Definition, scope and importance of geology:

Geology from the Greek *geo* (Earth) and *logos* (discourse) is that branch of physical sciences which deals with the study of the earth, including the materials that it is made of, the physical and chemical changes that occur on its surface and in its interior, and the history of the planet and its life forms. It also studies the ocean floor, and the interior of the earth. Geologists investigate the composition of earth materials and various geological processes to locate and exploit its mineral resources. They investigate geological phenomena such as earthquakes and volcanoes and attempt to predict and minimize their damaging effects.

Geology, or geoscience, is the study of the Earth. Not only do geologists address academic demands such as the formation and composition of our planet, the causes of earthquakes and ice ages, and the evolution of life, but they also address practical problems such as how to keep pollution out of groundwater, how to find oil and minerals, and how to avoid landslides. The complex science of geology is not a mere study of earth superficially, but it includes an inestimable amount of science which is involved in it from the present day climate change to even before the formation of the solar system as it contemplates on the origin of universe and solar system and has gained a great success in finding their original cause of formation along with the reason of the formation of the earth on the one hand and on the other hand has provided a significant evidence of the present day climate change, environmental degradation, air and water pollution as not being only an anthropogenic affair but beyond that . This subject accumulates events that the Earth has witnessed for more than 4.5 billion years, like the formation of the mineral resources (the back bone of modern society), the origin and evolution of the life, the evolution of atmosphere, and causes of disappearance of so many great organisms from the earth as a function of the varying environment. This time-span of million years and associated events and their causes and consequences are preserved on the earth as the pages in a book. The fascination of geology attracts many to careers in this science. Tens of thousands of geologists work for oil, mining, water, engineering, and environmental companies, while a smaller number work in universities, government geological surveys, and research laboratories. Recent developments in geology have further broadened its expanses into medical and health sciences with a new emerging field of medical geology growing very fast. There are countless fields where geological knowledge is a prerequisite to achieve a technologically sound society.

Branches of geology:

Physical geology:

Physical geology may be defined as the branch of geology which deals with the study of physical forces and processes that bring about changes in the earth's crust or to the surface of the earth on account of their prolonged existence and action

Structural Geology:

The study of the deformation of the rocks in the earth's lithosphere is the subject matter of the branch of geology known as structural geology. Structural geology also takes account of the forces that bring about the deformation of the lithospheric rocks.

Sedimentology:

Sedimentology deals with the study sediments, their formation, transportation and deposition.

Mineralogy:

The branch of geology which deals with the study of minerals, their formation, analysis, association, physical and chemical properties and classification is called mineralogy.

Petrology:

The branch of geology which is concerned with the study of rocks is called petrology. It is further subdivided into igneous, sedimentary and metamorphic petrology depending upon the rock group studied under the particular heading.

Paleontology:

The study of the past life on the earth is called paleontology. It is studied with the help of fossil records that is preserved in the sedimentary rocks of the earth.

Historical Geology:

Historical Geology is that branch of geology that studies the evolutionary history of the earth in a chronological manner. Historical geology is further subdivided into stratigraphy (the study of the stratified rocks of the earth).

Economic Geology:

The branch of geology which that deals with the study of the earth materials that are used for economic and/or industrial purposes such as petroleum, coal, ores, building stones, salt, gemstones, etc., is known as economic geology.

Engineering Geology:

Engineering geology deals with the application of geology to engineering practices and solving engineering problems. Engineering geologists are concerned with the distribution and relevance of earth materials; potentially dangerous naturally occurring and human-induced geologic hazards; assessment of the risks of damage and injury associated with those hazards, their planning, location, design, construction.

Hydrogeology:

The branch of geology which deals with the study of occurrence, movement and suitability of groundwater is called hydrogeology.

History of Geology:

Minerals like flint were mined in areas which are now Belgium, Sweden, France, Portugal and Britain in Neolithic and Bronze Ages, about 5000 to 2500 BC. However the Middle East people began to mine useful minerals such as iron ore, tin, clay, gold and copper as early as 4000 BC and Copper was probably the earliest metal to be smelted. From 4000 BC on, the use of clay for brick-making became widespread. The smelting of iron ore for making of tools and weapons began in Asia Minor at about 1300 BC but did not become common in Western Europe until nearly 500 BC.

Arabs were the first people along with romans to recognize the importance of the surface processes. Aristotle, for instance, recognized erosion and deposition of surface material. Empedocles and Pliny left descriptions of eruptions at Etna and Pompeii. The early philosophers did not leave much in the nature of records. Some of the theories put forward at the time to explain natural phenomena were based more on speculation than on observations and may seem amusing today. At about 540 BC, Xenophanes described fossil fish and shells found in deposits on mountains. Similar fossils were noted by Herodotus (about 490 BC) and by Aristotle (384-322 BC). Aristotle believed that volcanic eruptions and earthquakes were caused by violent winds escaping from the interior of the earth.

Eratosthenes, a librarian at Alexandria at about 200 BC, made surprisingly accurate measurements of the circumference of the earth by plotting the angles between the perpendicular and the sun's rays at two locations (Syene and Alexandria) on the same meridian. The Arabs recognized the magnetic properties of magnetite and used it to make crude compasses. Georg Bauer, also called 'Agricola' (1494-1556) did much to advance the knowledge of minerals and metal carrying veins. His great work 'De Re Metallica' (1556) gives a clear description of mining and metallurgy that was carried out at that time. In 1565 in Switzerland, Conrad Gesner published a fine descriptive and illustrated work with a long Latin title which meant, in short, 'all about fossils, stones and gems'. During about the same time George Owen in England carried out systematic observations on strata as early but unfortunately his work was not published until 1796. English scientist Nicholas Steno (1638-1686) was the first to state important principles about layers of sedimentary rock. He illustrated his theories with diagrams showing the geological history of Tuscany. He divided the history into six phases and believed, wrongly, that the six phases were of worldwide application. In the Eighteenth Century it became popular among men of culture to record their findings in the natural sciences.

The succession of rocks in the coalfields of England became well documented and it was believed to apply over a much wider area. Arduino classified the rocks of Northern Italy into Primitive, Secondary, Tertiary and Volcanic. His classification was based on the appearance of the rocks and on the occurrence of fossils. Lehmann in 1756 distinguished three orders of mountains:

a) Those he believed to have been formed when the world was made;
b) Those formed from sediment deposited in sheets under water;
c) Volcanic mountains.

Lehmann's work was followed by that of George Fuchsel (1722-1773) who published in 1762 one of the first geological maps in his book'A History of the Earth and the Sea'.

In Russia, Pallas recognized three broad divisions of mountains and rock groups. He saw that there was clear evidence of the presence of the sea in former time in some areas and supposed that the elevation of the mountains was caused by uplift during what he termed 'commotions of the globe'.

Development of geology as a separate branch of science took place in the years between 1775 and 1830. Geologists commemorate 1775 as the Geological year. In this year a small mining academy at Freiburg in Germany was established where Abraham Warner used to teach geology.

Charles Lyell published the classic textbook, 'Principles of Geology', in 1830-1833. Many basic principles of geology were recognized and described during this period. Particularly important were those set out by James Hutton in Scotland. Two other writers of note were William Smith in England and Georges Curvier in France. Abraham Werner (1749-1817) was a careful mineralogist who drew up an excellent system of classification of minerals based on their properties. Werner published few of his theories which were soon spread throughout Europe by the enthusiasm of his students. Werner held that rocks such as granite had formed during the earth's early history by crystallization in a worldwide ocean. He concluded therefore that the oldest rocks in any region were granites and other crystalline rocks. He did not believe that volcanoes were important in past geological eras. Because of his theory that what are known today as igneous rocks originated in the sea, Werner and his followers were called Neptunists. James Hutton (1726-1797) must be regarded as the 'father of modern geology'. Hutton recognized the importance of unconformities and pointed out that many igneous rocks clearly intruded surrounding rocks, and therefore were younger. Because Hutton and his followers held that igneous rocks came from molten material within the earth, they were called Plutonists. His friend, the mathematician John Playfair (1748-1819) publicized Hutton's theories and added further ideas.

Argument between Plutonists and Neptunists continued until nearly 1820, but eventually the views of the former group were found to be valid.
Several of Werner's best pupils became Plutonists after becoming convinced by field evidence. Hutton's most important concept was that of uniformity – the idea that processes active today were also active in the past, and thus that all geological phenomena can be understood in the light of present processes. The concept was developed from earlier ideas of G.H. Toulmin and became known as'uniformitarianism'. William Smith (1769-1839) is regarded as one of the greatest of the early geologists. His recognition of stratigraphical successions based on fossils and his excellent geological maps mark the beginning of a new era in geology. In 1822 the local names given by Smith to many units of the Secondary rocks began to be used in a wider sense and became the names in use today. W. Phillips and W.D. Conybeare suggested the name Carboniferous for what were popularly called 'coal measures'. The name Cretaceous (creta, chalk) was introduced by d'Halloy for the chalk rocks of England and France. The Jurassic System was also named by d'Halloy.The Jurassic System was the one which William Smith studied most when he established the principles of stratigraphy.
In 1833 Adam Sedgwick, professor of geology at Cambridge, mapped rocks in Wales which he called Cambrian after the old Roman name for Wales. At the same time Charles Lyell was suggesting a subdivision of the Tertiary period based on the relative number of fossils similar to living forms. His subdivision is still largely accepted. In Germany von Alberti introduced the name Trias (sic), and in 1835 Roderick Murchison published his work on the Silurian System.Lapworth 1879 named the Ordovician System. It included the upper part of Sedgwick's Cambrian and the lower part of Murchison's Silurian. In 1840, after visiting Russia, Murchison named the Permian System (Perm in Russia), while the Devonian System (Devon in England) was named in the same year.In about 1855 William Logan in Canada studied rocks older than the Cambrian and called them the Precambrian System. Thus, by the middle of the Nineteenth Century, the general geological time scale based on fossils and stratigraphic mapping was established. Hutton, Lyell and others recognized that the principle of uniformitarianism required very long periods of time, and that the presence of unconformities indicated long time breaks when a local area was being eroded.
There was, however, considerable opposition to the geological method of calculating the ages of minerals and rocks, both from religious authorities and from physicists. Some of the former based their concept of the age of the earth on Biblical chronology calculated by Bishop Ussher in the 17th Century. They thus thought that Creation occurred in 4004 BC.
The physicists, led by Lord Kelvin, maintained that the earth could not be more than 100 million years old. They made the assumption that the earth began as a molten mass and was in process of cooling. The discovery of radioactivity in minerals 1896 showed that the earth was cooling down at a much slower rate than Kelvin had estimated and thus his figure for the age of the earth was too low. Since then techniques based on the breakdown of radioactive isotopes of uranium, strontium, potassium, carbon and other elements have made it possible to measure the age of the earth and the extent of each geological period.During the second half of the l9th Century, while stratigraphic data on various parts of the world were being refined, many other geological advances were being made. The science of petrology had its origin early in the l9th Century in the careful descriptions of rock specimens by von

Buch, Nicol and others. Petrology expanded rapidly after the development of the petrological microscope.

In 1851 in England H.C. Sorby published the first description of thin sections of sedimentary rocks, and in 1870 Zirkel described basalts in Germany. Important advances in the understanding of the chemistry of rocks followed. Bunsen suggested in 1851 that igneous rocks were derived from two separate magmas, 'acid' and 'basic'. V.M. Goldschmidt, who collected a vast amount of data about the distribution of elements in the earth's crust and interior, may be considered as the founder ofgeochemistry. In 1910, Bowen began laboratory studies in experimental petrology, examining the behavior of melts of silicates under various conditions. Geomorphological studies were advanced by the work of Agassiz, who in the 1840s recognized the effects of Pleistocene glaciation in Europe and the USA.The strongest influence up to 1900 was the work of W.H. Davis, an American who worked both in USA and Europe and who first defined the cycle of erosion. Though first proposed by American geologist Frank Bursley Taylor in a lecture in 1908, the first detailed theory of continental drift was put forth by German meteorologist and geophysicist Alfred Wegener in 1912.Harry Hess was a geologist and Navy submarine commander during World War II. Part of his mission had been to study the deepest parts of the ocean floor. In 1946 he had discovered that hundreds of flat-topped mountains, perhaps sunken islands, shape the Pacific floor. The discovery of the Great Global Rift in the 1950s inspired him to look back at his data from years before. After much thought, he proposed in 1960 that the movement of the continents was a result of sea-floor spreading. In 1962, he added a geologic mechanism to account for Wegener's moving continents. It was possible, he said, that molten magma from beneath the earth's crust could ooze up between the plates in the Great Global Rift.

Theories of origin of the solar system:

Nebular Hypothesis:

The nebular hypothesis was first put forward by the German philosopher Immanuel Kant in 1755 and later in 1796 the French mathematician Pierre-Simon Laplace independently proposed a similar hypothesis for the origin of the solar system. According to Kant and Laplace there was a huge hot mass of gas which was rotating on its axis in the universe at a terrific speed. Due to this rotation the nebula started cooling and heat to its surroundings through radiation. As the nebula cooled enough it shrank and contracted in size which resulted in an increase in the rate of rotation and hence the centrifugal force and the equatorial part of the nebula was bulged. The outer surface of the nebula cooled more quickly than the inner core and which gave rise to differential rate of rotation. The slowly moving outer shell could not keep pace with the fast moving core. Eventually the nebula became unstable with the increase in the centrifugal force and differential cooling and gaseous rings began to come off the nebula which kept on rotating along the equatorial circumference of the nebula. With the further cooling these rings condensed into planets. Since the newly born planets remained in gaseous phases for long period of time before their solidification, they with a similar mechanism gave birth to their satellites. The central part of the nebula became the sun.

The biggest drawback of the hypothesis is the distribution the angular momentum among the member of the solar family; sun should have highest angular momentum as highest mass is contained in it, however it has only 2% of the angular momentum of the solar system. The other drawbacks of the hypothesis are failure in how the gaseous material condensed into planets and failure in explaining the irregularities in the planetary bodies.

Tidal Hypothesis (Gaseous Tidal Hypothesis):

James Jeans in 1916 and Harold Jeffery in 1929 proposed a hypothesis to explain the origin of the planetary system. According to their hypothesis the sun was travelling in the space at a very high speed, when a big star approached the sun and came very close to it. The approaching star exerted a very strong pull on the sun due to which a tide was raised on its surface. As the approaching star came nearer and nearer the size of tide increased. The approaching star then withdrew and went away leaving the protuberances on the surface of the sun. The shape of the tide on the sun was like that of a spindle i.e. thick in the middle and thin at the ends. This spindle shaped mass was unstable as the sun rotated very fast and it detached from the sun and broke into a number of fragments which condensed into planets and their satellites.

The limitation of the hypothesis is that it failed to explain how as to the encounter of a star could can raise protuberances on the surface of the sun. Also there is very least possibility of a star passing by the sun as stars are separated by extensive distances.

Planetesimal Hypothesis:

In 1905 two American scientists, Thomas Chamberlin and Forest Moulton postulated the origin of the solar system from small stellar fragments called Planetesimals, hence the hypothesis is commonly known as planetesimal hypothesis. According to the hypothesis the sun existed before the formation of the planetary system. The hypothesis postulate that the sun was moving in the space and anther star (bigger in size) approached it. The near approach of the larger star caused tidal distortions upon the surface of the Sun. These distortions together with the eruptive forces present in the Sun, led to the distortion of the Sun's mass. As the larger star came closer and closer the size of the tides increased (due to increased gravitational attraction) and caused imbalance in the sun. The imbalance caused a number of gaseous bolts to be shot into space for great distances. This gaseous solar material cooled down and assumed the shape of a number of solid particles called Planetesimals. These Planetesimals rotated around the Sun in highly elliptical orbits. They intersected and collided with each other. This led to the merger of several large Planetesimals, giving birth to planets.

The main drawbacks are the failures in explaining the mechanism of coalescence of Planetesimals into large plants and how a passing can such a large angular momentum as is seen in the solar family.

Modern Theories:

The modern Laplacian theory:

The solar nebular theory and the modern Laplacian theories are derived from original Laplacian theory that was put forward by the French mathematician Pierre-Simon Laplace in 1796. The modern Laplacian theory was given by Prentice in 1974 by following the suggestions of Reddish and Wickramasinghe (1969). In the theory it was assumed that the Sun formed from grains of solid molecular hydrogen settling within a dense cool cloud to which they were strongly coupled. The gravitational energy of the collapse vaporized the solid hydrogen grains so that by the time the cloud radius reached 104 solar masses with a dense core formed by faster falling CNO grains. By the time the radius of the cloud equaled that of Neptune's orbit, the boundary material was in free orbit. At this stage Prentice introduced turbulent stress. Supersonic turbulence within the cloud gave density variations and less dense regions were propelled outwards from the surface by buoyancy effects in the form of needle-like elements. Motion outwards would have been fast but inward motion slower, giving a higher density in the surface region (figure 9). Prentice showed that instability would occur from time to time at the cloud equator so that material would be lost in the equatorial plane in the form of rings, much as Laplace postulated. All the rings had a similar mass, about 103 M, with temperatures falling off with increasing ring radius. Prentice postulated that the several rings within the orbit of Mercury were vaporized, for a terrestrial ring there would have been silicate and metal grains with total mass 4M and in major planet regions there would have been additional ice grains giving a total ring mass of 11–13 M. Prentice presented an analysis in which solid material fell towards the axis of each ring and then came together to form a single planet or planetary core. In the major planet region the cores were sufficiently massive to accrete gas. While this gas contracted, a smaller scale version of the process, including supersonic turbulence, was taken to produce planetary systems. This theory is by far the most complex of the current theories but despite its attention to the fine details of the system it does have severe drawbacks. The several rings within Mercury would have had an angular momentum several hundred times that of the Sun so they would not fall into the Sun. It can be shown that the rings would not have been stable and have had lifetimes much shorter than the time required for material within them to aggregate. The process by which material falls towards a ring axis is based on rather dubious mechanics requiring quite large solid bodies to be strongly coupled to a very diffuse gas. Finally, the system produced by this model would be highly coplanar and could not explain the tilt of the solar spin axis.

Origin and evolution of continents:
Continental growth began soon after the formation of Earth and most of its hydrosphere. Perhaps it was only when decay processes became less effective that the continents could maintain integrity and a selectively depleted mantle could begin to develop. Analyses of the approximately 4 billion-year-old Acasta Gneiss suggest that the first continents developed before the Archean. The Archean, however, is the period during which the present continents took shape. Most present continents have shields at their cores that formed between 3 to 2.5 billion years ago during the early Archean. Evidence of ancient oceanic crust is often found in today's greenstone belts. Continental crust gradually grew from selective melting of dark-colored basaltic igneous rocks within the oceanic crust. Through time, these melts became increasingly rich in silica, as geologic processes melted more of the lower-temperature, lower density minerals. These silica-rich melts rose from deep within Earth and formed granitic plutons (intrusive bodies) nearer the surface. Early in the Archean the granitic crust of continents had begun to form from basaltic crust of the ocean floor. Continental landmasses began forming about 3.7 billion years ago from the horizontal accretion of smaller micro-continents. The Kenoran orogeny was one such event, which formed what is now the Great Lakes region of North America during the Late Archean.
The characteristic features of continents are shield areas, stable platforms, and folded mountain belts. With the theory of plate tectonics we can now relate these features to each other and describe them as different phases in the evolution of continents.

Role of physics, chemistry and paleobiology in the development of ideas about the earth:

Much before geology became a separate scientific discipline, naturalists, thinkers, philosophers and physicists were curious to gather the knowledge through observations, understanding and logic about the planet earth. For example Pythagoras (582–507 BC) and his followers were apparently the first to speculate that the Earth was a sphere. This idea was further propounded by the influential philosopher Aristotle (384–322 BC) and this speculation holds true even today although with little modifications. Similarly the first scientifically estimated size of the earth was made by Eratosthenes (275–195BC), which only deviates by 15% from the actual size of the earth. Similarly, many speculations were made in geology by ancient philosophers.

However, with the developments in the field of physics, more accurate and scientific estimates could be made by physicists regarding the various aspects about the earth system. For the origin of the sun and the planetary system from a hot gaseous nebula it is necessary that the system abides by the laws of physics particularly the distribution of angular momentum between the sun and the planets and the laws of planetary motion. Most of the hypothesis proposed from very ancient times for the origin of the solar system however, failed as they could not satisfy the laws of physics and at present only those hypotheses are considered which at least satisfy most of the physical laws.

Besides, the origin of the earth, the laws of physics plays an important role in understanding the various geological phenomena. The cooling history and the mechanical layering of the earth occur according to the laws of physics. The origin and emplacement of magma is also governed by the physical laws.

The theory of plate tectonics is an outcome of the concept of continental drift theory of Alfred Wagner and the concept of sea floor spreading given by Harry Hess. However the theory of plate tectonics received authenticity only after the geophysical survey of the sea floor revealed magnetic stripping. The study of physics of seismic waves in the earth is called earthquake seismology is again based on the principles of physics.

The energy and matter are the two important quantities physics deal with are also the subject of study in exogenic processes, the weathering, transportation and deposition take place at specific energies for a particular material and hence are governed by laws fluid physics.

Metamorphism of the rocks is reactions that take place due to pressure, temperature and fluid action. The pressure and temperature are the physical variables that determine the extent of metamorphism in the rocks.

The law of uniformitarianism, law of original horizontality and the law of lateral continuity have been laid down using the knowledge time, energy and space which are the basic concepts of physics.

The role of chemistry has been instrumental in establishing the principles of geology. Chemical studies of geological materials have helped to understand the positions of the continents in the geological past and have supported the theories of the earth system like continental drift, sea floor spreading and the plate tectonics. Through chemical analysis of the rocks, minerals and meteorites earth scientist have been able to estimate the age of the earth and have reconstructed the events that took place in the last 4.6 billion years. The changing composition of the atmosphere and the hydrosphere could only be understood by applying the laws of chemistry. Earth scientists have been able to classify different types of rocks only by using the tools of chemical sciences. Chemistry of the geological materials is key to understand the past climatic conditions and the distribution of different life forms on the earth. The isotope geology has particularly revolutionized the entire earth system science.

Paleobiology is the study of past life on the earth and is also known as paleontology and can be studied through fossil remains presents in the sedimentary rocks of the earth. Fossils are the only practical means of telling time in geology. Though isotopic decay methods, such as potassium-argon or uranium/lead dating, work only in rocks that have cooled down from a very hot state, such as igneous or metamorphic rocks. Most of geological history is contained in sedimentary rocks, which cannot be dated by radioisotopes. Consequently, fossils are the only practical method of determining the age of rocks in most geological settings.

Fossils are the only direct record of the history of life. Although evolutionary biology has made enormous strides studying living organisms such as bacteria, and lab rats, these studies see evolution only in the thin slice of time known as the Recent. Fossils provide the only direct evidence of 3.5 billion years of the history of life, and in many cases, they suggest processes that might not be explainable by what is known from living organisms. Fossils provide a fourth dimension (time) to the biology of many living organisms. Many groups of organisms, such as conodonts and graptolites, are extinct and are known only from the fossil record.

Fossils can provide direct evidence of ancient environments. Although many sedimentary rocks deposited in different environments look very similar, the fossils and trace fossils found within them are often their most diagnostic feature. They can be used to pinpoint the depositional environment more precisely than any other property of the sedimentary rock.

Fossils can be critical to determining ancient continental positions and connections. Some of the earliest evidence for continental drift came from the similarities of fossils on different continents, and paleontological evidence is critical to any understanding of biogeography.

The principle of stratigraphy like order of superposition and law of floral and faunal succession, have been established on the basis of fossil content of the sedimentary rocks.

Role of physics in crystallography:

The discovery that crystals will diffract x-rays came from one of the prominent laboratories of physics in Europe. The measurements were prompted by a discussion with Peter Paul Ewald, a physicist who went on to develop many key crystallographic principles and was instrumental in the organization of the worldwide crystallographic community through the formation of the International Union of Crystallography and the ActaCrystallographica journal. The scientific discipline of x-ray crystallography emerged within a year or two of Laue's discovery through Lawrence Bragg's early developments of the theory to relate x-ray diffraction to crystal structure and William Bragg's rapid improvements to x-ray instrumentation for crystallographic studies. Developments of the crystallographic method were very fast after 1912 and it is remarkable how quickly the essential theories of x-ray crystallography became established largely through the work of physicists. In a series of papers Charles Galton Darwin, Arthur Compton and others developed formulae for quantitative calculation of x-ray intensities in terms of electromagnetic theory and incorporating effects of crystal mosaicity. Douglas Hartree calculated the atomic form factors and Peter Debye calculated the effect of thermal motion further developed by Ivar Waller to give the Debye–Waller factor. Crystal structure solution methods using diffraction data quickly increased in sophistication : the Braggs developed methods of Fourier analysis in one and two dimensions (e.g. Lawrence Bragg's work on diopside); Arthur Patterson extended this to three dimensions in the 1930s; so-called 'direct methods' followed in the years after the Second World War (for which mathematician Herbert Hauptman and chemist Jerome Karle received the Nobel Prize in Chemistry in 1985); and these contributed towards the developments of multi-wavelength anomalous diffraction (MAD) and single-wavelength anomalous diffraction (SAD) techniques that are routinely used to determine protein structures from x-ray diffraction today. Most developments in instrumentation and sources that led to improvements in the crystallographic technique were initiated by physicists. William Bragg's two circle diffractometer design with an ionization chamber detector was a significant improvement on the photographic film methods of Laue, Paul Friedrich and Walter Knipping as it allowed the separation of Bragg reflections arising from different x-ray wavelengths and the measurement of absolute Bragg peak intensities. The downside of this approach was that it took a long time to collect significant quantities of data. Photographic methods were therefore still used to survey the scattering in reciprocal space using methods that separated the Bragg reflections in a convenient manner. These advanced rotating crystal methods were exemplified by the Weissenberg and precession cameras where the photographic film was also moved in tune with the crystal rotation the latter providing an undistorted picture of the reciprocal lattice and could be used to determine the crystal unit cell, index the Bragg reflections and identify the crystal symmetry. Photometric measurements of the Bragg spots could be used to estimate intensities, although this was never as precise as the intensities obtained when using x-ray detectors. Most modern single crystal diffractometers are based on a combination of William Bragg's spectrometer and the photographic film techniques developed after the First World War, albeit with vastly improved detectors, monochromatic x-ray sources, optics and mechanics. In powder diffraction all early x-ray diffractometers were developed by physicists, beginning with the Debye–Scherrer camera in 1916 (and another similar design by Albert Hull a year later) for samples loaded into glass capillaries and later improved by André Guinier through monochromatizing and focussing the incident x-ray beam to produce the Guinier camera. Optimization of the geometry for powder diffraction with divergent beams and flat plate samples was achieved by Johannes Brentano, in collaboration with Lawrence Bragg. Electron diffraction was demonstrated in the 1920s by physicists George Thomson, Clinton Davisson and Lester Germer; Thomson and Davisson went on to receive the Nobel Prize in Physics in 1937 for the discovery of the diffraction of electrons by crystals. Neutron diffraction was initiated by physicists Ernest Wollan and Clifford Shull while working at Oak Ridge National Laboratory; the latter received the Nobel Prize in Physics in 1994 with Bertram Brockhouse for the development of the neutron scattering technique, 10 years after the death of Wollan and nearly 50 years after their pioneering work. Their experiments were instrumental in showing how neutron diffraction can be used to locate hydrogen atoms in crystal structures and to determine the magnetic structure of materials. It is a similar story with x-ray and neutron sources; developments of x-ray tubes, synchrotrons and neutron-producing reactors and spallation sources all relied on substantial input from physicists. Physicist Wilhelm Rontgen discovered x-rays using Crookes-Hittorf vacuum tubes and these were used by early x-ray crystallographers until the development of tubes with hot-filament cathodes and better vacuums. The theory behind synchrotron radiation was developed by Alfred-Marie Liénard and Emil Wiechart at the turn of the 20th century, before being observed experimentally by physicists and engineers in the 1940s. This 'nuisance' radiation was later harnessed for x-ray crystallography and other x-ray scattering experiments leading to modern x-ray synchrotron facilities of which there are over 40 worldwide. Physicist John Madey developed the free electron laser (FEL) in the 1970s, a forerunner of x-ray FELs, the first of which became operational in Stanford, California in 2009. These XFELs now produce extremely intense beams with wavelengths suitable for crystallography applications.

Role of physics in gravity:

From the earliest times, gravity meant the tendency of most bodies to fall to earth. In contrast, things that leaped upwards, like flames of fire, were said to have “levity”. Aristotle was the first writer to attempt a quantitative description of falling motion: he wrote that an object fell at a constant speed, attained shortly after being released and heavier things fell faster in proportion to their mass. Of course this is nonsense, but in his defense, falling motion is pretty fast—it’s hard to see the speed variation when you drop something to the ground. Aristotle most likely observed the slower motion of things falling through water, where buoyancy and fluid resistance dominate, and assumed that to be a slowed down version of falling through air which it isn’t. Galileo was the first to get it right. (True, others had improved on Aristotle, but Galileo was the first to get the big picture.) He realized that a falling body picked up speed at a constant rate in other words; it had constant acceleration (as he termed it, the word means “addition of speed” in Italian). He also made the crucial observation that, if air resistance and buoyancy can be neglected, all bodies fall with the same acceleration, bodies of different weights dropped together reach the ground at the same time. This was a revolutionary idea as was his assertion that it should be checked by experiment rather than by the traditional method of trying to decipher what ancient authorities might have meant.

Role of physics in isostasy:

This concept of isostasy is evolved to explain how different topographic heights can exist at Earth's surface.. The phenomenon of isostasy concerns the response of the outer shell of the Earth to the imposition and removal of large loads. This layer, although relatively strong, is unable to support the large stresses generated by, for example, the positive weight of a mountain range or the relative lack of weight of an ocean basin. For such features to exist on the Earth’s surface, some form of compensating mechanism is required to avoid the large stresses that would otherwise be generated. The compensation that is achieved due to overload and stress on the surface of the earth is called isostasy

Role of physics in seismology:

Seismology is the scientific study of the seismic waves generated by earthquakes. As the seismic waves travel through the earth and on its surfaces; various laws of physics govern their propagation. The travel path and the velocity of these waves are dependent not only on the nature and amount of energy released during an earthquake event but also on the properties of the earth materials through which these waves travel. The theory of elastic wave propagation in solid materials was developed by Cauchy, Poisson, Stokes, Rayleigh, and others. They describe primary and secondary body waves (P- and S-waves) and surface waves. As the body waves travel through the interior of the earth, they strictly follow the laws of reflection and refraction when come in contact with different boundaries (discontinuities) of the earth. When the seismic waves are refracted and reflected at different interfaces in the earth they travel back to the seismographs, the instrument that works on the laws of physics and records seismic waves. The travel time and velocity of these waves is used to locate an earthquake and to understand the physical state and chemical nature of the interior of the earth.

Physics has been widely used to understand the mechanism of earthquakes, for example the location of epicenter, the fault plane solution, the earthquake stress field and the double-couple mechanism, rupture dimensions and displacements, Severity of an earthquake, deducing tectonic processes etc. can be understood only by understanding the behavior of seismic waves (travel paths and velocity) in the earth's interior.

Role of physics in microscopy:

Microcopy is an elementary and cost effective method in understanding different properties of minerals and rocks. Microscope is an optical instrument that is made of different types of lenses and magnifying glasses. In microscopy we make use of the physics of light as it travels through a medium (the minerals being studied). Though light has both a wave and a particle nature, in optical mineralogy we use the wave nature of light to describe the behavior of light through minerals. Light waves are a form of electromagnetic energy which subjected to reflection, refraction, diffraction, dispersion, interference, polarization, and other such processes. Using these processes we observe minerals under microscope and get useful information regarding the mineral which helps in its identification. The laws of refraction, absorption, reflection and transmission are very useful in mineral microscopy.

Role of chemistry chemical bonding:

Chemical bonding is the process by which atoms combine to form compounds. There are five types of chemical bond, of which the ionic bond and the covalent bond are, probably, of most interest to geologists and mineralogists.

The ionic bond:

An ionic bond is created when electrons pass between atoms creating cations (positively charged ions) and anions (negatively charged ions). Ions of opposite charge attract each other. The attracting force is equal in all directions and increases as the distance between the ions decreases. The ions therefore tend to pack together into a lattice whose shape is determined by the sizes, and therefore packing, of the ions involved.

The lattice unit cell determines a material's properties. The shape and dimensions of the unit cell determine the crystal system. The more closely the ions can pack, the greater is the bonding force and the greater is the hardness of the mineral. Some lattice arrangements have weak internal links that result in easy cleavage in one particular plane. A well-known example is the Mica family. In practice minerals are seldom formed by 100% ionic bond. They are usually part ionic/part covalent.

The covalent bond:

A covalent bond is created when two atoms share outer shell electrons so that the electrons orbit around both atoms giving each a full complement of electrons in its outer shell. In a covalent bond no electrons are given up or acquired so no ions are formed. A covalent bond is therefore possible between two atoms of the same type and is the means by which molecules are formed.

The metallic bond:

The outer electrons of metals are only loosely attracted to the nucleus and are therefore easily detached. The resulting metal cations tend to cluster together with the detached electrons surrounding the cations as an anionic cloud. This electron cloud is the source of the electric current that flows in a metal connected between the terminals of a battery. It is the reason why metals are such good electrical conductors.

The Van der Waal bond:

This is a weak force that binds the noble gases and some elements such as Sulphur and Graphite. It is associated with a low melting temperature.

Hydrogen bond:

Polar molecules, such as water molecules, have a weak, partial negative charge at one region of the molecule (the oxygen atom in water) and a partial positive charge elsewhere (the hydrogen atoms in water).Thus when water molecules are close together, their positive and negative regions are attracted to the oppositely-charged regions of nearby molecules and this force of attraction is called hydrogen bond.

Role of chemistry in crystal chemistry:

The character of chemical bonding is determined primarily by the electronic configurations and electronegativity values of the combining elements, whereas the crystal structure (which controls the shape and system of the crystal) is a function of the plane lattice and the coordination number(s) (C.N.).

Coordination Number:

Coordination number is the number of nearest neighbors in a crystal structure. It depends on the radius ratio and type of hybridization in covalent crystals and the radius ratio in ionic crystals. The coordination number is strongly controlled by the radius ratio; however the radius of an ion may change as a function of coordination number. Other factors influencing the size of an ion are its charge, the atomic number of its element, and the "shielding" effect of some electrons, especially those of the penultimate shell. Of particular interest is the "lanthanide contraction". Coordination numbers are usually 2, 3, 4, 6, 8, or 12. But the coordination numbers of 5, 7, 9, 10, or 11 can occur in some cases.

Some Examples of C.N. are

Sphalerite: ZnS

Zn: S = 4: 4

Fluorite: CaF2

Ca: F = 8: 4

Structure Controls for crystals with metallic bonding:

Bonding takes place between electropositive elements of similar electronegativities having similar radii and the radius ratio (r_A/r_B) ≅ 1. Three types of packing take place in compounds with metallic bonding which are;

Hexagonal close packing "HCP": with C.N. = 12.

Cubic close packing "CCP": with C.N. = 12.

Body centered cubic packing with C.N. = 8.

Structure controls for crystals with covalent bonding:

Hybridization of the orbitals forces this type of bonding to have a strong directional character. Because of hybridization, the covalent radius of an element will be different from its ionic or metallic radii. The structure of the mineral will be controlled by (i) the covalent radii of the elements; (ii) the type of hybridization.

Structure controls for crystals with ionic bonding:

The structure of the crystal with ionic bonding is chiefly controlled by the Pauling's Rules for ionic compounds.

Role of chemistry in solution chemistry:

Solution is a homogenous mixture of two or more substances in relative amounts that can be varied continuously up to what is called the limit of solubility. If one of the substances is present in much greater quantities than all the other substances then it is called the solvent. The other substances in solution are known as solutes. The term solution is commonly applied to the liquid state of matter, but solutions of gases and solids are possible. The components of a system are the chemical constituents needed to make the phases in it. The thermodynamic models developed till now only apply to systems of pure minerals and their corresponding liquids created by melting. In such systems of constant chemical composition, equilibrium states and directions of change in state are governed solely by P and T. However, a pure phase in any form in geologic systems is very rare. The state and nature of solutions is governed by the laws and principles of thermodynamics and chemistry. Chemistry tells us at what temperature and pressure which of the chemical species of the solution will change state and which will remain in solution. It also tells us how and at what rates the reaction will occur in the solution at a specific pressure and temperature. It also lets us know the type of reactions that will take place in the solution.

Role of chemistry in chemical energetics:

Chemistry is sole important in understanding the chemical energetics of geological systems. Chemical energetics is the study of chemical changes caused by energy. Chemical energetics takes into account both thermodynamics and kinetics or reactions. Thermodynamics discusses changes based on amounts of energy. Since energy is conserved, energy transferred into a system is called internal energy. The amount of energy in a reaction remains the same regardless whether the reaction (or change) takes place in one or several steps. This principle is illustrated by the Hess's law, the application of which gives the estimate of energy in a process. Measurements of energy are called calorimetry, and they can be measured under constant volume or constant pressure. A system tends to minimize its Gibb's free energy, G, and such a tendency leads to the concept of chemical equilibria.

Chemical Kinetics is the study of the rate of reactions. A good example to illustrate the two factors is the existence of diamond and graphite. At room temperature and pressure, thermodynamics indicates that the stable form of carbon is graphite. From a thermodynamic point of view, diamond should convert to graphite. But the reaction rate (kinetics) is so slow that there is no detectable change. The temperature dependence associated with chemical kinetics is discussed in terms of activation energy, which is often perceived as the energy barrier that has to be overcome in order for a reaction to proceed. However, kinetics of chemical reaction also deals with rate laws, elementary steps, and mechanism of reactions.
