Program : **B.Tech**

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UNIT II Mineralogy & Crystallography

Mineralogy and crystallography: fundamentals of mineralogy, physical properties, study of common rock forming minerals and ore minerals, importance to civil engineering, and element of crystals and introduction to crystal systems.

Definition of a Mineral

A mineral is a naturally-occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

1.) "Naturally occurring" means that synthetic compounds not known to occur in nature cannot have a mineral name. However, it may occur anywhere.

2.) "Homogeneous solid" means that it must be chemically and physically homogeneous down to the basic repeat unit of the atoms. It will then have absolutely predictable physical properties (density, compressibility, index of refraction, etc.). This means that rocks such as granite or basalt are not minerals because they contain more than one compound.

3.) "Definite, but generally not fixed, composition" means that atoms, or groups of atoms must occur in specific ratios. For ionic crystals (i.e. most minerals) ratios of cat-ions to anions will be constrained by charge balance, however, atoms of similar charge and ionic radius may substitute freely for one another; hence definite, but not fixed.

4.) "Ordered atomic arrangement" means crystalline. Crystalline materials are three-dimensional periodic arrays of precise geometric arrangement of atoms. Glasses such as obsidian, which are disordered solids, liquids (e.g., water, mercury), and gases (e.g., air) are not minerals.

5.) "Inorganic processes" means that crystalline organic compounds formed by organisms are generally not considered minerals. However, carbonate shells are minerals because they are identical to compounds formed by purely inorganic processes.

Physical Properties of Minerals:-

Physical properties can be determined in inspection or by simple test it can be determined by hand specimen. The chief physical properties are color, streak, luster, hardness, habit, cleavage, fracture, odor, and tenacity; specific gravity and crystal forms. Correct identification are made of with polarizing microscope

1. **Crystal form and habit (shape).**
2. **Luster and transparency**
3. **Color and streak.**
4. **Cleavage, fracture**
5. **Specific gravity**
6. **Habit**

7. **Tenacity**

8. **Density**

9. **Hardness**

Crystal form and habit.

Recognizing crystal forms (a crystal face plus its symmetry equivalents) in the various crystal systems is one of the reasons we spend some time in lab studying block models. The crystal faces developed on a specimen may arise either as a result of growth or of cleavage. In either case, they reflect the internal symmetry of the crystal structure that makes the mineral unique. The crystal faces commonly seen on quartz are growth faces and represent the slow rest growing directions in the structure. Quartz grows rapidly along its c-axis (three-fold or trigonal symmetry axis) direction and so never shows faces perpendicular to this direction. On the other hand, calcite rhomb faces and mica plates are cleavages and represent the weakest chemical bonds in the structure. There is a complex terminology for crystal faces, but some obvious names for faces are prisms and pyramids. A prism is a face that is perpendicular to a major axis of the crystal, whereas a pyramid is one that is not perpendicular to any major axis.

Crystals that commonly develop prism faces are said to have a prismatic or columnar habit. Crystals that grow in fine needles are acicular; crystals growing flat plates are tabular. Crystals forming radiating sprays of needles or fibers are satellite. Crystals forming parallel fibers are fibrous, and crystals forming branching, tree-like growths are dendritic.

Luster and transparency

The way a mineral transmits or reflects light is a diagnostic property. The transparency may be opaque, translucent, or transparent. This reflectance property is called luster. Native metals and many sulfides are opaque and reflect most of the light hitting their surfaces and have a metallic luster. Other opaque or nearly opaque oxides may appear dull, or resinous. Transparent minerals with a high index of refraction such as diamond appear brilliant and are said to have an adamantine luster, whereas those with a lower index of refraction such as quartz or calcite appear glassy and are said to have a vitreous luster.

Color and streak

Occur due to certain wavelength of light by atoms making of crystals. Color is fairly self-explanatory property describing the reflectance. Metallic minerals are white, gray, or yellow. The presence of transition metals with unfilled electron shells (e.g. V, Cr, Mn, Fe, Co, Ni, and Cu) in oxide and silicate minerals causes them to be opaque or strongly colored so that the streak, the mark that they leave when scratched on a white ceramic tile, will also be strongly colored.

On the basic of color of a mineral; may belong to anyone of three types

Idiochromatic: show a constant color appear metallic crystal ex. Copper

Allochromatic: Show variable colors, appear non-metallic ex. Quartz

Pseudochromatic: Shows false color

Some minerals viewed in different directions shows irregular changes in color

1. Play of color: Change in rapid succession on rotation ex. Diamond
2. Change of color: Rate of change of colors on rotation and intensity is low ex. Labrodorite
3. Iridescence: Shows rainbow colors in interior or exterior surface ex. Limonite, hematite
4. Tarnish: Change of original color due to oxidation ex. Bornite
5. Greasy luster: Luster exhibited by grease ex. Talc
6. Dull or earthy: No luster said to earthy luster ex. Kaolin

Cleavage, fracture

Cleavage: It is defined as a tendency of mineral to break more easily with smooth surface along plane of weak bonding. The cleavage can be classified as perfect, good, poor, and indistinct PERFECT CLEAVAGE: Mica, Galena, and Calcite

NO CLEAVAGE: Quartz

Fracture: The nature of the surface of a mineral is called as fracture. The common types of fracture are

1. Even fracture: Surface almost flat ex. Flint, Chert
2. Uneven fracture: Surface is irregular and rough ex. Fluorite
3. Conchoidal fracture: Curved surface showing concentric line like shell ex. Quartz
4. Hacky fracture: Rough surface with sharp and jagged point's ex. Asbestos
5. Earthy fracture: Smooth, soft and porous ex. Chalk, kaolin

Specific gravity:

It is the number which represents the ratio of weight of the mineral to the weight of an equal volume of water.

Habit (Form): The chief habits of minerals are shown as follows,

1. Accicular: Needle like crystal ex. Natrolite
2. Fibrous: Aggregate of long thin fibre ex. Asbestos
3. Foliated: Thin separate sheet ex. Mica
4. Bladed: Occur as small knife blade ex. Kyanite
5. Tabular: Broad flat surface ex. Gypsum, feldspar
6. Columnar: Columnar crystal ex. Tourmaline
7. Granular: Aggregate of equidimensional grains ex. Magnetite
8. Reinform: Kidney shaped form ex. Hematite.
9. Oolitic: Aggregate bodies resembling fish roe ex. Bauxite
10. Massive: Structural less mass ex. Flint

Tenacity

It is the ability of a mineral to deform plastically under stress. Minerals may be brittle, that is, they do not deform, but rather fracture, under stress as do most silicates and oxides. They may be sectile, or be able to deform so that they can be cut with a knife. Or, they may be ductile and deform readily under stress as does gold.

Density

It is a well-defined physical property measured in g/cm3.a Most silicates of light element have densities in the range 2.6 to 3.5. Sulfides are typically 5 to 6. Iron metal about 8, lead about 13, gold about 19, and osmium, the densest substance, and a native element mineral, is 22. Density may be measured by measuring the volume, usually by displacing water in a graduated cylinder, and the mass. Specific gravity is very similar to density, but is a dimensionless quantity and is measured in a slightly different way. Specific gravity is measured by determining the weight in air (Wa) and the weight in water (Ww) and computing specific gravity from SG = Wa / (Wa-Ww). In practice this is done using a Jolly balance as we will see in lab.

Hardness

HARDNESS: Hardness of mineral depends on chemical composition determined by rubbing or scratching a mineral of unknown hardness against one of known hardness. It is usually tested by seeing if some standard minerals are able to scratch others. A standard scale was developed by Friedrich Moh's in 1812 the standard minerals making up the Moh's scale of hardness are:

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Feldspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

This scale is approximately linear up to corundum, but diamond is approximately 5 times harder than corundum.

Unique Properties

A few minerals may have easily tested unique properties that may greatly aid identification. For example, halite (NaCl) (common table salt) and sylvite (KCl) are very similar in most of their physical properties, but have a distinctly different taste on the tongue, with sylvite having a more bitter taste. Whereas it is not recommended that students routinely taste mineral specimens (some are toxic), taste can be used to distinguish between these two common minerals.

Another unique property that can be used to distinguish between otherwise similar back opaque minerals is magnetism. For example, magnetite (Fe_3O_4), Ilmenite ($FeTiO_3$), and pyrolusite (MnO_2) are all dense, black, opaque minerals which can easily be distinguished by testing the magnetism with a magnet. Magnetite is strongly magnetic and can be permanently magnetized to form a lodestone; Ilmenite is weakly magnetic; and pyrolusite is not magnetic at all.

Classification of Minerals

It has constant physical property which are used in the identification of mineral in the field, it can be divided into 2 groups

Rock forming mineral: Found in abundance of earth crust

Ore forming minerals: Economic valuable mineral.

Minerals are classified on their chemistry, particularly on the anionic element or polyanionic group of elements that occur in the mineral. An anion is a negatively charge atom, and a polyanion is a strongly bound group of atoms consisting of a cat-ion plus several anions (typically oxygen) that has a net negative charge. For example carbonate, $(Co_3)^2$-, silicate, $(Sio_4)^4$- are common poly anions. This classification has been successful because minerals rarely contain more than one anion or polyanion, whereas they typically contain several different cat-ions.

Native elements: The first group of minerals is the native elements, and as pure elements, these minerals contain no anion or polyanion. Native elements such as gold (Au), silver (Ag), copper (Cu), and platinum (Pt) are metals, graphite is a semi-metal, and diamond (C) is an insulator.

Sulfides: The sulfides contain sulfur (S) as the major "anion". Although sulfides should not be considered ionic, the sulfide minerals rarely contain oxygen, so these minerals form a chemically distinct group. Examples are pyrite (FeS_2), Sphalerite (ZnS), and galena.

Halides: The halides contain the halogen elements (F, Cl, Br, and I) as the dominant anion. These minerals are ionically bonded and typically contain cat-ions of alkali and alkaline earth elements (Na, K, and Ca). Familiar examples are halite (NaCl) (rock salt) and fluorite (CaF_2).

Oxides: The oxide minerals contain various cat-ions (not associated with a polyanion) and oxygen. Examples are hematite (Fe2O3) and magnetite (Fe3O4).

Hydroxides: These minerals contain the polyanion OH- as the dominant anionic species. Examples include brucite (Mg $(OH)_2$) and gibbsite ($Al(OH)_3$).

Carbonates: The carbonates contain Co_3^{2-} as the dominant polyanion in which C^{4+} is surrounded by $_3O^{2-}$ anions in a planar triangular arrangement. A familiar example is calcite (CaCO3). Because NO3- shares this geometry, the nitrate minerals such as soda niter (nitratite) ($NaNO_3$) are included in this group.

Sulfates: These minerals contain SO_4^2- as the major polyanion in which S6+ is surrounded by four oxygen atoms in a tetrahedron. Note that this group is distinct from sulfides which contain no O. A familiar example is gypsum ($CaSO_4\,2H_2O$).

Phosphates: The phosphates contain tetrahedral PO43- groups as the dominant polyanion. A common example is apatite ($Ca_5\,(PO_4)_3(OH)$) a principal component of bones and teeth. The other trivalent tetrahedral polyanion, arsenate AsO43-, and vanadate VO43- are structurally and chemically similar and are included in this group.

Borates: The borates contain triangular BO33- or tetrahedral BO45-, and commonly both coordination's may occur in the same mineral. A common example is borax.

Silicates: This group of minerals contains SiO44- as the dominant polyanion. In these minerals the Si^{4+} cat-ion is always surrounded by 4 oxygen's in the form of a tetrahedron. Because Si and O are the most abundant elements in the Earth, this is the largest group of minerals and is divided into subgroups based on the degree of polymerization of the SiO_4 tetrahedral.

Mineral Groups:

Mineral Group	Examples
1. Oxides 2. Silicates 3. Carbonates 4. Sulphides 5. Sulphates 6. Chlorite	1. Quartz, magnetite, hematite 2. Feldspar, mica, hornblende, augite, olivine 3. Calcite, dolomite 4. Pyrites, galena, Sphalerite 5. Gypsum 6. Rock salt

Table 1. Mineral Groups

Rock forming minerals:

1. Silicate minerals: Constitute 90% of earth crust
2. Non- silicate minerals: There are 2 groups,
   A. Stable (quartz group, feldspar group)
   B. Unstable (pyroxene group, amphibole group, mica group, olivine)

Quartz Group

Quartz is found in almost every geological environment. It is a common constituent in most of the rock types and soil groups. Granite, sandstone, limestone, and most of the igneous, sedimentary, and metamorphic rocks contain quartz. Quartz contains mainly oxygen and silicon. These two constituents make upto 75 % of the earth's crust. An alternate name for the Quartz Group is the Silica Group. It is chemically inert in contact with most substances. Quartz occurs in hydrothermal veins and pegmatite. Well-formed crystals may reach several meters in length and weigh hundreds of kilograms. It has electrical properties and heat resistance that make it valuable in electronic products. Its luster, color and diaphaneity make it useful as a gemstone and also in the making of glass. It has a hexagonal crystal structure and is made of trigonal crystallized silica. Some quartz crystal structures are piezoelectric and are used as oscillators in electronic devices such as quartz clocks and radios. An amorphous (glass) SiO2, called Lechatelierite, is caused by lightning strikes in sand, distinct from typical window glass that is impure. The structure of quartz is built from SiO_4 tetrahedra which are linked by sharing each corner with another tetrahedron. In a three dimensional framework, every Si has four oxygen (O) and every 'O' has 2 Si as nearest neighbor. The chemical composition of quartz is nearly 100% SiO_2.

Varieties of quartz group of minerals are divided into two varieties namely

1. Crystalline varieties
2. Crypto crystalline varieties

The Crystalline varieties includes:-

1) Amethyst
2) Milky quartz
3) Rose quartz
4) Rock crystal
5) Aventurine quartz
6) Citrine
7) Smoky quartz
8) Blue quartz

Amethyst is the beautiful Violet colored quartz crystal. The color is due to the presence of the trace element of Ferric iron, which turns white when heated to 300°C (571°F), then to yellow (citrine) at 500°C (932°F), but becomes violet again if exposed to x-rays or bombarded with particles.

The Cryptocrystalline varieties includes:-

Cryptocrystalline quartz is those, which by nature, having a microscopic crystalline structure. They are: 1) Agate 2) Chalcedony 3) Carnelian 4) Jasper 5) Onyx 6) Tiger's eye 7) Rutilated quartz 8) Chrysoprase 9) Heliotrope 10) Flint or chert Agate is a concentric, banded, fibrous variety of quartz formed by precipitation from watery solutions in rounded cavities of volcanic rocks (geodes) . It occurs with beautiful clusters of rock crystal or amethyst at the centre.

Physical Properties of Quartz:

1. Crystal system: Hexagonal
2. Habit: Crystalline or amorphous
3. Fracture: Conchoidal
4. Hardness: 7
5. Specific gravity: 2.65-2.66(low)
6. Streak: No

Transparency: Transparent/semi-transparent/opaque

Uses:

1. Used as semi precious stone
2. Form of sand in construction

3. Used as abrasive in industries
4. Used for making watches
5. Piezoelectric crystal for frequency state

Feldspar Group

This group of minerals consists of framework tecto silicates Feldspar is the most common rock-forming mineral (~ 60% of the earth's crust). The mineral name feldspar is derived from the German words feld + spar. The word "feld" is "field" in German and "spar" is a term for light colored minerals that break with a smooth surface. The feldspars are by far the most abundant group of minerals and are found in igneous, metamorphic and many sedimentary rocks and thus can be found throughout different geological environment. It is more commonly found in igneous and metamorphic rocks. Feldspar minerals are essential components in igneous, metamorphic and sedimentary rocks, to such an extent that the classification of a number of rocks is based upon feldspar content. Feldspars are tectosilicates with every oxygen atom shared by adjacent silicon or aluminum tetrahedra.

Chemical Composition:

1) Potash feldspar $KAlSi_3O_8$
   a. Orthoclase
   b. Sanidine
   c. Microcline
2) Soda-lime feldspar $NaAlSi_3O_8$ (OR) $CaAl_2Si_2O_8$
   a. Albite
   b. Oligoclase
   c. Andesine
   d. Amarthitite
   e. Labrodorite

Physical properties of Feldspar Group

1. Potash Feldspar
a) Crystal system: Monoclinic, Triclinic
b) Habit: Tabular (crystalline)
c) Cleavage: Perfect (2- directional)
d) Fracture: Conchoidal or uneven
e) Color: White, grey, pink, green, red
f) Luster: Vitreous
g) Hardness: 6-6.5
h) Specific gravity; 2.56-2.58(low)
i) Streak: No
j) Occurrence: Igneous rock
k) Uses: Ceramics, glass, tableware, enamels, electric porcelain, false teeth

2. Orthoclase Feldspar
a) Crystal system: monoclinic
b) Color: red
c) Chemical composition: kalsi3o8
d) Microcline:
e) Crystal system: triclinic
f) Color: flesh red
g) Chemical composition: $KAlSi_8o_8$
h) Uses: ceramic semiprecious

Pyroxenes Group:

It is important group of rock forming minerals. They are commonly occur in dark colors, igneous and metamorphic rocks, they are rich in calcium, magnesium, iron, silicates It show single chain structure of silicate It is classified into orthopyroxene and clinopyroxene. It is based on internal atomic structure

Augite is a common rock-forming pyroxene mineral with formula (Ca, Na) (Mg, Fe, Al, Ti) (Si, Al) $2O^6$. The crystals are monoclinic and prismatic. Augite has two prominent cleavages, meeting at angles near 90 degrees.

Physical properties of Augite

1. Crystal system: Monoclinic
2. Habit: Crystalline
3. Cleavage: Good (Prismatic cleavage)
4. Fracture: Conchoidal
5. Color: Shades of grayish green and black
6. Luster: Vitreous
7. Hardness: 5-6
8. Specific gravity: Medium
9. Streak: White
10. Occurrence: Ferro magnesium mineral of igneous rock (dolerite)
11. Uses: Rock forming mineral
12. Composition: [(Ca, Na) (Mg, Fe, Al) (Al, Si) $2o^6$
13. Transparency: Translucent/opaque

Hypersthene is a common rock-forming ino silicate mineral belonging to the group of orthorhombic pyroxenes. Its chemical formula is (Mg, Fe)SiO3. It is found in igneous and some metamorphic rocks as well as in stony and iron meteorites. Many references have formally abandoned this term, preferring to categories this mineral as enstatite or ferrosilite.

1. Color: Gray, brown or green.
2. Luster: Vitreous to pearly. Weathered specimens can have a sub-metallic luster ("bronzite").
3. Transparency: Crystals are generally translucent and rarely transparent.
4. Crystal System: Orthorhombic

5. Crystal Habits include rare individual crystals that have a stubby prismatic habit typically massive or in coarse lamellar or fibrous aggregates.
6. Cleavage is perfect in two directions at nearly 90 degrees.
7. Fracture is uneven.
8. Hardness is 5 - 6.
9. Specific Gravity is approximately 3.4 - 3.9+ (above average for non-metallic minerals)
10. Streak is white.
11. Other Characteristics: Index of refraction is approximately 1.69 - 1.77.
12. Associated Minerals include iron and stony meteorites, olivine, biotite, quartz, feldspars such as Labrodorite and certain types of garnets such as almandine.
13. Notable Occurrences include the North Creek, New York, USA and Labrador, Canada.
14. Best Field Indicators are color, crystal habit, hardness, cleavage, index of refraction and luster.

Amphibole Group:

Amphibole is an important group of ino silicate minerals, forming prism or needlelike crystals, composed of double chain SiO_4 tetrahedra, linked at the vertices and generally containing ions of iron and/or magnesium in their structures. Amphiboles can be green, black, colorless, white, yellow, blue, or brown. These are closely related to pyroxene group It shows double chain silicate structure Rich in calcium, magnesium, iron oxide and Mn, Na, K and H.

Hornblende is a group name used to describe Ferro-hornblende and Magnesio-hornblende, but the term is generally more inclusive for all calcium aluminum amphiboles. (Hornblende is frequently also used to describe any dark, opaque amphibole mineral without individual analysis.) The individual Hornblende minerals appear very similar and can be virtually indistinguishable without complex analysis, and are often just grouped under a Hornblende label without further distinguishing.

Physical Properties of Hornblende: (Compound-Complex Silicate)

1. Crystal system: Monoclinic
2. Habit: Crystalline
3. Cleavage: Good (prismatic)
4. Fracture: Conchoidal
5. Color: Dark green, dark brown black
6. Luster: Vitreous
7. Hardness: 5 to 6
8. Specific gravity: 3 to 3.5 (medium)
9. Streak: Colorless or white
10. Composition: Hydrous silicates of Ca, Na, Mg, Al
11. Transparency: Translucent/opaque
12. Occurrence: Found in igneous rocks
13. Uses: Road material

Mica Group:

The mica group of sheet silicate (phyllosilicate) minerals includes several closely related materials having nearly perfect basal cleavage. All are monoclinic, with a tendency towards pseudo hexagonal crystals, and are similar in chemical composition. The nearly perfect cleavage, which is the most prominent characteristic of mica, is explained by the hexagonal sheet-like arrangement of its atoms. Shows basal cleavage

Classification of Mica

1. Light Mica:
   a) Muscovite-KAl_2 $(AlSi_2O_{10})(OH)_2$-Potash mica
   b) Paragonite-$NaAl_2$ $(AlSi_3O_{10})$ $(OH)_2$-Soda mica
   c) Lepidolite-KLiAl (Si_4O_{10}) $(OH)_2$ –Lithium mica
2. Dark Mica:
   a) Biotite-K (Mg, Fe)$_3$(AlSi3O10)(OH)$_2$.(Fe Mg mica)
   b) Phogopite-KMg_3 (Al3Si3O10)(OH)2-(Mg mica)
   c) Zinwaldite-Complex Li-Fe mica

Physical Properties of Mica

1. Crystal system: Monoclinic
2. Hardness: 2-3
3. Luster: Vitreous
4. Habit: Foliated
5. Cleavage: Perfect (basal)

Physical Properties of Muscovite Mica:

1. Crystal system: Monoclinic
2. Hardness: 2-3
3. Luster: Vitreous
4. Habit: Foliated
5. Cleavage: Perfect
6. Specific gravity: 2.7-
7. Streak: Colorless
8. Composition: kal_2 $(Alsi_2o_{10})(OH)_2$
9. Occurrence: In igneous rock (granite and pegmatite) and accessory mineral in sedimentary rock
10. Uses: Electrical industry
11. Transparency: Transparent
12. Fracture: Even
13. Color: Colorless

Physical Properties of Biotite:

1. Crystal System: Monoclinic
2. Habit: Foliated
3. Cleavage: Perfect
4. Fracture: Even

5. **Color: Black, deep green**
6. **Luster: Vitreous**
7. **Hardness: 2.5-3**
8. **Sp.Gravity: 2.7-3**
9. **Streak: Colorless**
10. **Composition: $(Mg\ Fe)_3(Al\ Si3O_{10})(OH)_2$**
11. **Occurrence: Commonly found in igneous rocks, sedimentary rocks**
12. **Transparency: Translucent**
13. **Uses: Electrical industries**

Carbonate Mineral:

Calcite:

1. **Crystal system: Hexagonal**
2. **Habit: Tabular**
3. **Cleavage: Perfect**
4. **Fracture: Even**
5. **Color: Milky white, grey, green, yellow, colorless etc**
6. **Luster: Vitreous**
7. **Hardness: 3**
8. **Sp. Gravity: 2.71(low)**
9. **Streak: Colorless**
10. **Composition: $CaCO3$**
11. **Transparency: Transparent**
12. **Uses: Used for manufacture of cement and lime it is also used as fertilizer**
13. **Occurrence: Rocking forming mineral in sedimentary rocks.**

Clay Mineral Group:

Clay is a finely-grained natural rock or soil material that combines one or more clay minerals with possible traces of quartz ($SiO2$), metal oxides (Al_2O_3, MgO etc.) and organic matter. Clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Clays are plastic due to particle size and geometry as well as water content, and become hard, brittle and non–plastic upon drying or firing

Clay minerals include the following groups:

Kaolin group which includes the minerals kaolinite, dickite, halloysite, and nacrite (polymorphs of $Al_2Si_2O_5(OH)_4$).

Smectite group which includes dioctahedral smectites such as montmorillonite, nontronite and beidellite and trioctahedral smectites for example saponite.

Illite group which includes the clay-micas. Illite is the only common mineral Chlorite group includes a wide variety of similar minerals with considerable chemical variation.

Physical Properties of Kaolin Group:

Kaolinite:

1. It is formed by weathering of Aluminate- silicate minerals. The feldspar rick rocks are commonly weathered to kaolinite.
2. Crystal system: Triclinic
3. Habit: Massive
4. Color: White sometimes brown
5. Cleavage: Perfect
6. Fracture: Even
7. Streak: White
8. Luster: Dull earthy
9. Hardness: 2
10. Specific gravity: 2.6(low)
11. Transparency: Translucent
12. Composition: $Al_2Si_2O_5(OH)_4$
13. Occurrence: secondary mineral formed by alternation of alkali feldspar
14. Uses: ceramic industries, medicine, cosmetics and main components in porcelain

Physical Properties of Smectite Groups:

Montmorillonite:

1. It is derived from weathering of volcanic ash In contact with water it expands several times its original volumes act as drilling mud and it is main constituents as patronize
2. Crystal system: Monoclinic
3. Habit: Lamellar/ Globular
4. Color: White, blue or yellow
5. Streak:
6. Luster: Dull Earthy
7. Fracture: Uneven
8. Cleavage: Perfect
9. Hardness: 1-2
10. Sp. Gravity: 1.7-2(low)
11. Transparency: Translucent
12. Composition: (Na, Ca) 0.33(Al Mg) $_2$ Si_4O_{10} (OH) $_{2.nH2O}$
13. Occurrence: derived from volcanic ash also weathering of muscovite, illite, kaolinite
14. Uses: Mainly used for oil industry (drilling mud)

Physical Properties of illite:

The illite clay has a structure similar to that of muscovite. They form by alternate minerals like muscovite and feldspar.

9) Chemical composition: (K, H) Al $_2$(Si Al) $_4O_{10}$ (OH) $_2$ XH_2O

10) Uses: in oil industry
11) Crystal system: Foliated Monoclinic
12) Habit: Foliated
13) Color: Grey, Green
14) Streak: White
15) Cleavage: Good
16) Fracture: Even
17) Luster: Vitreous
18) Sp. Gravity: Low
19) Hardness: 2-3

Crystallography: - Crystallography is the experimental science of determining the arrangement of atoms in crystalline solids.

Crystal: A crystal is defined as a solid body bounded by plane natural surfaces, which are the external expression of a regular arrangement of its constituent atoms or ions (Berry, Mason and Dietrich 1983).

Unit Cell – This is a pattern that yields the entire pattern when translated repeatedly without rotation in space. The repetition yields infinite number of identical unit cells and the pattern is regular. In order to fill space without gaps, the unit cell must at least be a parallelogram in 2D (2-dimensional) space.

Symmetry Elements: Symmetry is the most important of all properties in the identification of crystalline substances. In this section we shall be concerned with the symmetrical arrangement of crystal faces, an arrangement which reflects the internal symmetry of the lattice. Symmetry may be described by reference to symmetry planes, axes, and the centre of symmetry as discussed here below.

1. Plane of Symmetry – This is defined as a plane along which the crystal may be cut into exactly similar halves each of which is a mirror image of the other. A crystal can have one or more planes of symmetry. A sphere for example has infinite planes of symmetry.

2. Axis of Symmetry – This is a line about which the crystal may be rotated so as to show the same view of the crystal more than once per revolution, e.g. a cube. Alternatively it can be defined as a line along which the crystal may be rotated such that the crystal assumes a position of congruence i.e. the crystal presents the same appearance to a fixed observer.

3. Center of Symmetry – Center of symmetry is the point from which all similar faces are equidistant. It is a point inside the crystal such that when a line passes through it, you'll have similar parts of the crystal on either side at same distances. A cube possesses a centre of symmetry.

Crystal system: - In crystallography, the terms crystal system, crystal family, and lattice system each refer to one of several classes of space groups, lattices, point groups, or crystals. Informally, two crystals are in the same crystal system if they have similar symmetries, although there are many exceptions to this.

Crystal systems, crystal families and lattice systems are similar but slightly different, and there is widespread confusion between them: in particular the trigonal crystal system is often confused with the Rhombohedral lattice system, and the term "crystal system" is sometimes used to mean "lattice system" or "crystal family".

1. Triclinic, also known as anorthic, is a crystal system with the lowest symmetry. In this system there are no restrictions on angles or sides.

1. $a \neq b \neq c$
2. $\alpha \neq \beta \neq \gamma$

2. Monoclinic crystal system introduces a restriction on two of the angles. Now α and γ must equal to 90°. This makes the b side the symmetry unique axis.

1. $a \neq b \neq c$
2. $\alpha = \gamma = 90°$ and $\beta \neq 90°$

3. In the Orthorhombic crystal system, all the angles must be 90°. The sides, on the other hand, can change independently of each other.

1. $a \neq b \neq c$
2. $\alpha = \beta = \gamma = 90°$

4. In the Tetragonal crystal system we introduce yet another restriction. Now, not only do all the angles have to equal 90°, but the two sides a and b have to be the same length too. This makes the c side a symmetry unique axis.

1. $a = b \neq c$
2. $\alpha = \beta = \gamma = 90°$

5. For the Trigonal, also known as Rhombohedral, crystal system, the length of the sides and the angles are equal, but the shape of the cell is harder to visualize.

1. $a = b = c$
2. $\alpha = \beta = \gamma \neq 90°$

6. The Hexagonal crystal system can be visualized as a prism with hexagons as the bases. In order to describe it in terms of a, b, c and the three angles, we introduce restrictions such as γ must equal 120°.

1. $a = b \neq c$
2. $\alpha = \beta = 90°$ and $\gamma = 120°$

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