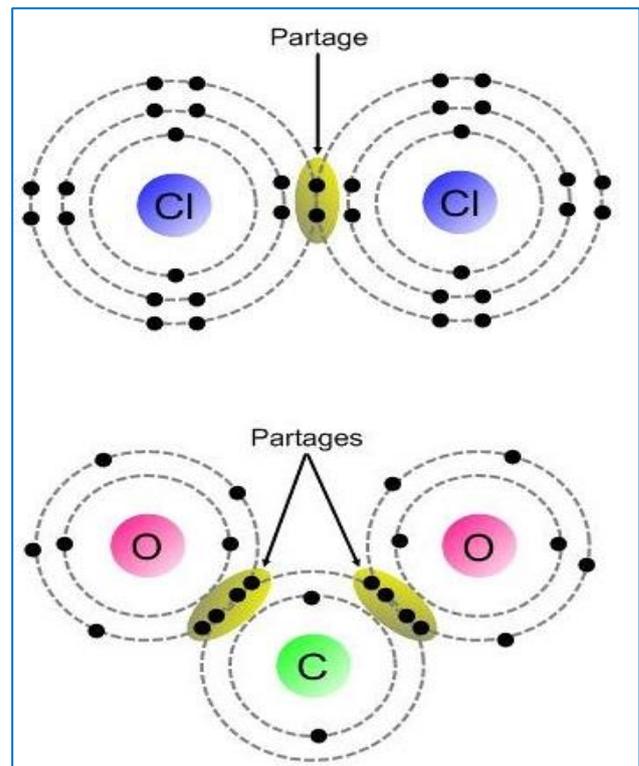
Since crystals have ionic bonds, most are silicates.

I.1.2.3 Covalent bond

Covalent bonds are called homopolar or atomic bonds. The covalent bond is single or multiple depending on the number of electrons but shared by the atoms.

The greater the difference in electronegativity between two (O₂) atoms, the more marked the ionic character of their bond, and two (O₂) atoms of the same electronegativity having a covalent bond.

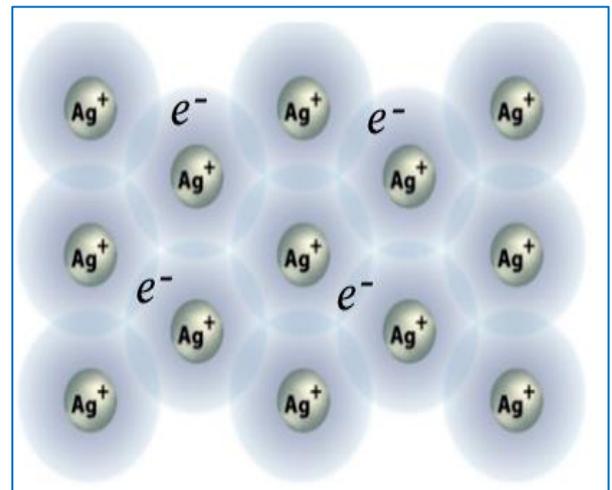
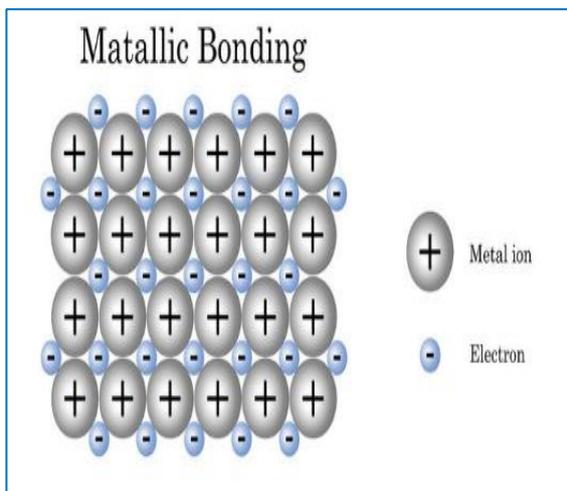
N.B. We can explain that in the covalent bond, two (O₂) atoms share their peripheral electrons.



I.1.2.4 Metallic bond

The metallic bond is known by the fact that all the atoms release their valence electrons by becoming positive ions, while free electrons circulate between these ions, which form electronic margins.

Metallic bonds are the chemical bonds that hold atoms together in metals. They differ from covalent and ionic bonds because the electrons in metallic bonding are delocalized, that is, they are not shared between only two atoms. Instead, the electrons in metallic bonds float freely through the lattice of metal nuclei. This type of bonding gives metals many unique material properties, including excellent thermal and electrical conductivity, high melting points, and malleability.



I-1-2-5 Van der Waals connection

Atoms take up space in space. We cannot superimpose them. When brought together, the atomic orbitals repel each other with electrostatic forces. These forces have very short ranges in space. This repulsion energy varies as $(d/R)^{12}$, where R is the distance between the atoms and a distance below which the energy becomes repulsive. d depends on the type of atom, we speak of van der Waals radius. when two atoms approach each other, this term is weakly attractive as long as the distance R between the atoms is greater than d . Closer, this term becomes strongly repellent. This bond is weaker than the ionic, covalent and metallic. (Example: Graphite)

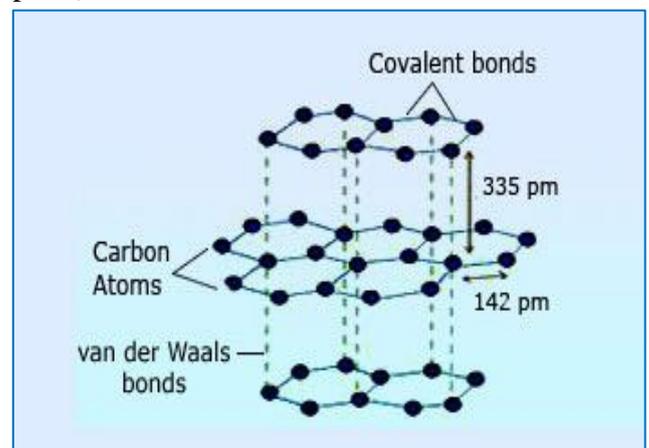
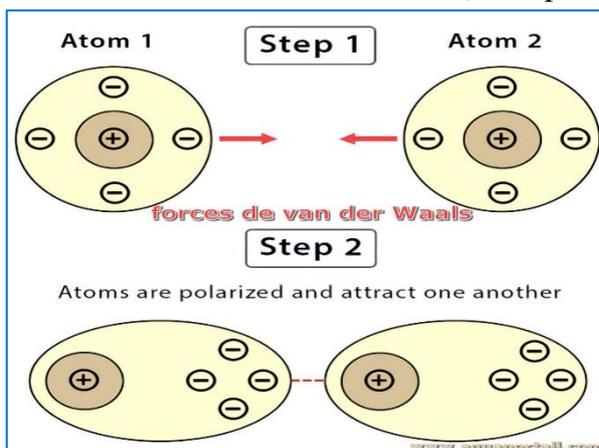


Figure: Van der Waals connection

Figure: **Graphite** Van der Waals connection

I.2.6 Types of crystals

The types of crystals ensure the cohesion of the crystals.

I.1.2.6.1 Ionic crystals

They are formed by ions between them through electronic interactions, they are formed by the assembly of ions of opposite signs. There are purely ionic crystals such as fluorides and alkaline chlorides (Example: Halite) Halite is made up of chloride ions (Cl⁻) and sodium ions (Na⁺)

Other examples:

Blende ZnS

Rutile TiO₂

Fluorine CaF₂

Silica SiO₂

I.1.2.6.2 Covalent crystals

Atoms are linked only by covalent bonds.

The characteristics of diamond and graphite are:

Diamond	Graphite
1. Crystalline, transparent with extra brilliance	Crystalline, opaque shiny substance
2. Hardest	Soft having soapy touch.
3. High density (3.52 g mL ⁻¹)	Low density (2.5 g mL ⁻¹)
4. Bad conductor of electricity	Good conductor of electricity
5. Does not leave any mark on paper	Leaves a black mark on paper
6. <i>sp</i> ³ -hybridisation. Three dimensional tetrahedral structure	<i>sp</i> ² -hybridisation. Two dimensional layer structure
7. Chemically inert	Chemically more active
8. Less stable, more energy	More stable, less energy

I.2 Reminders of some definitions (crystal, mineral etc ...)

I-2-1 Introduction

Mineralogy is part of the geological sciences studying the earth's crust, mineralogy is the science that studies minerals. She is led to study the minerals contained in meteorites and other parts of the universe.

A mineral is a naturally formed, inorganic, exceptionally organic substance. A mineral is defined by a chemical formula and a crystal system, that is to say by the nature of the atoms which compose it and their arrangement in space.

A mineral is a natural, homogeneous solid with a defined chemical composition and an ordered atomic structure.

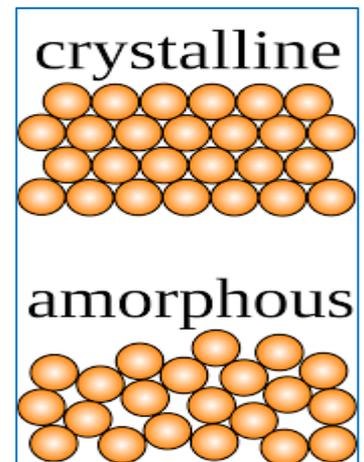
I-2-2 The physical properties of minerals: provide important assistance in identifying and characterizing them. Most physical properties can be recognized by eye or determined by performing simple tests. The most important properties are dust, color, cleavage, breakage, hardness, luster, density and fluorescence.

Minerals are atomic structures. They can appear in two states:

***Amorphous state:** atoms are associated without any regularity.

***Crystalline state:** The arrangement of atoms is regular. They are distributed according to very regular and well-defined structures which are characteristics of each mineral species (Sodium Chloride NaCl where the atoms occupy the tops of cubes). Atomic buildings are often very complex and will not be studied here.

The mineral thus constituted then forms a homogeneous solid crystal, limited by flat surfaces forming well-defined angles between them, and which has geometric and physical properties of which it is interesting to say a few words.



I-2-3 Geometric properties of crystals

Crystals have characteristic shapes and elements of symmetry. Among the many existing crystal forms, we could choose a certain number of simple shapes, each of which is the leader of a **crystal family** (or system). We have thus defined seven crystal systems.

For example, the cube is the leader of the cubic system, in which sodium chloride (NaCl) crystallizes.

The majority of **minerals** appear in **crystalline form** when the formation conditions are favorable.

Crystallography is the study of the growth, shape and geometric appearance of crystals. The arrangement of atoms within a crystal is determined by examination of X-ray diffraction.

Crystal chemistry is the study of the relationship between the chemical composition of **minerals**, the arrangement of atoms, which make them up and the forces that connect the atoms together. This relationship determines the chemical and physical properties of minerals.

Crystals are organized into six main symmetry classes: **isometric, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic**. See Crystal.

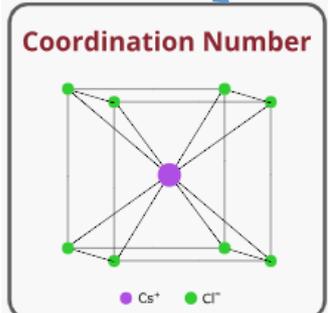
crystal, solid of homogeneous material having an ordered and defined atomic structure, and an external shape limited by smooth, flat, symmetrically arranged surfaces (faces). A crystal forms whenever a solid is gradually formed from a fluid, whether by freezing a liquid, by deposition (or precipitation) of a dissolved substance or by direct condensation of a gas. The angles, between

corresponding faces of two crystals of the same substance, are always identical, whatever the size or differences superficial shape of these crystals.

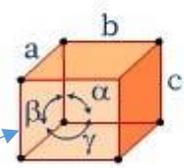
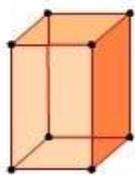
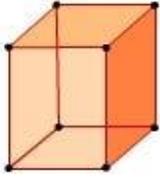
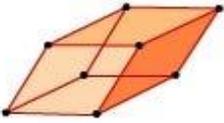
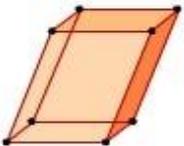
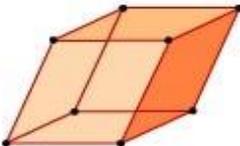
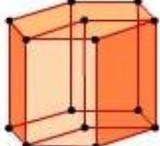
I-2-4 The crystal system

A crystal system is a classification of crystals based on their symmetry characteristics, with prioritization of certain criteria over others resulting in different systems. The different forms of crystals have been classified into seven large families called systems: We distinguish 7 crystal systems.

Coordination Number



● Cs⁺ ● Cl⁻

			
Simple Cubic	Tetragonal	Orthorhombic	Rhombohedral
$a = b = c$	$a = b \neq c$	$a \neq b \neq c$	$a = b = c$
$\alpha = \beta = \gamma = 90^\circ$	$\alpha = \beta = \gamma = 90^\circ$	$\alpha = \beta = \gamma = 90^\circ$	$\alpha = \beta = \gamma \neq 90^\circ$
			
Monoclinic	Triclinic	Hexagonal	
$a \neq b \neq c$	$a \neq b \neq c$	$a = b \neq c$	
$\alpha = \gamma = 90^\circ, \beta \neq 90^\circ$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	$\alpha = \beta = 90^\circ, \gamma = 120^\circ$	

I-2-5 Morphology of minerals

I-2-5-1 Aggregates: The morphology of minerals depends on the growth of their formation of adjoining crystalline grains called “mineral aggregate”.

I-2-5-2 Types of mineral aggregates

I-2-5-2-1 Grainy aggregate (granular): composed of crystalline grains, sometimes combined with well-formed crystals, this type of aggregate is most common in the earth's crust.

I-2-5-2-2 Compact aggregates: In these aggregates it is impossible to distinguish the contours of the grains even with a magnifying glass.

Example: Chalcedony (SiO_2)

I-2-5-2-3 Earthy aggregates: they resemble friable soil in appearance, they can be easily crushed between the fingers.

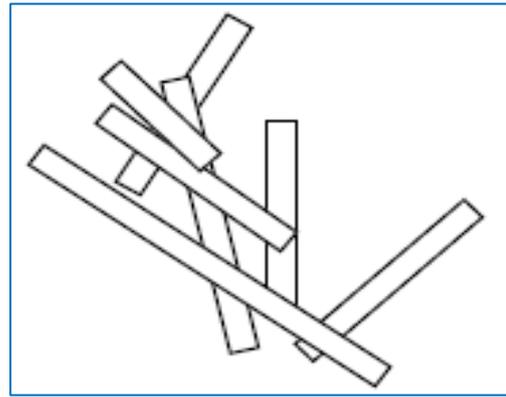
Example: Kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5 ((\text{OH})_4)$)

I-2-5-2-4 Acicular, prismatic aggregates: The crystals have an aligned shape.

Example: Actinote (or Actinolite) $\text{Ca}_2 (\text{Mg}, \text{Fe})_5 \text{Si}_8\text{O}_{22}(\text{OH})_2$



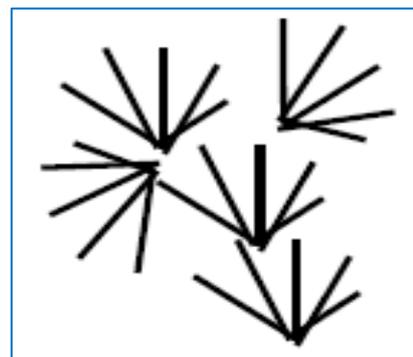
Actinote mineral



Actinote crystals

I-2-5-2-5 Radiated aggregates: The crystals are arranged in the form of rays that diverge from a single center or from several centers.

Example: Wolframite CaSiO_3



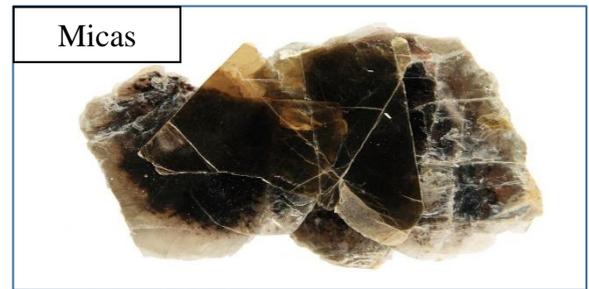
I-2-5-2-6 Laminated, lamellar aggregates:

With the tip of the penknife you can easily detach lamellae; *Example: Micas



I-2-5-2-7 Scale aggregates:

Are composed of scales that are easily detached;
Example: Micas



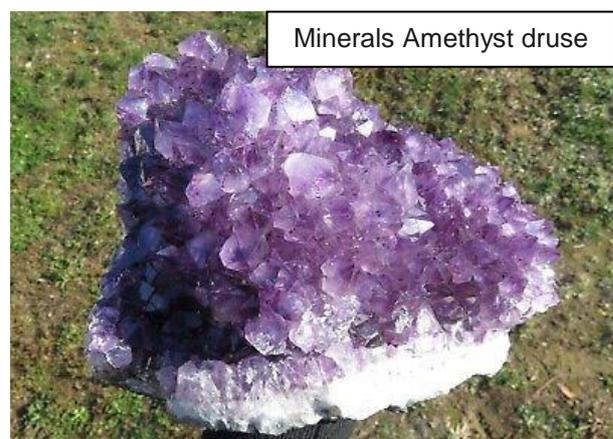
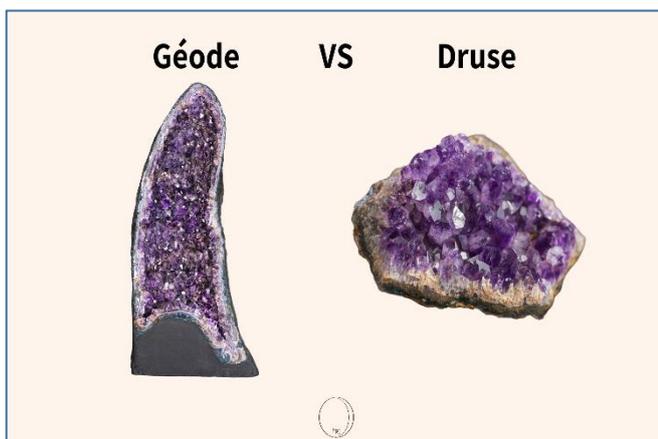
I-2-5-2-8 Fibrous aggregates: The crystals in a mineral aggregate are composed of fibers

Example: Tremolite, Gypsum



I-2-5-2-9 Druses: These are rock cavities of very variable size (from millimeter to meter), on the walls of which aggregates of protruding crystals have formed. These are irregular clusters of crystals, large druses are found.

Example: Druse of quartz, calcite and pyrite.



I-2-5-2-10 Concretions: They have the appearance of spheroid-shaped nodules with a radiated or crusted structure. Often in the center of concretions we observe organic remains around which the substance is concentrated.

Crystal growth is directed from the center to the peripheries.

Concretions usually form in loose sedimentary rocks.



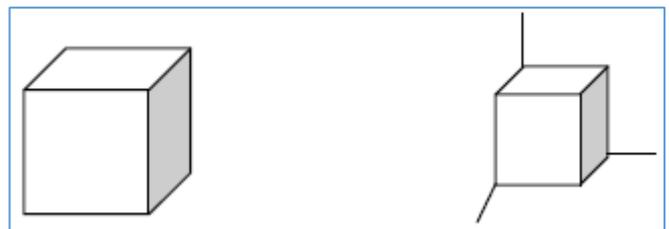
I-2-6 HABITUS

Habitus Latin word meaning aspect; It is the form usually taken by a substance, an object, a body.

Example: quartz has the common habitus of the hexagonal bipyramid prism.

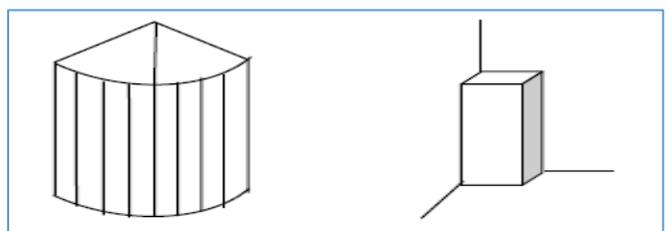
Example: Calcite the rhombohedron. There are several types of habitus:

I-2-6-1 Isometric habit: When the growth of the mineral is similar in the three directions.
Example: Cubic crystals. Example: Cubic crystals



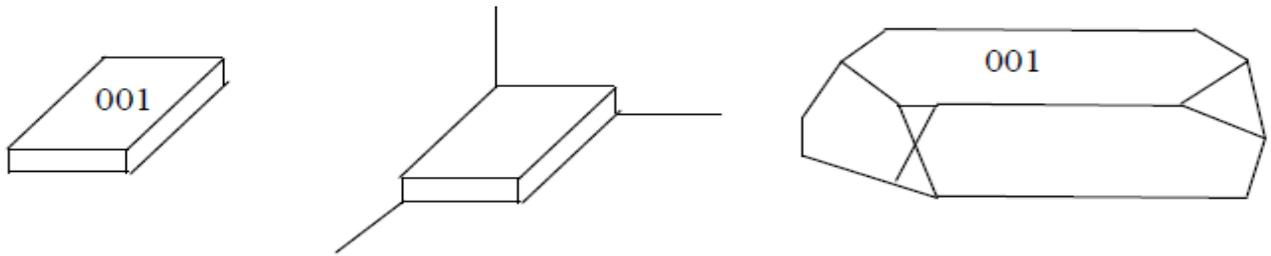
I-2-6-2 Linear habit: When the crystals are acicular, filiform (in rows), tabular, etc.

Exemple : Tourmaline et Asbeste



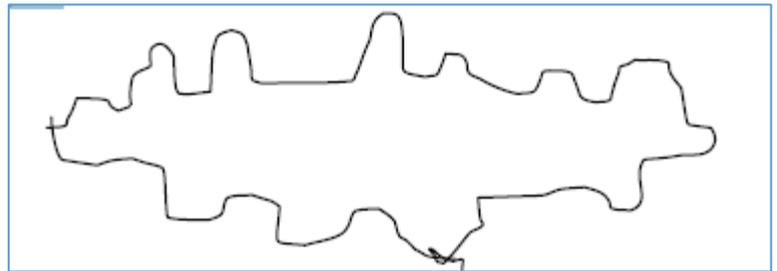
I-2-6-3 Two-dimensional habit: When the crystals are usually eb sheets, pellicular, tabular.

Example: Barite



I-2-6-4 Dendritic habit: Crystals often have a skeletal shape.

Example: Gold and Silver



I-2-7 PROPERTIES OF MINERALS

Each mineral presents its complex of physical properties (hardness, density, cleavage, luster, etc.).

I-2-7-1 Optical properties of minerals.

Optical properties constitute a fundamental diagnostic element in the identification of a mineral. But the determination of these properties is more a matter for the specialist. In geology, technical means make it possible to thin slices of minerals stuck on glass strips so thin (30 micrometers) that they become completely transparent. We can then study these minerals under the microscope, as biologists do with tissues or microorganisms. Each group of minerals has its own optical properties, meaning they transmit light differently and produce characteristic colors when viewed in polarized light, which ultimately allows them to be identified. .

Very important in mineralogy, the optical properties of a mineral are used to determine them using a microscope. Let us cite the refractive index, the phenomenon of double refraction.

I-2-7-1-1 Color

Minerals have different colors, for some minerals it is a stable and constant characteristic for example: cinnabar (HgS) is always red, pyrite (FeS₂) is always brass yellow. But for most minerals this is not the case, for example there are different varieties of calcite.

Calcite (CaCO₃): colorless, yellow, green, blue, etc.

The color of minerals is not a sufficient characteristic when determining minerals.

The color of the mineral depends mainly on its chemical composition and the additions of other coloring chemical elements called chromatophores such as cobalt, copper, nickel, chromium, etc.

Example :

Pure corundum (Al_2O_3) is colorless and transparent, additions of chromium give it a red color, so that gives us ruby; the additions of Iron and Titanium change its color to blue, we then have a Sapphire.

According to Fersman we distinguish three (03) types of colors:

I-2-7-1-1-1 Idiochromatic color: Characterizes the mineral. Example: cinnabar (HgS) is always red.

I-2-7-1-1-2 Allochromatic color: The mineral can present different colors depending on the impurities it contains and their possible reticular distortions (deformation) (physical impurities).

I-2-7-1-1-3 Pseudo-chromatic color: is due to the interference of light in the crystal.

I-2-7-1-2 Line (Mineral dust color)

The color of the line or dust of the mineral is obtained by crushing or rubbing the mineral on a raw porcelain surface, in order to obtain a line of powder on a kidney-shaped white background.

The color of the line is a more constant characteristic than the color of the mineral itself.

The line is a property that relates to color, but which is a little more reliable and easy to test, it is the line. This is actually the color of the

mineral powder. This property is determined by the trace left by the mineral when it is rubbed on an unglazed porcelain plate (as long as the hardness of the plate is greater than that of the mineral - see hardness). For example, hematite, a mineral from which iron is extracted, has a black color when freshly broken but a reddish brown streak on the porcelain plate. Pyrite, golden yellow in color, leaves a black line.

Example: Hematite Fe_2O_3 can be gray, yellow-brown, black, but all varieties of this mineral have the bright red trait.

Pyrite FeS_2 is yellow, and its line is black.

The evaluation of color can be comparative by referring to the color of any well-known object or material.

Example :

Milky white, milky yellow, honey yellow, carmine red, apple green, emerald green, chocolate brown, pewter white, lead gray, etc,...

As a basic reference we can accept the following colors:

Violet – amethyst (Quartz variety)

Blue – azurite $\text{Cu}_3 (\text{CO}_3)_2(\text{OH})_2$

Green – malachite $\text{Cu}_2 \text{CO}_3 (\text{OH})_2$

Yellow – orpiment As_2S_3

Red – cinnabar PbCrO_4 (Chromates)

Brown - limonite $\text{FeO}(\text{OH}).n\text{H}_2\text{O}$ (Hydroxides)

Yellow brown – limonite

White tin – arsenopyrite FeAsS (sulphide)

Lead gray – molybdenite MoS₂ (sulphide)

Iron black – magnetite

Copper red – native copper

Latin yellow – chalcopyrite

Gold metallic – Gold

I-2-7-1-3 Effervescence

Minerals of the carbonate class. Are chemically decomposed by acids (hydrochloric, muriatic, acetic acids); this chemical reaction releases gas bubbles carbon dioxide, a phenomenon that we call effervescence (bubbling). Depending on the carbonate minerals, this effervescence occurs, on the mineral mass itself or on the dust, cold or hot. A great way to verify the authenticity of rhodochrosite or malachite jewelry!

I-2-7-1-4 Radiance of minerals

The brilliance of minerals depends on the character of the reflection of the rays of light from the surface of the crystal or mineral aggregate; we distinguish the following groups:

I-2-7-1-4-1 Metallic luster: it is characterized by a strong reflective power of the surface and a strong observation of light in the volume of the mineral.

Example: opaque minerals, native metals, sulphides, oxides.

I-2-7-1-4-2 Non-metallic shine: the following varieties are distinguished:

I-2-7-1-4-3 Vitreous shine: resembles the shine of glass.

Example: Rock salt NaCl, CaCO₃, quartz, Fluorine, sulfates, etc.

I-2-7-1-4-4 Adamantine Luster: Also called diamond luster, it is an intense and brilliant luster.

Example: Sphalerite ZnS, native sulfur, diamond.

I-2-7-1-4-5 Pearly sheen: specific to certain varieties of micas.

I-2-7-1-4-6 Silky shine: is a shimmering shine specific to minerals with a fibrous structure, resembles the shine of silk threads.

I-2-7-1-4-7 Greasy or creamy sheen: this is when the surface of the mineral appears to be covered with a layer of grease. Example: Talc, quartz breakage.

I-2-7-1-4-8 Matte minerals: these are minerals that have no shine, their surface is porous or earthy.

I-2-7-1-4-9 Semi-metallic luster: resembles the luster of metals that have become faded over time.

Example: Kaolin

I-2-7-1-5 Transparency

Transparency is the property of matter that allows light to pass through.

When natural light passes through a mineral, some natural light passes through a mineral, part of it is reflected, part of it is absorbed, and a third of it is reflected, part of it is absorbed, and part of it is refracted. These three (03) processes generally act at the same time, but if the reflected part is dominant, the mineral will appear opaque and will most often present a metallic luster, this is the case with native metals (Gold, Silver, Copper, Arsenic, Platinum) and many sulfides and many metal sulfides and oxides.

In other minerals, the majority of the light refracted, we then speak of transparent and colorless minerals in other minerals, the majority of the light refracted, we then speak of transparent and colorless minerals or even minerals translucent and white.

So depending on the degree of transparency we distinguish:

- **Transparent minerals:** rock crystal, rock salt.
- **Translucent minerals:** we only see the contact of objects, Example: Chalcedony SiO_2 , Opal $\text{SiO}_2 \cdot n\text{H}_2\text{O}$
- **Opaque minerals:** do not allow light to pass through, Example: Pyrite.

I-2-7-1-6 Characteristics particular to certain minerals:

- Magnetic properties
- Flavor (rock salt)
- Odor (wet clay, sulfur)
- Fluorescence, thermoluminescence (fluorine, radioactive minerals)
- Fusibility

I-2-7-2 Mechanical properties of minerals

I-2-7-2-1 Break: This is the appearance of the surface that forms when the mineral is broken.

I-2-7-2-1-1 Conchoidal fracture: The appearance of the surface is concave or concentrically wavy.

Example: Quartz.

I-2-7-2-1-2 Splintering (or fleshing) break: The surface is covered with splinters oriented in the same direction; Example: Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

I-2-7-2-1-3 Earthy fracture: The surface is dull and rough, Example: The kaolin of limonite.

I-2-7-2-1-4 Granular breakage: It is observed in minerals with a granular structure (or grained structure); Example: Apatite.

I-2-7-2-2 Cleavage

A cleavage “is characterized by a family of parallel planes according to which the minerals are cut or broken more less easily.

Cleavage is the property possessed by certain minerals of breaking and splitting in well-defined crystallographic directions. This is a property linked to the structure of the crystal lattice.

This characteristic specific to each crystalline material constitutes one of the important clues for the identification of the mineral.

Depending on the ease with which the mineral can be cleaved, we generally distinguish:

I-2-7-2-2-1 Very perfect cleavage: The crystal cleaves (divides) easily into sheets or strips.

Example: Micas.

I-2-7-2-2-2 Perfect cleavage: Under a light blow the mineral divides into smooth strips, small cubes, etc.,....

Example :

The breakage of galena (PbS) gives small cubes – cubic

The cleavage of calcite (CaCO₃) gives rhombohedra – Rhombohedral.

Cleavage of Fluorite (CaF₂) gives octahedra – Octahedral

I-2-7-2-2-3 Average cleavage: On the mineral fragments we observe both cleavage planes and uneven breaks.

Example: Feldspars and amphiboles.

I-2-7-2-2-4 Imperfect cleavage: Surfaces with uneven fractures predominate.

Example: Apatite, Native Sulfur, Cassiterite (SnO₂), etc.,...

I-2-7-2-2-5 Very imperfect cleavage: Cleavage is practically non-existent, the breaks have uneven surfaces.

Example: Quartz, Pyrite,....

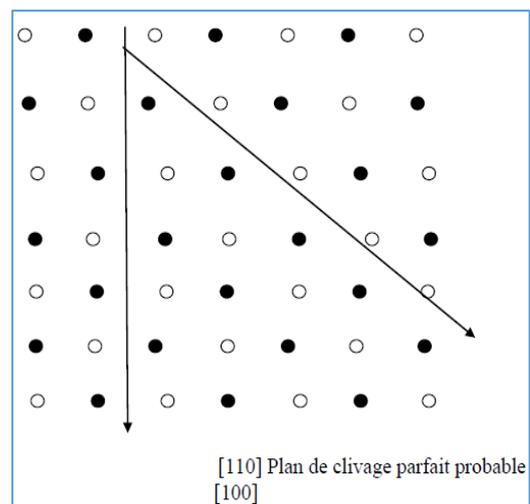
I-2-7-2-2-6 Non-existent cleavage: Zero cleavage (0).

Noticed :

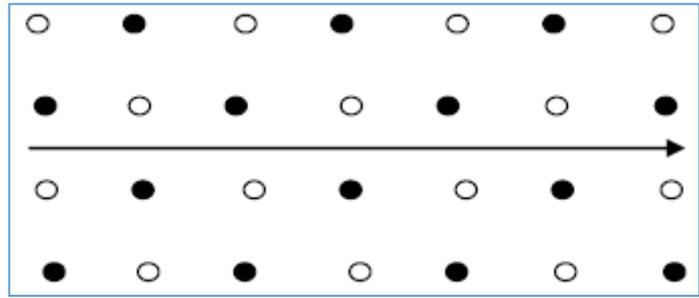
Cleavage should not be confused with the smooth surface of the mineral; cleavage should be looked for on a fresh surface following a break caused.

The cleavage of minerals depends on their crystal structure.

Example: Minerals of the type – Halite (NaCl) minerals with ionic structure.



Moving a Part of the Crystal by report another



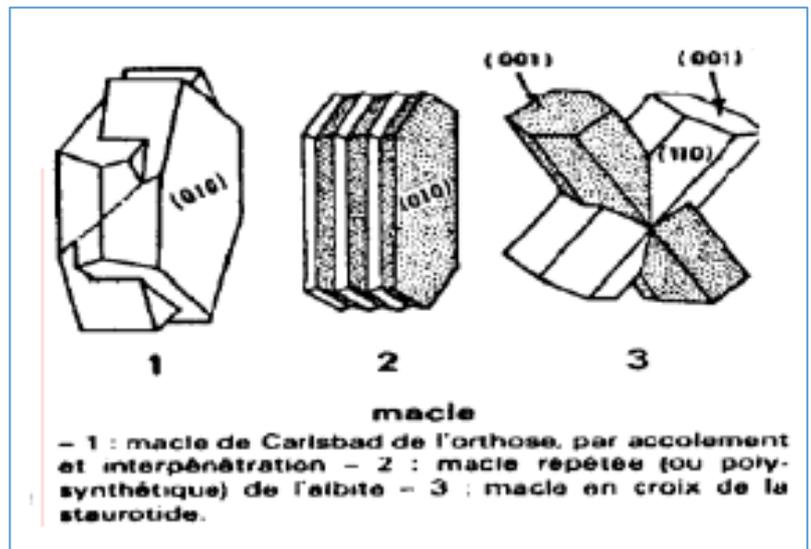
Cleavage Plane

I-2-7-2-3 Twinning

A “Twinning” is a complex crystalline structure formed by the association of two or several crystals juxtaposed and oriented relative to each other in a determined manner. This joining does not happen no matter how they are included in the symmetry of the crystal.

There are several types of twinnings:

I-2-7-2-3-1 Simple or geminate twinnings: They are formed by the association of crystals of different or similar types;



I-2-7-2-3-1-1 Twinning by adjoining: The two crystals are adjoined according to one side.

Example :

- Cassiterite SnO₂ twin, this type of twin is called a “tin beak”
- Tin beak macle

I-2-7-2-3-1-2 Twinnings by penetration: the two crystals are interpenetrating;

Example: Carlsbad twin or orthoclase Al₂O₃K₂O₆SiO₂ / KAlSi₃O₈

I-2-7-2-3-2 Multiple twins or poly-geminates:

They are formed by several crystals in a cyclical manner:

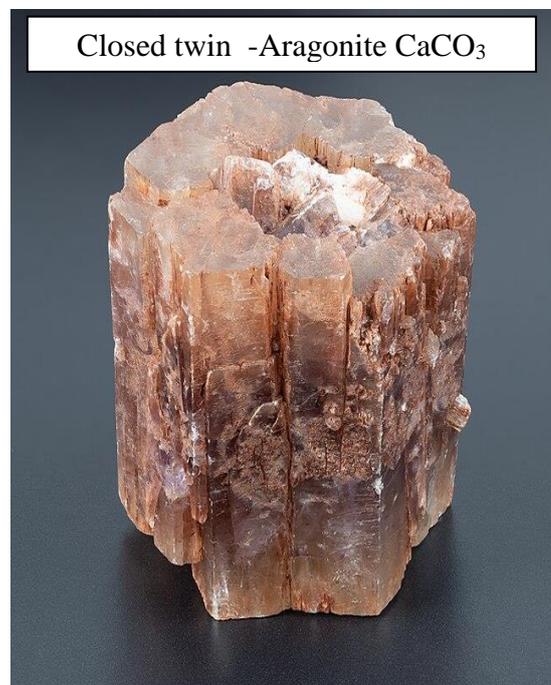
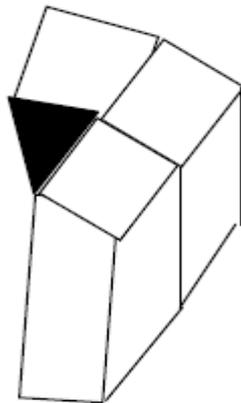
I-2-7-2-3-2-1 Open twin: The crystals twin in different directions;

Example: The knee twin of rutile TiO_3 .



I-2-7-2-3-2-2 Closed twin: The crystals are all twinned in the same direction:

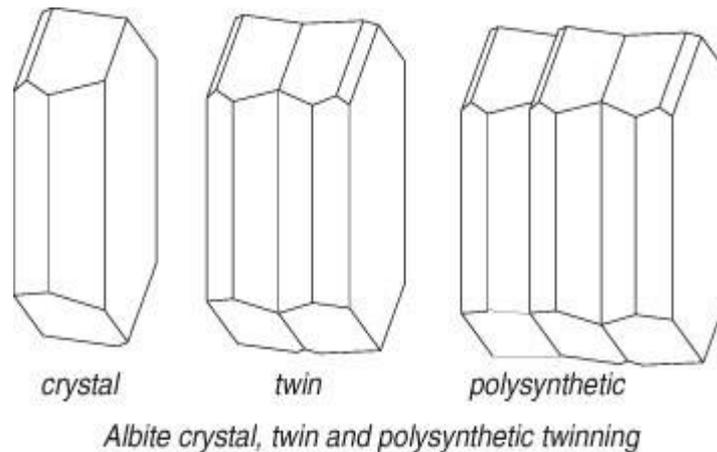
Example: Aragonite CaCO_3 , it often appears in the form of prisms hexagonal resulting from the association of three (03) orthorhombic prisms including the obtuse angle is close to 120° .



I-2-7-2-3-2-3 Polysynthetic twins

The crystal appears to be unique, but in reality it is made up of a large number fine twinned blades.

Example: The polysynthetic twin of Albite $\text{Na}_2\text{OAl}_2\text{O}_3 \cdot 6\text{SiO}_2$



I-2-7-2-4 Hardness: The hardness of a mineral corresponds to its resistance to leave to scratch. It varies from one mineral to another. Some minerals are very hard, like diamond, others rather soft, like talc, one of the main constituents of the famous “soap stone”.

Mineralogists have a relative hardness scale that uses ten minerals common, tired from the softest to the hardest, from 1 to 10. This scale was constructed by the Austrian mineralogist Friedrich Mohs and is therefore called the Mohs scale. This scale is entirely relative and does not take into account the relationships between the absolute hardness of minerals.

On this scale, we have a few benchmarks. Minerals like talc and gypsum are so soft that they are scratched by the fingernail. No wonder we use talc in skin powders. Calcite is scratched by a one-cent copper coin, while a steel penknife blade will scratch all minerals with hardness less than 5, but will not be able to scratch feldspars and quartz. A very hard piece of corundum, a mineral used in abrasives, can scratch quartz, but will be scratched by a diamond.

Various interpretations, depending on the use one wants to make of it, are applied to this term. In mineralogy, hardness is defined by the ability of a mineral surface to resist scratches. A soft surface is scratched more easily than a hard surface; thus, a mineral hard, such as diamond. Can scratch a soft mineral such as graphite and the hard mineral will not be scratched by the soft mineral. The relative hardness of minerals is determined according to the Mohs hardness scale.

By hardness is meant the degree of resistance that a mineral gives to external action, in particular to scratching.

It is useful to know the hardness (H) of some common objects:

- Pencil: 1
- Nail: 2 – 2.5
- Copper needle: 3 – 3.5
- Keys, nail: 4
- Glass ; 5 – 5.5
- Steel penknife or needle: 6 – 6.5
- Hardened steel: 7.5

There is a more rigorous method for evaluating the hardness of a substance, based on measuring the variations of the imprint left by a steel ball or a diamond point pressing on the solid studied with a known force: VICKERS hardness.

In general, minerals containing heavy metals such as Ag, Hg, Pb are soft with a hardness lower than 3 (≤ 3).

Sulfides, with the exception of those of Fe, Ni or Co, have a hardness less than 5 (≤ 5).

Carbonates, sulfates, phosphates generally have a hardness of 5.5.

Anhydrous oxides and silicates, except those containing heavy metals, have a hardness greater than 5 (≥ 5).

There is a MOHS (Austrian Mineralogist) scale. The hardness scale from least hard to hardest.

1- Talc $Mg_3(OH)_2Si_4O_{10}$

2- Gypsum $CaSO_4 \cdot 2H_2O$

3- Calcite $CaCO_3$

4- Fluorine CaF_2

5- Apatite $Ca_5(F, Cl, OH)(PO_4)_3$

6- Orthoclase KSi_3AlO_8

7- Quartz SiO_2

8- Topaz $Al_2SiO_4(F, OH)_2$

9- Corundum Al_2O_3

10- Diamond C

I-2-7-2-5 Density (D) or Specific Gravity (SG): The density of minerals is a measurable property; it is a physical constant which characterizes a given mineral. Many minerals have a density of around 2.7 gr/cm³, or 2.7 times heavier than an equal volume of water. But some have a relatively low density, like salt which has a density of 2.1; others are at the other extreme, such as galena (lead sulfide) with a density of 7.5 and gold with a density of 19.3.

Density is the ratio of mass per unit volume to the density of water.

Density (D): is defined as mass per unit volume. It has the SI unit $kg\ m^{-3}$ or kg/m^3 and is an absolute quantity. **Specific Gravity (SG):** is the ratio of a material's density with that of water at 4 °C (where it is most dense and is taken to have the value $999.974\ kg\ m^{-3}$).

Empirically we can classify minerals in the following way.

Very light: D = 2 Carnalite 1.6

Light: D = 2-3 Quartz 2.65

Medium Heavy: D = 3-5 Diamond 3.5

Heavy and very heavy: D = 5-10

Density calculation

$$D = \frac{M}{V}$$

$$D = \frac{Z \times Mg}{N \times V}$$

Z: Number of atoms in the unit cell

Mg: Molar or molecular mass

N: Avogadro constant $0.6023 \cdot 10^{23}$

V0: Volume of the elementary cell

I-3 DEFINITION OF COORDINANCE, ISOTYPISM, ISOMORPHISM AND POLYMORPHISM

I-3-1 General

I-3-1-1 Ionic or heteropolar bond

These are bonds which occur between particles of opposite signs or ions which attract each other according to the laws of electrostatics.

Ex: NaCl Na⁺ and Cl⁻

There is transfer of electrons from the electropositive electron (cation) to the electronegative electron

I-3-1-2 The ionic ray

We can compare an ion to a sphere whose radius would then be the ionic radius. We can also assume that the radius remains constant whatever the ionic combination in which it is engaged.

X-ray analysis makes it possible to determine the distance between the two ions in a crystal.

Let A=the anion and M=the cation we therefore have: $d_{AM}=R_A+R_M$ with R =ionic radius

The distance d_{AM} is equal to the distance between the 02 nuclei separating the anion from the cation.

Everything happens as if an ionic crystal were made up of a stack of contiguous anionic and cationic spheres.

Thanks to the RX we can determine d_{AM} precisely but the RX do not give R_A and R_M .

RM /RA	Coordinance	Types d'édifices
Between 0 et 0,155	II	Linear
Between 0,155 et 0,225	III	Triangle
Between 0,225 et 0,414	IV	Tetrahedron
Between 0,414 et 0,732	VI	Octahedron
Between 0,732 et 1	VIII	Cube
1	X - XII	Cube-octahedron

In theory, it is enough to know a single ionic radius to deduce the other ionic rays step by step.

The interest in knowing ionic radii lies in the possibility of predicting for compounds of unknown structure the distance of ionic radii (d_{AM}), ions of opposite spheres and their coordination.

I-3-1-3 Concept of coordination or coordination

In an ionic crystal, the hypothetical spheres representing the ions tend to move away from each other as much as possible so as to constitute a compact structure. A cation M will be surrounded by n anionic spheres A and n is called the coordination number or coordination of M in the structure considered.

At a given pressure and temperature, the coordination of a cation depends on the R_M/R_A ratio, that is to say ionic radius of the cation / ionic radius of the anion associated with it.

Suppose that M is surrounded by 03 anions A touching it and touching each other. The anion nuclei are located at the 03 vertices of an equilateral triangle whose center is occupied by the radius of the cation R_M . The geometric calculation of R_M/R_A equal to 15% or 0.15 we then have coordination III. This value is a limiting value, in fact: If R_M/R_A is less than 0.155 (<0.155) the 3 anions interfere with each other and can no longer get sufficiently close to the cation. The cation can only be brought closer to 02 anions and we will then have the II coordination.

If R_M/R_A is greater than 0.155, the anions are no longer joined but the coordination will always be equal to III.

If now a 4th anion is put in place we will have a regular tetrahedron whose cation will occupy the center and the limit value R_M/R_A will be equal to 0.225. The coordination is imposed by simple geometric considerations linked to the possibilities of assembling spheres of different radii while taking into account the necessary neutrality of the building.

The coordination can vary depending on the temperature and pressure for the combination of the same cation with the same anion.

Thus the coordination increases when the crystal formation pressure increases and this coordination decreases when the crystal formation temperature increases.

Ex: In the case of $Al^{3+} O^2$ and the R_{Al}/R_O ratio = $0.57/1.32 = 0.43$ this value is a limiting value with 0.414, that is to say between the IV and VI coordination.

At normal temperature and pressure, the Al ion is likely to be surrounded by 4 or 6 oxygens but we note a preference for VI.

At high pressure only VI coordination allows stable buildings.

But at high temperatures, IV coordination is favored.

So pressure and temperature work in opposite directions.

I-3-2 Isotypism

Two mineral species are isotypes when they have distinct chemical compositions but similar structural formulas, they belong to the same crystal system and the coordination polyhedra involved in the two structures are identical or comparable.

Ex halite: NaCl; and sylvine: KCl

Are isotypes and they both belong to the face-centered cubic group.

Na and K are hexacoordinated.

I-3-3 Isomorphism

Two mineral species are isomorphic, if they are isotypes, made up of cations and anions of neighboring ionic radii to consider their syn crystallization into mixed crystals. Both species form solid solutions.

Ex: peridots whose composition varies from a magnesium term (Mg_2SiO_4) forsterite to an iron-bearing term (Fe_2SiO_4) fayalite. The intermediate term being olivine.

I-3-3-1 Conditions for replacements or isomorphic substitutions

Isomorphic substitutions will only be possible if certain conditions are met.

- The ionic radii must be close, the difference between the ionic radii must not exceed 15%.
K and Na cannot substitute each other because the ionic radius of K = 1.33 and the ionic radius of Na is 0.97 (the difference between the 2 ionic radii is greater than 15%).
- The coordination polyhedra must have identical shapes, as does the coordination
- The valency and electronic structure must be similar. If the valences are different, the excess or lack of charges must be compensated by another replacement restoring balance, this is a heteromorphic replacement. Ex albite (Si_3AlO_8Na) and anorthite ($Si_2Al_2O_8Ca$). Ca^{2+} - Na^+ and Si^{4+} - Al^{3+}
- Temperature and pressure play an important role. Some isomorphic replacements are complete at high temperature and high pressure, but partial at low temperature and low pressure. Ex sodipotassium alkali feldspars where the decrease in temperature causes the formation of two phases: perthites.

I-3-4 Polymorphism

Two or more mineral species are said to be polymorphic if they have the same chemical composition but different crystal structures. This change in shape is linked to variations in temperature and pressure.

Ex: $CaCO_3$

if it crystallizes in the rhombohedral system, it is calcite

if it crystallizes in the orthorhombic system, it is aragonite

Ex: SiO_2

If it crystallizes in the rhombohedral system, it is α quartz

If it crystallizes in the hexagonal system, it is Tridymite

If it crystallizes in the quadratic system, it is Cristobalite

If it crystallizes in the monoclinic system, it is Coesite

Ex: $SiAl_2O_5$ (alumina silicates)

Triclinic: Kyanite, Orthorhombic: Andalusite, quadratic: Sillimanite.

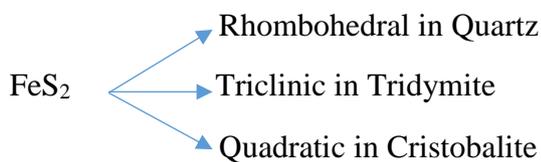
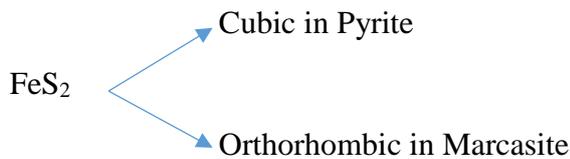
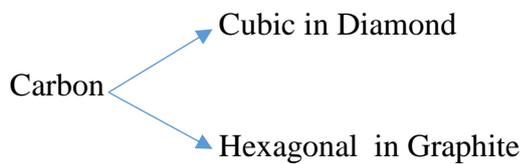
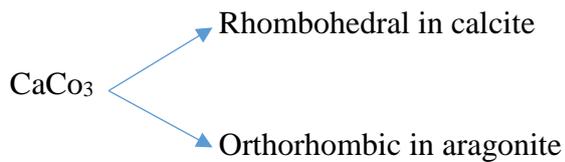
When these mineral species concern simple elements such as Fe, C, S, etc. they are called allotropes.

Ex: carbon C

1. When it crystallizes in the **cubic system**, it gives **diamond**
2. And when it crystallizes in the **hexagonal system**, it gives **graphite**.

When they concern simple elements such as, C, S, etc., they are called allotropes

Polymorphism consists of the substance having the same chemical composition but presenting different crystal forms.



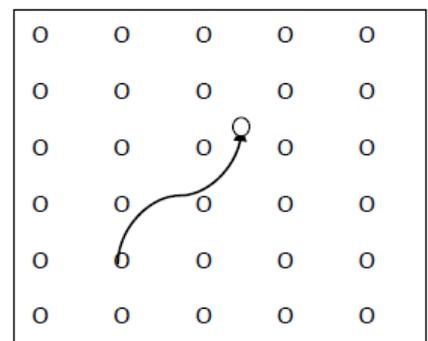
I-3-5 Imperfection of crystals

Crystalline buildings are not always perfect. They present imperfections linked to the position of the atoms in the crystal structure or to defects in the alignment of the crystal cells.

I-3-5-1 Defects in the position of atoms.

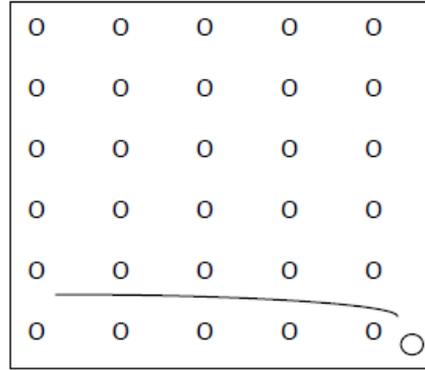
I-3-5-2 FRENKEL fault

Explanation: An atom leaves its location and is placed in an interstitial position.



I-3-5-3 SCHOTTKY fault

Explanation: Here an atom is expelled from the equilibrium location towards the crystal surface.



I-3-5-4 Defect in the alignment of the crystal meshes.

There are two (02) main types of dislocations:

I-3-5-4-1 Dislocation corner

The effect of a corner dislocation on a lattice amounts to partially inserting (or subtracting) into this lattice a reticular plane called a half-plane. This $\frac{1}{2}$ plan is inserted between two (02) opposite locations

Around a dislocation line the reticular planes wind up in a spiral.



CHAPTER II- CLASSIFICATION OF MINERALS (THE NINE GROUPS)