ENVIRONMENTAL GEOSCIENCES

Prof. Prasoon Kumar Singh

Department of Environmental Science and Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Lecture-24

Summary of Module 4

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module 4 and in this module we have discussed the crystal systems, different crystal classes, concepts of minerals, its properties, properties of common silicate minerals, sulphide and oxide minerals. So this is the lecture 6 comprising the summary of the total module 4 lectures. In this lecture, the important concepts we will cover like crystallography, crystal forms, elements of symmetry and law of crystallography, crystal system, types of crystal system, crystal classes, mineral and its types, physical properties of minerals, electrical and other diagnostic properties of minerals, chemical properties of minerals, rock forming silicates, types of silicates, major silicate families, non-silicate minerals, properties of common sulphide minerals and oxide minerals and their properties.

So first of all we will understand the crystallography. In crystallography, external shape is denoted by the word habit whereas form is used in a special and restricted sense. A crystal is a solid material whose atoms are arranged in a highly ordered repeating pattern that extends in all the three spatial dimensions. Now characteristics of crystals. Crystals are polyhedral bodies.

Crystals are formed due to slow cooling. It possesses a typical internal atomic structure and accordingly the faces of a crystal are arranged in a regular pattern. They are in a regular pattern and formed due to operation of interatomic forces. Now crystal forms. A form consists of a group of like crystal faces, all which have the same relation to the elements of symmetry and display the same chemical and physical properties.

On crystals drawings, each face that belongs to the same form is labeled with the same letter. By selecting one individual face in a form and performing all of the symmetry operations of the crystal class, one can generate the remaining faces in that form.

Although faces of the form may be of different sizes and shapes, because of distortion of the crystal, their similarity is frequently evidenced by natural striations, etchings and growths. On some crystals, the differences between the faces of different forms can be seen only after etching with acid. In each crystal class, there is a form, the faces of which intersects all of the crystallographic axes at different lengths, and this is the general form.

All other forms that may be present are called as special forms. For most crystal classes, the general form consists of a large number of faces than any of the special forms of the same class. There are 48 kinds of crystal forms on the basis of the angular relation of the crystal faces. Of these 48 forms, 32 are general forms, 10 are special forms of the isometric system, and 6 are special forms of the hexagonal and tetragonal systems. In this scheme of nomenclature, the name of each of the 32 general forms in the hexagonal system becomes the descriptive name of each of the 32 crystal classes.

Now, the elements of symmetry and law of crystallography. The geometric locus about which a group of repeating operation act is known as elements of symmetry. The symmetry developed in a crystal may be studied and defined with reference to plane of symmetry, axis of symmetry, center of symmetry. Through studies of external forms and angular relationship between the crystal faces, some fundamental laws have been established which govern the whole crystallography and the laws are law of constancy of interfacial angle, law of rational indices, law of axial ratio, law of crystallographic axis and law of constancy of symmetry.

Crystal System. 32 crystal classes with common symmetry characteristics are grouped together in one of the 6 crystal systems. Each of the 6 crystal systems is defined by a set of crystallographic axes. In crystals, it is convenient to refer the external forms or internal symmetry to a set of 3 or 4 reference axes. These imaginary reference lines are known as crystallographic axes and are designated as a, b and c except for the hexagonal system which has 4 crystallographic axes i.e. a-1, a-2, a-3 and c. The notation of a, b and c indicates that each axis is of different length.

The ends of axis are designated plus or minus with the orientation as the positive end of a is to the front, the positive end of b is to the right, the positive end of c is to the top and the opposite ends are negative. The angle between the positive ends of the axis are conventionally designated by the Greek letters that is α, β and γ. The α angle is between axial directions b and c, β is between a and c, and γ is between a and b. Now types of crystal systems. We have discussed already, again we are discussing, there are different types of crystal system. First one is triclinic.

Three axes of an equal length, a, b, c all intersecting at different oblique angles. That is, α is not equal to β, is not equal to γ. Monoclinic symmetry. Monoclinic system, three axes of unequal length a, b and c, two of which are inclined to each other at an oblique angle and the third is perpendicular to the plane of the other two, that is β angle is not equal to 90° and α is equal to γ is equal to 90°. Orthorhombic system, three mutually perpendicular axes all of different lengths that is a, b, c and α is equal to β is equal to γ is equal to 90°.

Tetragonal three mutually perpendicular axis two of which the horizontal axis are of equal length a-1 and a-2 but the vertical axis c is shorter or longer than the other two that is a-1 is equal to a-2 is not equal to c and α is equal to β is equal to γ is equal to 90°. Hexagonal system, this system has four crystallographic axes, three equal horizontal axes a-1, a-2 and a-3 that lie in a plane with their positive ends separated by angles of 120°. The fourth axis that is the vertical one is of different length c and is perpendicular to the plane of the other three axes that is a-1 is equal to a-2 is equal to a-3 is not equal to c and β is equal to 90°. Isometric system, three mutually perpendicular axes of equal lengths a-1, a-2 and a-3. And in isometric system, a-1 is equal to, a-2 is equal to a-3, and α is equal to β is equal to γ is equal to 90°.

Now crystal classes. Isometric crystal class are normal class, holohedral class, holosymmetric class, or hexa-octohedral class, gyroidal class, or plagiohedral class, hexa-tetrahedral class, tetrahedral class, deploidal or pyritohedral class, tetartohedral class. Tetragonal system of classes, normal class, ditetragonal dipyramidal class or zircon type, tetragonal trapezoidal class or trapezohedral class, ditetragonal pyramidal or hemimorphic class, tetragonal dipyramidal or tripyramidal class, tetragonal scalenohedral class or sphenoidal class, tetragonal pyramidal class or pyramidal hemimorphic class, tetragonal disphenoidal or tetartohedral class. Hexagonal system class grouped into two divisions, namely hexagonal division, trigonal division. Further seven classes in hexagonal division and five in trigonal division.

Orthorhombic system class, normal class or orthorhombic dipyramidal class, orthorhombic pyramidal class, orthorhombic disphenoidal class. Monoclinic system class, normal or prismatic class, dometic class, sphenoidal class, and triclinic system classes, normal or pinacoid class, asymmetric or hemihedral class or Pedial class. Now mineral and its types. Mineral science also referred as mineralogy is the study of minerals. A mineral is naturally occurring solid with a highly ordered atomic arrangement and a definite homogeneous chemical composition. Minerals are usually formed by inorganic processes.

They form the building blocks of the rocks and are fundamental to the earth crust, mantle and core and naturally occurring that is formed by the natural processes. On the basis of chemical composition, minerals are divided into classes depending on the dominant anionic group. For example, oxides, halides, sulfites, sulfates, silicates, etc. Minerals having the same anion or anionic group dominant in their composition have unmistakable family resemblances. Thus, the carbonates resemble each other more closely than do the minerals of copper.

Minerals related by the same anion tend to occur together or in the same or similar geological environment. Thus, the sulfides occur in close mutual association in deposits of vein of replacement type, whereas the silicates make up the great bulk of rocks of the earth's crust. Mineral classification is based on chemical composition and internal structure because these together represent the presence of a mineral and determine its physical properties. This large mineral group was divided into subclasses partially on the basis of chemical composition but principally in terms of internal structure within the silicate class, framework, chain and sheet silicate. Subclasses exist on the basis of structural linkage of SiO_4 tetrahedra.

The broadest divisions of the classification are sulfides, sulfosalts, then oxides, the hydroxides, halides, carbonates, nitrates, borates, phosphates, sulfates, silicates. These classes are subdivided into families on the basis of chemical types, the family is divided into groups on the basis of structural similarity. A group is made up of species, which may form series with each other. A species may be subdivided into chemical varieties that reflect the presence of unusual amounts of chemical constituents. Now physical properties of minerals. The physical properties of minerals are the microscopic expression of its internal makeup, specifically its crystal structure and chemical composition.

These physical features also make many minerals valuable. Soft minerals are lubricants, hard minerals are abrasives. First is the lusture. It refers to the general appearance of a mineral surface in reflected light. There are two distinct types of lusture, metallic and non-metallic.

Minerals with an intermediate lusture are said to be submetallic. Color, it is easily observed in a mineral. Many gemstones are recognized on the basis of their color alone. Color is directly related to the chemistry and structure of a mineral. Streak, it is commonly a diagnostic property.

However, if a mineral has a hardness higher than that of the streak plate, it will simply scratch the streak plate leaving a white powder. It is useful in the identification of metallic minerals because their streaks are characteristically colored. Most minerals with a non-metallic lusture will have a whitish streak even if the minerals themselves are colored. Luminescence, It is the phenomenon that results from a material absorbing a form of energy, thermal, mechanical, electromagnetic and re-emitting that energy as visible light.

Most luminescence is faint and can be seen only in the dark. Cleavage, it is a tendency of minerals to break along the parallel planes. It occurs because the mineral has a weaker bonds holding the atoms together in specific directions. The mineral breaks preferentially along these directions. It is well displayed by layered structures such as mica and graphites.

Fracture, it is the breakage of minerals when they do not yield along cleavage or parting surfaces is fracture. Fracture pattern can be distinctive and diagnostic in mineral identification. Hardness, it is the resistance of a smooth surface of mineral to scratching. The hardness of mineral is determined by observing if mineral is scratched by another material of known hardness and it is said to be its scratchability. Hardness is related to bond strength.

Tenacity, it is the resistance of mineral to breaking or deforming or its cohesiveness is known as tenacity. The tenacity of mineral also relates to its internal bonding and is useful in identification of metallic minerals. Electrical and other diagnostic properties of minerals. Electrical properties, that is, piezoelectricity. Under directed pressure, certain minerals will develop an electric charge;

they become positively charged on one side and negatively charged on the others are referred to as piezoelectric. Example: tourmaline and quartz. It is extensively used in industrial applications for the control of radio frequencies in electronic circuits. Pyroelectricity: During heating certain minerals can also develop an electric charge, these termed as known as pyroelectric minerals.

Heat is non-directional and cause mineral structure to distort and displaces the positive and negative charges relative to each other. For example in tourmaline. Other diagnostic properties. Magnetism. Magnetic strength in minerals ranges from being so strong as to lift steel bars, to barely deflecting a compass needle, to non-existent. Most minerals experience no attraction to a magnetic field, then they are referred as diamagnetic. A few minerals may be drawn to a magnetic field as long as the field is present, they are known as paramagnetic. The most magnetically active minerals are ferromagnetic, that is magnetite.

These types of minerals are important to geology, because they can record the direction of the Earth's magnetic field through time. Next diagnostic property is the radioactivity. Minerals containing radioactive elements such as uranium and thorium will continually undergo decay reactions and reduce energy in the form of α and β particles and γ radiations. Example is uraninite pitchblende thorianite and autunite. Chemical properties of minerals. The chemical phenomena usually found with minerals are isomorphism, polymorphism, pseudomorphism, homeomorphism, and paramorphism. The members of an isomorphous series show a gradation in chemical composition, crystal forms, specific gravity, refractive index, etc. from one extreme to the other, for example, plagioclase feldspars. The polymorphic forms in case of elements are known as allotrope and its types are, on the basis of number of polymorphic forms, they are dimorphic type, trimorphic type.

On the basis of reversibility, they are enantiotropy, monotropy, a pseudo morphism mineral forms due to incrustation, infiltration, replacement, alteration, etc. Homeomorphism occurs if the geometry of the arrangement of the dissimilar ions is similar. The appearing crystals may result like Rutile and Zircon which are tetragonal but have different chemical composition. Paramorphism is the phenomenon in which a crystal whose internal structure has changed to that of a polymorphous form without any change in the external form.

Now rock forming silicates. The silicate mineral class is of great importance because about 27 % of the known mineral and nearly 40 % of the common minerals are of the silicates group. With few exceptions, all the igneous rock formations minerals are silicates and they constitute well over ninety percent of the earth crust. In addition, most metamorphic rocks are composed primarily of the silicate minerals. Rock forming minerals are those minerals that make up the major components of a rock and they are used in the classification of the rock types.

The more important rock-forming silicate minerals include olivine, garnet, pyroxenes, amphiboles, micas, clay minerals, feldspars, and quartz. Other rock-forming minerals are calcite, dolomite, etc. in sedimentary rock. The silicate mineral group includes a considerable number of industrial minerals. Types of silicates. On the basis of degree of tetrahedral linking, the silicates are nesosilicates, sorosilicates, cyclosilicates, inosilicates and tectosilicates. Now first one is the nesosilicates.

In nesosilicate, the SiO tetrahedra are bound to each other by ionic bonds from interstitial cations. Their structures depend primarily on the size and charge of the interstitial cations. The minerals of this group have relatively high specific gravity and hardness. Bond strength are equal in all directions. Common members in high temperature igneous rocks of the nesosilicate group are forsterite, olivine, garnet, zircon, sillimanite, kyanite, topaz and fayalite.

Then, sorosilicate. The sorosilicates are characterized by isolated double tetrahedral groups formed by two SiO_4 tetrahedra sharing a single apical oxygen. The resulting ratio of silicon:oxygen is 2:7. More than 70 minerals are known in this group. Some of them are hemimorphite, lawsonite, epidote group, clinozoisite, epidote, allanite, vasovianite, etc.

Then cyclosilicates. The cyclosilicates contain rings of linked SiO_4 tetrahedra having a ratio of Si:O is 1:3. Three possible closed cyclic configuration of this kind may exist. The SiO_4O_{12} ring occurs in rare silicate papagoite. The Si_6O_{18} rings occur in common and important minerals, beryl, tourmaline.

In the structure of beryl, Si_6O_{18} rings are arranged in layers parallel to 0001. The silicon-oxygen rings are so arranged as to be non-polar that is a mirror plane passes through the tetrahedra in the plane of the ring. Inosilicates, simple chains may be joined side-by-side by further sharing oxygens in alternate tetrahedron to form bands or double chains. In the simple chain structure, two of the four oxygens in each SiO_4 tetrahedron are shared, giving a ratio of Si:O is 1:3. In the double chain structure, half of the tetrahedra share three oxygens and other half share two oxygens, giving a ratio of Si:O is 4:11.

Included in the inosilicates are the two important rock-forming group of minerals in the pyroxenes, the pyroxenoid, single-chain members, and the amphiboles, double-chain members. Most pyroxenes and amphiboles are monoclinic. Both groups have orthorhombic members, the repeat distance along the chains is approximately 5.2 Å. Amphiboles and pyroxenes contains the same cations, but amphiboles also have hydroxyl ions which are absent in pyroxenes. This difference results in slightly lower specific gravity and the refractive indices for amphiboles.

Both minerals have similar color, lusture, and hardness. They differ in crystal form. Pyroxenes are blocky while amphiboles are elongated or acicular. Their cleavage angles also differ due to their distinct chain structures. Pyroxenes are anhydrous and crystallize at higher temperatures, forming early in cooling igneous melts and in high-temperature metamorphic rocks.

Tectosilicate, about 64 ％ of the Earth's rocky crust, consists of tectosilicate minerals, which are made up of SiO_4 tetrahedra linked together. In these minerals, the oxygen ions in each tetrahedra are shared with neighboring tetrahedra, creating a stable, strongly bonded structure with a Si:O ratio of 1:2. Members of the feldspar, feldspathoid, zeolite, quartz group of minerals show this type of silicate structure. Major silicate family. Silicate minerals can be classified into groups based on their structural similarity as olivine group, silica group, pyroxene group, mica group, feldspar group and amphiboles group.

Olivine group, nesosilicate, orthorhombic mineral, existing in two forms, forsterite, Mg_2SO_4, and faylite, Fe_2SiO_4, with vitreous lusture, with pale yellow-green to olive green color and granular in nature, fracture conchoidal with hardness value of 6.5 to 7 on Moh's scale of hardness, making it harder than glass. Chemical joining with Mg-rich ores and Fe-rich rims is found in high-temperature igneous rock. It is found principally in Mg-rich igneous rock such as gabbro, peridotite, and basalt, coexisting with plagioclase and pyroxenes. Distinguished usually by its glossy, lusture, conchoidal fracture, green color, and granular nature. Under very high pressures, the olivine structure transforms to one of two different high-pressure polymorphs.

Now, Quartz-silica group. Quartz is a silica group mineral with tectosilicate structure and chemical formula SiO_2. Its crystalline structure does not apply to silica glass, Lechatelierite. Crystalline silica occurs in various forms including quartz, tridymite, cristobalite, coecite, stishovite, and keatite. Quartz, tridymite, and cristobalite are its primary polymorphs, each forming at distinct temperature ranges. i.e. quartz below 870°C, tridymite 870°C to 1470°C, cristobalite above 1470°C. Silica occurs in non-crystalline forms such as Lechatelierite, Opal and Chalcedony.

Key physical properties of the quartz include crystal system, quartz hexagonal, tridymite orthorhombic, cristobalite isometric. Streak, white, Lusture, vitreous to sub-vitreous.

Hardness seven on Mohs scale. Crystal is none, important characteristics. Specific gravity low, that is 2.65.

Mica group. Mica crystallize in the monoclinic system but have crystallographic angle beta close to ninety degree making their monoclinic symmetry less apparent. They form tabular crystals with prominent basalt planes and outlines that appear either diamond-shaped or hexagonal with angles of approximately 60° and 120°, giving them the appearance of orthorhombic or hexagonal symmetry. Micas are distinguished by their perfect cleavage. Striking a cleavage plate with a dull-pointed instrument produces a six-rayed percussion figure, with two lines nearly parallel to prism edges and the third, more pronounced line parallel to the mirror plane.

Limited ionic substitution occurs among mica group members and two members can crystallize together in parallel with cleavage extending through both. Mica group include muscovite, biotite, crystals and the physical properties are like muscovite is colorless, biotite-dark colored, lusture-pearly, splendant, cleavage-perfect, basal cleavage, hardness-2 to 3, specific gravity-low, twinning-Rarely seen. They possess unique combination of the properties like elasticity, toughness, flexibility, transparency, resistance to heat and property of splitting into thin films. Then Pyroxene group. The common pyroxenes are Ca, Mg and Fe silicates having general formula $X_2SiO_2O_6$. Broadly divided into two groups ortho-pyroxenes and clino-pyroxenes.

Ortho-pyroxenes include enstatite, ferrosilite, pigeonite and clino-pyroxenes include diopside, hedenbergite, augite. Physical properties-Orthorhombic crystals, good cleavage, specific gravity 3.2 to 3.6. Vitreous in lusture, greyish, yellowish or greenish in color. Habit-massive or lamellar. Magnesium rich orthropyroxenes are a common constituent of peridotites, gabbros, norites and basalts. They are found associated with augite, olivine, and plagioclase. Feldspar. Most abundant of all minerals, they fall into two main series, potassium-sodium feldspars, called alkali feldspars and calcium-sodium feldspars, called the plagioclase feldspars.

Physical property, cleavage-good in two directions at an angle of 90°. Specific gravity 2.55 to 2.63. Lusture-vitreous, color-white, gray, pink or green. Habit generally tabular, use in the manufacture of porcelain. The alkaline feldspar, which include orthoclase, microcline, and albite, have a similar occurrence.

They are commonly found in igneous rocks such as granites, pegmatites, cyenites, rhyolites, and trachytes. Oligoclase is commonly found in granodiorites and monzonites, whereas labradorite is a common constituent of gabbros, basalts, and anorthosites. Then amphiboles. The amphiboles contain hydroxyl groups in the structure and angle between the two sets of cleavage is 124°. The important members of amphibole group are tremolite, actinolite, hornblende. Crystal system-monoclinic, cleavage-perfect, specific gravity-3.0 to 3.3, lusture -vitreous or silky, color-white or gray in tremolite and green in actinolite. Habit-termolite is often bladed and sometimes in silky fibres.

Actinolite is often in radiating aggregate and fibrous. These minerals are commonly found in metamorphic rocks. Non-silicate minerals. Non-silicate minerals are less important as rock forming minerals. These are oxides, hydroxides, carbonates, and sulphides, sulphates. Sulphide minerals include a large group of minerals predominantly metallic in character.

Sulphide minerals exhibit ionic, homopolar, or metallic alloys like bonding types and are opaque, but non-opaque ones have high refractive indices and often transmit only red light. The most common examples of sulphide minerals are argentite, chalcocite, bornite, galena, then sphalerite, chalcopyrite, then millerite, pyrite, arsenopyrite, etc., Properties of common sulphide minerals. The first one is the Ag_2S, Argentite. Argentite is an important primary silver mineral found in hydrothermal sulphide ore deposits, often associated with ruby silvers, native silver and argentiferous galena.

It crystallizes in the isometric system which has a sub-conchoidal fracture, indistinct cleavage and a hardness of 2 to 2.5 with a specific gravity of 7.2 to 7.4 and it is black with sine streak and a metallic opaque lusture. Chalcosite is a significant copper source, primarily found in the supergene-enriched zones of sulphide deposits. It appears as a fine-grained massive material and may alter covellite, malachite, or azurite. Chalcocite has a monoclinic crystal system, conchoidal fracture, and indistinct cleavage. Its hardness is 2.5 to 3, with a specific gravity of 5.5 to 5.8.

It is dark gray to black with a metallic, opaque, lusture and its tenacity ranges from brittle to somewhat sectile. Bornite is a significant copper source, is a common mineral found in major copper deposits worldwide. It occurs in dikes, basic intrusive, metamorphic deposits, pegmatites, coagulants, and disseminated in basic rocks. It crystallizes in the isometric system and has a hardness of 3, specific gravity 5.06 to 5.08, and displays a metallic opaque lusture. Color ranges from copper red to golden brown or bronze on fresh fracture surfaces with a conchoidal to uneven fracture and traces of cleavage.

Galena, lead sulphide, the primary source of lead, is found in various deposits, including sedimentary rocks, hydrothermal veins, pegmatites and contact metamorphic deposits. It has an isometric crystal system, highly perfect cleavage, a hardness of 2.5 and a specific gravity of 7.58. Its color is lead gray with a metallic or opaque lusture. Spherite a primary source of zinc is closely associated with galena in major lead-zinc deposits. It has an isometric crystal system, perfect cleavage, hardness 3.5 to 4, specific gravity of 4.096.

Color ranges from brown to yellow with a resinous to nearly metallic lusture. Chalcopyrite, a significant copper source, forms under diverse conditions and most common is sulphide or deposits. Found as irregular masses in moderate to high temperature veins, it belongs to the tetragonal system with distinct cleavage. Uneven fracture and hardness 3.2 to 4, its specific gravity varies from 4.1 to 4.3 and it appears brass yellow with a metallic lusture. Millerite, primarily of low temperature, origin is commonly found as capillary crystals, tufts in limestone or dolostone cavities, carbonate veins, or as an alteration of other nickel minerals.

It belongs to hexagonal system with perfect cleavage, hardness 3 to 3.5, specificity 5.5. Its color ranges from pale brass yellow to greenish sea black with a metallic lusture. Pyrite, the next one. It occurs in a variety of igneous rocks, pegmatites, and other contact metamorphic deposits, hydrothermal veins, and sedimentary and metamorphic rocks. It belongs to the isometric cubic system, has an existing cleavage, conchoidal fracture, and a hardness of 6 to 6.5. Its specific gravity is 5.0 one with a brass yellow color and metallic lusture. Pyrite is a paramagnetic and significant source of sulphur.

Then oxide minerals and their properties. Oxides are minerals where metal, atoms or cations combine with oxygen, typically exhibiting ionic bonding. Unlike carbonates or sulphates, oxides lack discrete anionic radicals. Common oxide minerals include cuprite, zincite, magnetite, chromite, hematite, ilmenite, rutile and pyrolusite. Cuprite (Cu_2O) is found in the oxidized zones of the copper deposits and is associated with minerals like malachite, azurite, iron oxides, clays, and tenorite.

It has an isometric crystal system, distinct but interrupted cleavage and conchoidal fracture, and its hardness ranges from 3.2 to 4, with a specific gravity of 6.10. The mineral appears red to nearly black, has a brownish-red streak, and gives a sub-metallic lusture, showing red under transmitted light. Zincite. It is a rare mineral found mainly in zinc deposits at Franklin and Sterling Hill, New Jersey, where it constitutes about 1% of the ore. It is associated with willemite, franklinite, and calcite, typically in granular form.

The mineral has a hexagonal crystal system, perfect but challenging cleavage, conchoidal fracture, and hardness of 4.

Its specific gravity is 5.68 with orange-yellow to deep red color and orange-yellow streak. Zincite has a sub-admantine lusture and is translucent in thin silver. Magnetite is a common oxide mineral found in igneous rock and significant iron ore deposits. It has isometric crystal system, no cleavage, hardness of 5.5 to 6.5, specific gravity of 5.17. Its color and streak are black with a metallic lusture and opaque nature. Chromite, $FeCr_2O_4$, is found in ultra-basic igneous rocks, often forming segregated masses of grains in sufficient quantities to serve as an ore.

It belongs to isometric crystal system and an uneven fracture. Its hardness ranges from 5.5 to 6, with a specific gravity of 4.5 to 4.8. Chromite is the sole ore mineral of chromium. Hematite, Fe_2O_3, is a key source of iron commonly found in Indian rock, hydrothermal veins, and metamorphic deposits. It has hexagonal crystal system, hardness of 5 to 6, and a specific gravity of 5.26.

Colors range from dull red to steel gray with a red-brown streak. It exhibits metallic to submetallic lusture, and thin splinters show deep blood-red in transmitted light. Ilmenite. It is an important source of titanium, occurs in association with gabbros, diorites, and anorthosites, either as veins, disseminated deposits, or large masses. It has a hexagonal crystal and hardness of 5 to 6. Its specific gravity is 4.72 and exhibits a metallic to submetallic luster and is opaque. Rutile, the most common polymorph of titanium dioxide, typically formed as an alteration product of minerals like titanite and ilmenite. Found in greisens, pegmatites, veins, and metamorphic rocks.

It has a tetragonal crystal system, distinct cleavage, conchoidal fracture, hardness of 6 to 6.5, brown color, and streak, adamantine to metallic lusture, and is transparent in thin pieces, and a key source of titania for paint pigments. Pyrolusite, MnO_2, the common manganese mineral found in oxidized environments like bogs and deposits. It has a tetragonal crystal system, perfect cleavage, uneven fracture, hardness of 6 to 6.5, specific gravity 5.06, and bluish-black metallic appearance. Thank you very much to all.