THE STORY OF CREATION
THE STRUCTURE OF ATOM

It is not all true that the scientist goes after the truth, it goes after him.
(Soren Kierkegaard)

4.01. INTRODUCTION

Humans are always enthusiastic to go over unknowns. The great Nature does not appear shy to unfold its marvels. Among its numerous wonders, it shows a very unique property in some inert matter, called **radio-activity**.

The radio-active elements spontaneously decay into other elements. It is a surprise that inert things can change on its own without any external influence, as a natural system. In the process, alpha (α) and beta (β) particles, and gamma (γ) rays emerge from that. The alpha particle was identified by Rutherford and beta by Becquerel. Gamma rays discovered by the French scientist **Paul Ulrich Villard** (1860-1934) in 1900, was found similar to Roentgen ray.
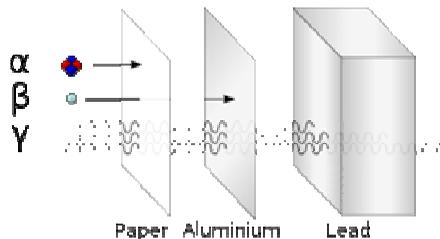

Fig:4.01. illustration of the relative abilities of three different types of ionizing radiation to penetrate solid matter. Alpha particles (α) are stopped by a sheet of paper while beta particles (β) are stopped by an aluminium plate. Gamma radiation (γ) is dampened when it penetrates matter.

The discovery of radio-activity and X-ray, at the end of 19th century, were two major significant events that led to probe deep into the heart of matter, to find out the ultimate smallest thing of

Nature. We come to know about atoms, about fundamentals of our micro-world. Without knowledge of the microworld, we cannot enquire about the macroworld or Creation of the World. Cathode ray started the drama of series of incidents. What is Cathode ray?

4.02. CATHODE RAY & X-RAY

Michael Faraday unsuccessfully tried to discharge electricity through vacuum. The German mechanic and glass blower, **Johann Heinrich Wilhelm Geissler** of Bonn, could do it in 1854. He made a vacuum pump within a glass tube fitted with metal electrodes, called *Geissler tube*. When electricity was passed through it, a green glow could be seen in the tube.

Five years later, **Julius Plucker** (1801-1868), also of Bonn, studying conduction of electricity in gases, discharged high voltage electricity in a Geissler tube and found the gas glowing. Conductivity of gas when charged, depends on concentration and degree of emptiness of gas in the tube. Further evacuation of the tube caused a dark space near negative cathode, slowly spreading in the whole tube. Then a ray could be observed. A student of Plucker, **Johann Wilhelm Hittorf** (1824-1914) found (1869) that the glowing rays emitted by cathode, followed rectilinear path and was deflected by magnetic field. Another student, **Eugen Goldstein** (1850-1931), called it *Cathode Ray*. This happened around 1876. What kind of thing this ray would be – some kind of electromagnetic radiation or stream of particles?

William Crookes (1832-1919) and Michael Faraday, investigated properties of radiant matter of the tube. It travelled in a straight line, caused glowing, deflected by electric and magnetic field, and could penetrate solid body. Next year, an electrical engineer, **Cromwell Fleetwood Varley** (1828-1883) found them negatively charged. At last in 1895, **Jean Perrin** (1872-1942) in Paris, proved conclusively that the cathode rays are charged negative.

When **Wilhelm Conrad Roentgen** (1845-1923) was working with the cathode ray tube in 1895 in the university of Wurzburg, Germany, he was running fifty. It so happened that once he left inadvertently some unexposed photo-plates, tightly wrapped near the cathode

ray tube. Later papers were found fogged. The incidence happened on 8th November. The glow was observed on the piece of paper covered with fluorescent barium salt. The paper was far away from the tube which was also covered with opaque cardboard casing. Still the invisible ray reached the paper, penetrating everything on its way. It could pass even through a steel door. He named the mysterious ray, *X-ray.* It originated from the point on the anode struck by the cathode ray. When it was allowed to pass through the human body, it left an image of bones. This enabled us to observe inside our body. On 23rd December, fluorography was born when the picture of Mrs. Roentgen's left hand was taken.

Fig:4.02. *Hand mit Ringen* (Hand with Rings): print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Professor Ludwig Zehnderof the Physik Institut, University of Freiburg, on 1 January 1896

On 28th December, Roentgen wrote the paper entitled "*Uber eine Art von Strahlem - Vorlaufige Mitheilung*" (On a new kind of rays - Preliminary Communication) which was published in a journal from Wurzburg. It was suggested that the new rays are electro-magnetic radiation like light. This was later confirmed by Laue who found it having shorter wavelength (5×10^{-9} to 6×10^{-10} m).

Roentgen was awarded the first Nobel Prize in Physics in he year 1901. Unfortunately his death too came because of that ray.

4.03. RADIOACTIVITY

The French mathematician, **Henry Poincare** (1854-1912), expressed around 1896 AD that X-rays are not unique to Crooke's tube. It might be emitted by all fluorescent things.

Fluorescence is a kind of visible radiation given off by some matter when exposed to ultraviolet rays. These things were dealt in the family business of **Antoine Henry Becquerel** (1852-1908). After the discovery of X-ray, Becquerel thought that the invisible X-ray might

be somehow related to fluorescence and decided to study its emanations. He thought it X-rays but came across to discover something else. Interestingly, Becquerel born in Paris, studied mathematics and civil engineering at Ecole des Chaussees. After receiving Doctorate (1888) from Paris, he became professor at Musee d'Histoire Naturelle from 1891. From 1894, he worked as chief engineer at Ponts et Chaussees.

On 26th February 1896, a cloudy weather hang over Paris. It so happened that budding scientist made himself ready for some experiment but, as the cloud covered the sun, it had to be postponed. He left in the drawer photographic plates wrapped in black paper with a metal cut-out pattern on top and then a pinch of uranium salt on it. It was expected that the sun would excite the salt and leave impressions on the plate. After four day's of waiting in vain, he decided to develop the plate, possibly to prove that without sun, there would be little or no effect. To his surprise, the plates were found all deeply affected with the clear image of the cut-out. It was not due to fluorescence or sunlight but presence of uranium in the salt. This proved that uranium emits some ray other than X-ray. It was named *uranique ray*. Two years later, Becquerel found that radiation coming out from radioactive materials was made of electrons. Later it was called beta radiation. Unfortunately the discovery was not immediately appreciated in scientific circle. Disheartened, the young scientist lost all interest on the subject. When Curies too discovered the same puzzling radiation, Becquerel's work was acknowledged. He was honoured by the Nobel Prize (1903) alongwith Curies.

While the Polish researcher **Marie Sklodowaska** (1867-1934) and her French husband **Pierre Curie** (1859-1906) were working in Sorbornne of Paris, they also observed the fascinating phenomenon of Becquerel. They called it **radioactivity**. For Marie Curie, science was a way of life, not a means or an end in itself. She fought against poverty and odds with courage. She was born in Warsaw, Poland and came to Paris in 1891 to study physics. After her graduation in physics and mathematics, she married Pierre Curie, the laboratory chief in the School of Industrial Physics and Chemistry, in 1895 and began to work in her husband's

laboratory. Her study was about the new phenomena discovered by Becquerel.

Like Uranium, the element thorium also emitted radiation, as discovered by **G. C. Schmidt** (1865-1949). In the paper submitted to Academie des Sciences on 12th April 1898, Marie noted that thorium radiated that rays, more actively. Therefore uranium cannot be the only element having the property. How many elements in Nature might have such unusual quality? They began to explore the possibility with the radioactive mineral, pitchblende (uranium oxide), four times active than uranium. Pitchblende appeared to contain more radioactive elements. In July 1898, they announced the discovery of a new element, *polonium*. It was named in memory of her mother country Poland.

In December, she isolated another new element, *radium*. By 1903, they extracted few grams of radium chloride from tons of pitchblende. The isolate was highly radioactive. It ionised the air and made it hot, decomposed water, and glowed in the dark. She suggested that the new property would be atomic in nature. Their effort to isolate radium took long twelve years of painful research. Radium was 900 times more active than uranium. It was found useful to kill cancer cells.

In November 1903, the couple came to know that they were to share the Nobel Prize in physics with Becquerel for work on radioactivity. Madam Curie established Radium Institute in Paris. Pierre Curie unfortunately died in 1906 in a road accident. In 1911, Madame Curie was honoured with the second Nobel Prize in chemistry, this time for discovery of radio-active elements, radium and polonium, the first person to get the honour twice. She died of leukaemia due to prolonged effect of radiation.

4.04. ELECTRON

The mystery of cathode ray, raised by works of Faraday, Plucker and Crookes, could only be explained in 1897, by a Fellow of Trinity College, **Joseph John Thompson** (1856-1940), popularly referred to as JJ. When an electric discharge was sent through rarefied gas in vacuum tube, a stream of cathode rays was emitted from the surface of the cathode and moved in straight line towards anode. Thompson, the son of a bookseller, wanted to

study engineering. Untimely death of his father forced him to be in the stream of general science. He was a good scholar and rose to become Fellow of Trinity College, Cavendish Professor and Master of Trinity.
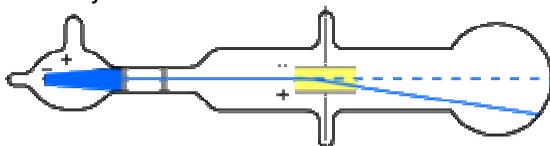

Fig:4.03. The cathode ray (blue line) was deflected by the electric field (yellow).

From the study of deflection of cathode rays in electric and magnetic field, Thompson showed that the ray was a flow of negatively charged particles. He determined the ratio of charge (e) and mass (m) of the particle. Its mass appeared to be 0.001 times to that of hydrogen and charge equal to hydrogen ion. It was a new particle of an atom, named **electrons.** Thompson declared his results on 30th April, 1897, in a lecture at Royal Institution. In August, he submitted papers on corpuscular properties of cathode rays to the *Philosophical Magazine*.

Thus the tiny electron became the first atomic particle after forty years of intense research. It makes an atom which is no longer the ultimate entity of matter. Dalton's atom is no more the indivisible ultimate one but a structured product. Speed of this new particle electron is 10% to that of light, mass 9.109554×10^{-24} gm and charge 4.80325×10^{-10} esu. Its charge was measured by the American physicist, Robert Millikan. The particle proved to be the cause of many chemical properties and reactions. Thompson was awarded the Nobel Prize in physics (1906).

One very important property of X-ray is its ability to electrify air. The phenomena is known as *ionisation*. In the process, X-ray split the air into equal numbers of charged particles, ions. Thomson and Rutherford studied this in 1896. The negatively charged ions were identified as electrons. But what about those positively charged ions?

4.05. PLANCK'S THEORY

Hot body radiates heat at certain rate. Bodies also reflect or absorb radiation. A perfect reflector or white body, would reflect in all wavelengths and would absorb none while a perfect absorber, a

blackbody, would absorb in all wavelengths and reflect none. Thus a white body would not emit any radiation but a blackbody would do it and emission would be quite different from absorption. What happens inside the blackbody? Radiation striking the blackbody would completely disappear inside and increase the temperature of the body. It would then emit or radiate energy but the radiated energy would be a mixture of continuum of wavelengths with total energy equal to the incident beam.

If we consider a hollow sphere with a hole on it, any radiation trapped inside the sphere, would bounce off and off around the walls until absorbed. The sphere would then behave like a blackbody. It is quite unlikely that the trapped radiation would come out from the hole. Usually black surfaces are both good absorbers and radiators of heat than polished surfaces. This we know from our experience. Around 1859-60 AD, Kirchoff deduced the law of blackbody radiation from thermodynamic considerations.

Experimentalists analysed blackbody radiation when it spreads out in spectrum into various wavelengths from infrared (of very long wavelength) to ultraviolet (of very short wavelength) and then measured the intensity in each wavelength. Plotted on wavelengths on horizontal and intensity on vertical axis, a continuous curve was obtained. It is called Planck radiation curve. At very long wavelengths, the curve was close to wavelength axis and would rise slowly to maximum for a given colour. It would then turn around and drop very sharply to zero in the ultraviolet region. Total energy emitted per second in all wavelengths would be given by the area under the plotted curve. As the temperature rises, the curve get shifted upwards.

In 1879, the Austrian physicist **Joseph Stephan** (1835-1893), observed that heat loss by very hot bodies is faster than Newton's law of cooling. He established a relation that the radiation is proportional to the fourth power of absolute temperature. Five years later his ex-student Boltzmann deduced the same relation from classical thermodynamics and showed that quality of radiation was like radiation from a perfectly blackbody and would depend on temperature. The law is known as *Stephan-Boltzmann law*. It was further observed that as the body becomes hotter, the peak shifts towards shorter wavelengths (or higher frequencies) from infrared to red, to blue and then to ultra-violet.
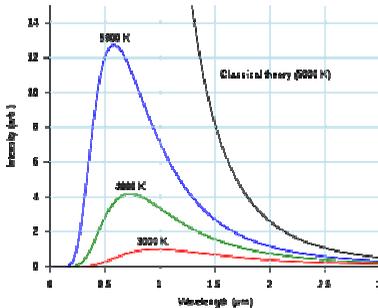
Fig:4.04. As the temperature decreases, the peak of the blackbody radiation curve moves to lower intensities and longer wavelengths. The blackbody radiation graph is also compared with the classical model of Rayleigh and Jeans.

Classical statistical mechanics and electromagnetism, could not explain properly such phenomena. **John William Strutt Lord Rayleigh** (1842-1919) and **James Jeans** deduced a formula that gave incorrect results for high frequency end of blackbody radiation spectrum though it delivered good results for low frequency range. **Wilhem Wien** (1864-1928), on the other hand deduced a formula in 1896 that worked well at high frequency end of the spectrum but gave wrong results for low frequency range.

The German physicist **Max Karl Earnst Ludwig Planck** (1858-1947) was working on the subject since 1895. Born in Kiel, Germany, he graduated from Maximilian Gymnasium, Munich and attended Munich and Berlin universities. With his Ph.D. in 1879, he joined Kiel University as associate professor (1885) and switched to Berlin four years later. For six years, he was studying emission of light in a different way. Let the light be given off by 'oscillators' whose oscillations produce light waves in the same way plucked strings produce sound waves. Total energy of oscillators could have only finite values. The oscillators are unable to vibrate at any energy level in order to fit in experimental results in theoretical model. After some day's of uncertainty, he decided as "an act of desperation" that oscillators could only have certain discrete energies. Due to this, it could produce light in specified frequencies.

On 19th October 1900, Planck submitted a new formula of blackbody radiation to the *Berliner Physikalische Gesellscahft*. The experimentalist **Heinrich Rubens** checked the prediction derived from this. To his surprise, it agreed perfectly well to the tiniest detail. Planck worked out the formula after two year's of puzzle

from a non-classical approach. It was finally obtained by applying Boltzmann's statistical concepts. Two months later (on 14th December), he presented before the German Physical Society his paper '*On the Theory of the Energy Distribution Law of the Normal Spectrum*'.

The whole idea was based on 'quantization of action'. The vibrating atoms would absorb or emit radiant energy only in discrete bundles, called *quanta*, described by expression,

$$E = \hbar\nu$$ (where ν = frequency and '$\hbar$' = Planck's constant).

Radiation can be absorbed by whole numbers of quanta and each quantum (E), has certain amount of energy. Higher the frequency of the wave (i.e. shorter the wavelength), greater is the energy. At very high frequency, radiation of single quantum needs more energy. This would make radiation at high frequency reduced. At very low frequency, very many low-energy quanta are given off. Hot body would thus eventually lose energy at a finite rate. At the dawn of 20th century, this idea of quanta marked the end of classical physics and the beginning of a new era. Its true implications could be understood a few years later.

Unit of Planck's constant ($\hbar$) is in erg-sec which mean action. All actions appear an integral multiple of elementary quantum of action. Quantization soon became a basic law of Nature.

Interestingly, Planck himself was a classicist though he began quantum revolution. He did it against his will as his effort to avoid it, ultimately failed. "We have to live with it" if that be the hard truth of Nature, he thought. Planck was honoured with the Nobel Award in physics (1919).

4.06. ATOMIC STRUCTURE

When Max Planck began his enquiry, **Earnest Rutherford** (1871-1937) was working in the field at his home. He was born at

Brightwater, near Nelson, on the north coast of South Island and educated at Christchurch in New Zealand. He came to study in England as a research assistant to J.J. His career began at Cavendish Laboratory, Cambridge, in 1895.

Rutherford worked with X-rays (1896). He showed in a paper (1898) that the Becquerel emission consisted of, at least, two different rays. A samples of uranium was covered with

sheets of aluminium foil absorbing radiation. As the thickness of foil was increased, less and less radiation was penetrated through the foil. This was expected. After a while the radiation appeared to maintain its intensity undiminished even when he increased the thickness. On addition of more foil, radiation began to diminish slowly and finally became completely absorbed. So he concluded that there must be two types of radiation. One that was less penetrating, was called alpha ray and the more intensive one beta ray. When thorium was taken instead of uranium, the result was the same. Two years later, he found a more penetrating radiation, gamma ray.

In 1898 AD, Rutherford joined McGill university in Montreal, Canada, where he found that thorium compounds emanated some unknown radio-active gas. Pierre and Marie also observed similar emanation from radium. Two years later, **Frederick Soddy** (1877-1956), a talented British chemist from Oxford, joined him at Montreal. Two together proved that emanation from radium was an inert gas, now known as *radon*. Soddy further showed that thorium produced another substance, thorium-X, chemically different from thorium. It turned out to be radium. Thus thorium transformed into radium which transformed into an inert gas, radon. At each stage of transformation, matter scattered some radiation.

Within two years (1902), it became clear that radio-activity is nothing but decomposition of atom into charged particles and transformation of one atom into atom of another element chemically different. This is known as *hypothesis of radio-active decay*. In physical Nature, matters are not thus immutable. At least, radio-active elements succumb to change spontaneously into other elements. At last, our long cherished alchemy was found to work in Nature, in its own way.

Frederick Soddy and William Ramsay made an experiment (1903) to show how one element (radium bromide) would turn into some other elements. The decay of radium transformed into radon and helium may be represented by : $^{226}Ra_{86} \rightarrow {}^{222}Rn_{86} + {}^{4}He_2$.

Rutherford showed (1903) that the α-rays deviated in strong fields and carried +ve charges. It appeared thousand time heavier than electron. Further the charge-mass ratio (e/m) for α-particles emitted by polonium and radium were same. Within two years, he

could definitely say that α-particles are charged at the moment of their expulsion from radium atom.

In 1907, Rutherford moved from Montreal to Manchester. He felt that positive particles detected earlier while working at Montreal, were ions of helium. Next year in a joint paper with **Hans Geiger** (1882-1945), he summarised nature of α-particles and proved that they are simply helium nuclei. It was proved by an experiment in 1909 conclusively by trapping alpha particles and then studying their spectral lines.

Rutherford was rewarded with Nobel Prize for Chemistry (1908) for his work on radio-activity and transmutation of element. A brilliant experimentalist of his calibre did not stop there. Next year, he was found working with radioactivity and structure of atoms at Manchester.
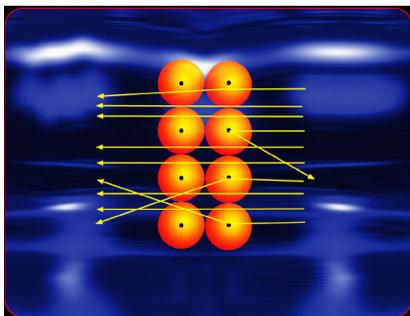

Fig:4.05.Deflection of α-particles

A beam of alpha particle from a radio-active source (radium C) was directed on a Zinc sulphide screen. When a gold foil was placed in its path, some particles were found deflected by about 2° degrees. Rutherford in a wild guess instructed his laboratory technician **Ernest Marsden** (1889-1970) to check if any particle was reflected back. To their surprise, they found some particles bounced back. For next two years, Geiger and Marsden counted over million scintillations to find 1 in 8,000 particles bouncing back. How alpha particles which hardly deflected in a strong electrical field, could be bounced back? As Rutherford put it, '... quite the most incredible event that that has ever happened to me in my life ... It was as though you had fired a 15-inch shell at a piece of tissue paper and it had bounced back and hit you'. Late in 1910, Rutherford came to understand the puzzle. Atoms must possess a very small but massive nucleus with all +ve charges within it to balance outer -ve charge of electrons. On 7th March, 1911, he presented this view in a report "*The*

Scattering of α and β particles by matter and the Structure of Atom". He proposed the structure of atom.

Some years ago, the ultimate minute particle, the building block of all matter was indestructible atom, as proposed by Dalton. Meanwhile Thompson broke up the atom and discovered one of its constituents, electron. Rutherford discovered the nucleus occurring inside the atom. The time was thus set to define atomic structure.

Fig:4.06.   Thomson's atomic model
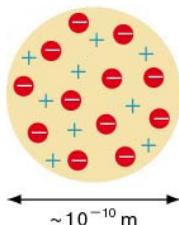
~10^{-10} m

First model of atom was proposed by Thompson in 1904. An atom is taken as a sphere about 10^{-10} m in diameter with uniformly distributed positive charge in it. Negatively charged electrons, about 10^{-13} cm across, are embedded within like plums in pudding or seeds in melon. It was just a guess.
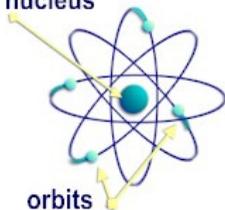

Fig:4.07. planetary model of atom.

After Rutherford's work, scientists began to think of atom in terms of our planetary system. An atom consists of two things – (1) nucleus behaving like the central sun and (2) electrons like orbiting planets. The **nucleus** was the positively charged atomic centre, minute in size but containing most of the mass. They are 10^{-15} to 10^{-14} m across. Electrons with -ve charges orbit around the nucleus. Most of the space between the nucleus and electron, is empty and that was the reason for alpha particles easily passing through atoms in straight line. An alpha particle is heavier than electron by 7000 times for which electrons can not deviate alpha particles. The atom has +ve charges in its centre for which +ve charged alpha particles are deviated when they come closer to nucleus. Out of millions alpha

particles, if one or two could hit the nucleus, it would return at 180° angle by direct repulsion.

Electrons carried -ve charges in an atom. What carried +ve charges in the nucleus? Alpha particles could penetrate atoms, but not the nucleus. Rutherford decided to fire alpha particles to hydrogen atoms. After collision with hydrogen, the particles came to halt nearly at the same range. But a few scintillation occurred beyond the range and travelled four times farther. The scintillation was caused by some positive charged particles. Rutherford called those new particles, *H-particles*. It was argued that they must be nuclei of hydrogen, knocked out by more energetic alpha particles.

Around 1914, Marsden observed that some alpha particles travelled for a long range in air. Were they same type of H-particles? Then came WWI. Scientists stopped doing science as they were to be engaged in war – the most effective art of human killing by human being.

In 1917, Rutherford after careful study of Marsden's work, decided that long-range particles would be the same H-particles. They were knocked out from nitrogen atoms of the air present in the detector. He began to fire alpha particles to atoms of boron, fluorine, sodium, aluminium, phosphorus and nitrogen and knocked out H-particles from them. This experiment led to the discovery of *artificial disintegration*. Alpha particles striking atomic nuclei of nitrogen would knock out a proton and leave a lighter nucleus different from the parent one. Hence nuclei could be disintegrated by artificial means. In 1919, Rutherford published results of nuclear transmutation that led finally to the discovery of nuclear fission. Meanwhile JJ retired as Cavendish Professor (1918) and Rutherford took over the chair.

Late in the year, he named the nucleus of hydrogen atom **proton**. The particle in fact was discovered much earlier. Around 1886, the German physicist Eugen Goldstein discovered a new radiation in cathode ray tube, in opposite direction to that of cathode rays. He called it then channel rays. Thompson named it positive rays. Particles of positive ray could pass through matter. Their deflection in an magnetic field indicated that the particle had the same charge as that of hydrogen ion. Ultimately it was understood that those particles are protons.

In 1920, Rutherford proposed *theory of radioactivity* in a lecture. Hydrogen is the simplest element of Nature. Its atom is made up of one electron and one proton. Most of the atomic

space is void while proton in the centre occupies only 1 in 100,000 part, in a space of diameter 10^{-13} cm. The charges of electron and proton are 1 unit each making free hydrogen atom neutral. The electron orbits the nucleus like helio-centric model. Although proton is heavier than electron and charges are opposite, electron does not fall upon proton since centrifugal force of electron is in equilibrium with the attractive forces of the centre. Lastly elements higher than hydrogen have their number of electron and proton increased.

If the single electron is removed from an hydrogen atom, it reduces to proton. If both the electrons from helium atom are removed, it reduces to alpha particle. In general, units of positive charge in the nucleus equals units of negative charges of electrons. Rutherford further anticipated one neutrally charged particle, as massive as proton, in the nucleus.

Meanwhile in 1911, the English physicist **Charles Glover Barkla** found that X-rays given off by metal, showed sharply defined penetrating power, depending on type of metal. It meant that each element could produce its own *characteristic X-ray*. That showed us a way to identify elements from its atomic features. Barkla was awarded the Nobel Prize in physics (1917).

What is X-ray to be more precise? Is it a stream of particles or radiation? One way to check its property is to investigate its diffraction pattern, if any.

The German physicist **Max Theodore Felix von Laue** (1879-1960) worked during Roentgen's directorship at Physics Institute at Munich under Sommerfeld. His experiment came in 1912. If X-rays were very short waves that pass through crystals having ordered arrays of atoms with spacing comparable to wavelength of X-rays, they would diffract and interfere. In experiment, X-rays diffracted and formed a pattern on the plate. This proved wave nature of X-ray. The diffraction pattern is known as '*Laue diffraction pattern*'. Later **Walter Freidrich** (1883-1968) and **Paul Knipping** (1883-1935) proved experimentally what Laue predicted theoretically. In quick recognition, Laue was honoured with Nobel Prize (1914). **William Lawrence Bragg** (1890-1971) and his father **William Henry Bragg** (1862-1942) developed an accurate method of calculating the wavelength of a specific X-ray from its diffraction pattern.

Around 1911 nuclear charge was observed by Rutherford to be about half the atomic weight of an element. Two years later, the

Dutchman **Antonius Van den Broek** (1870-1926) pointed out that the *atomic number of an element equalled to number of positive charges of the nucleus.*

Atoms of different elements began to be measured by both atomic weight and atomic number. While *atomic weight* is the relative weight compared to one standard weight of an element, *atomic number* is determined by number of positive charges in the atom. Atomic number of carbon is 6 but its atomic weight is 12.011. Atomic number of oxygen, calcium, iron and radium are 8, 20, 26 and 88 respectively while their atomic weights are 16, 40, 56 and 226.

Precise information about elements can be obtained through study of X-ray spectra of elements. The way-out came from the English physicist **Henry Gwyn Jeffreys Moseley** (1887-1915) working in Rutherford's laboratory at Manchester during 1913-14. He used crystal of potassium ferrocyanide as diffraction grating and photographed X-ray spectra of thirty eight elements from aluminium to gold and detected several lines or group of lines (K and L lines). As the atomic number of elements increased, the lines of each series shifted regularly in the direction of decreasing wavelengths. Moseley established a relation between atomic number of element and frequency of the same in K line.

Wavelengths decrease in a regular way as we go up the periodic table. The atomic number of elementary matter represented by number of protons is a more fundamental property than its atomic weight. Later we derived another factor, *mass number.* This number sums up number of protons and neutrons. *Periodic law* was thereafter restated: *The properties of elements are a periodic function of their atomic numbers.*

Once radio-active matter was observed to transform into varieties by emitting particles, chemists began to search in details. How many different varieties of such radio-active matter, we encounter? Scientists identified about forty element-like matter in between uranium (92) and lead (82). In the periodic table, we had provisions of ten places. How to accommodate forty elements in the table?

Further some elements were found basically identical to one another in many chemical properties. These were identified later as *isotopes.* In 1913, Soddy proposed it in case of unstable elements only but later the idea was applied to both stable and unstable

radio-active elements. After the discovery of neutrons, we could understand isotopes as having equal number of protons and electrons but different number of neutrons. For example, carbon atom (C-12) contains 6 electrons, 6 protons and 6 neutrons but carbon-13 isotope have 6 electrons, 6 protons and 7 neutrons. In 1921, Soddy was rewarded with Nobel Prize in chemistry for this excellent explanation.

4.07. BOHR'S MODEL

We know that once Dalton's atomic theory came in conflict with practical observations. As a result, Dalton's theory had to be revised. In the same way, Rutherford's atom soon failed to explain why line spectra occurred in the experiments. It raised also the question of stability of atom itself. In Rutherford's model, rotating electron is constantly accelerating and should lose energy by radiation. Electron should then fall into the nucleus within 10^{-11} sec and would make the atom extremely unstable. But an atom is found really a stable one. How then it becomes stable when theoretically it should not be? Again, continuous loss of energy by radiation from atom should mean continuous spectra to be observed in the experiments. Instead we get only line spectra. Why observed things are not in agreement with theoretical predictions? Surely we cannot do away with what we observe. Therefore we are to revise and update theory. That is how science work out its ways. Here comes another brilliant scientist, Neils Bohr who solved the riddle applying quantum idea.

The Danish scientist **Neils Henrik David Bohr** (1885-1962) was born in Copenhagen. Early in 1911, he received his Ph.D. and getting Fellowship from the Cailsberg Brewery went to England. He began his work with JJ at Cambridge. Bohr met Rutherford in the annual Cavendish dinner in December and joined him in Manchester in the following year. He was fascinated by the structure of atom proposed by Rutherford.

It was postulated that electron revolved around the nucleus without falling into it. Available theory suggested that revolving electron should radiate energy and fall into the nucleus. But it was not happening as per available theory. So Bohr had to think of a new way that would prohibit electron from falling into it. He argued

that the spectrum of element must be such that this fall would not happen and then he explored the conditions   required for not-happening of the event.

Already in 1905 Einstein proposed that light consists of quanta. Inspired by this, it occurred to Bohr (1912) that stability of atom might be explained by quantum theory. In February, 1913, a glance at Balmer's formula finally convinced him that he was on the right track. He prepared a draft and mailed it to Rutherford. The long paper was published without edition in *Philosophical Magazine* in its July, September and November issues.

Bohr came up with what is now known as *Bohr's postulates*. The famous postulates based upon the queer idea of *stationary orbits* and *quantum jump*, are as follows: (1) *The electrons rotate in certain orbits round the nucleus of the atom without radiating energy in the form of electromagnetic waves;* and (2) *Emission or absorption of radiation occurs when an electron jumps from one of the stationary state of energy (E_1) to another state of energy (E_2), the frequency (v), of the   emitted or absorbed light being given by E_1 - E_2 = hv. In case E_1> E_2,   light is emitted and conversely light is absorbed.*

Now Rutherford's model of atom had to be modified. An atomic electron differs from a satellite because electron's orbital momentum (l) is a product of mass, velocity and radius (i.e. l = m.v.r). It cannot be arbitrary. The orbits are also such that angular momentum is an integral multiple of nh/2 where *h* is   Planck's constant and n are integers (1, 2, 3 etc).
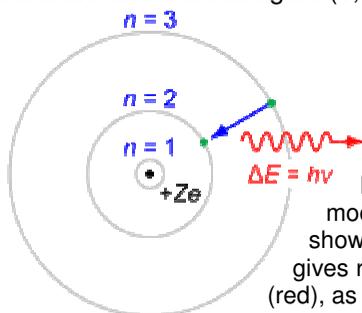
Fig:4.08. A schematization of the Bohr model of the hydrogen atom. The transition shown from the *n*=3 level to the *n*=2 level gives rise to visible light of wavelength 656 nm (red), as the model predicts.

From above relationship, we get some idea of stationary orbits. Electrons move around nucleus in fixed stationary orbits which are function of some integer. No other intermediate orbit is possible inside. When an electron jumps from one level to another

level, it emits or absorbs energy. If it jumps from some k-th level with energy E_k to some n-th level with energy E_n, it emits energy $\Delta E = (E_n - E_k)$ and frequency of that emission would be $\nu = \Delta E/h$. Bohr's formula for the frequency of radiation of hydrogen atom is given by, $\nu = m.e^4 (1/n^2 - 1/ k^2)/ (4.\pi.h^3)$

But why there would be stationary orbit where no radiation is permitted? Why electrons would move or jump into another orbit? Those were not clear, though theory explained nicely what we observed. Our views on atomic structure of fundamental particles, began to change significantly with more facts coming out.

Earlier, we mentioned about spectral D-lines. Spectrography became a popular field of study and tens of thousands of spectral lines of various elements were discovered. The Swiss scientist **Johann Jacob Balmer** (1825-1898) observed in 1885 that there occurred four spectral lines in the visible range of the hydrogen spectrum. They were called hydrogen Balmer lines, located in distinct series that could be described by some formula. Next year **Carl David Tolme Runge** (1856-1927) revised Balmer's formula in terms of wavelength. In 1890, the Swedish physicist **Johannes Robert Rydberg** (1854-1919) empirically determined a relation. If Bohr's postulates were right, the Rydberg constant (R) should be given by an equation he deduced. In experiments, theoretical value of Rydberg constant was found to agree with results from spectroscopic measurements. Hence Bohr's postulates were in right direction.

Fig:4.09. Excitation & emission of atom.
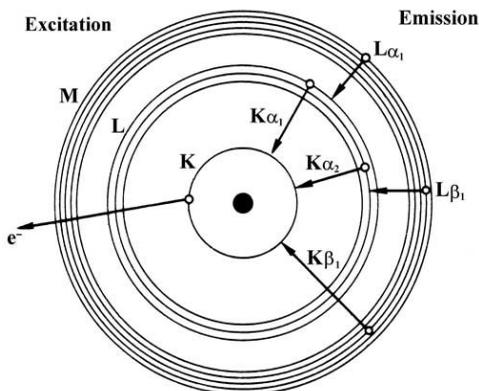
When innermost electrons move from very high to very low energy state, they would give off high energy light (X-ray). The energy of X-ray would depend on the electric charge of the nucleus. If the positive charge of the nucleus is stronger to attract

electron, more energy would be required to move the electron and higher would be the frequency to the corresponding X-ray. Frequencies of the X-rays given off could be measured and that would determine the charge of the nucleus. This would further prove the correctness of Bohr's model.

In an experiment Mosley shot electrons at different elements, light to heavy. Some electrons hit inner electrons of the target atom and made them free. Other electrons then rushed to fill up the place and gave off X-rays as predicted in the process. When elements were heavier, the X-ray frequency increased and the increase matched with Bohr's idea. In other words, Bohr's theory could explain the fine structure of the spectrum and confirmed the new model of atom.

The radius of hydrogen atom in its ground or unexcited state, was found accordingly about 0.53×10^{-8} cm (or 0.53 Angstrom). The size calculated from Bohr's theory was found in good agreement with that derived from kinetic theory of matter. The size of an atom was thus as small as 10^{-8} cm or so.

The tiny atom cannot be seen with our naked eyes but that they exist, is a reality. Reality of matter can be checked out scientifically in many different ways.

4.08. QUANTUM NUMBERS

Still some flaws remained in the atomic structure. From 1913 to 1927, a kind of race occurred to improve state of affairs. Bohr anticipated earlier circular orbit of electrons. First change came on this issue by the German scientist **Arnold Johannes Wilhelm Sommerfeld** (1868-1951), much in the same way Kepler improved on Copernicus.

Sommerfeld introduced the term, quantum number (1916). The first one (n) is called *principal quantum number* and the second (l) *azimuthal quantum number*. Electrons may travel either in circle or in ellipse with the nucleus at one of the foci. Ellipses with the same major axis are described by the same principal quantum number (n). Their orbits may differ only in degree of ellipticity depending on orbital moment (l). For a given value of n, the elliptical orbits must have ellipticities such that there could be n permissible ellipses. For example, for n=3, there would be 3 ellipses with l = 0, 1, 2).

Electrons in elliptical orbits with same n-number but various l-number, would differ slightly in energy. So energy levels in atom had to be labelled by two quantum numbers. Spectral lines

produced by transitions of electrons between levels with different n and l, must split accordingly into components. The inference was confirmed by the German physicist **Freidrich Paschen** (1865-1947) when he examined helium spectrum.

These two quantum numbers were found unable to explain finer details of spectra. The Dutch physicist, **Peter Zeeman** (1865-1943) noticed in 1896 that emission spectral lines of sodium or lithium flames, broadened due to splitting in magnetic field. It was known as *Zeeman effect.* Zeeman shared with Lorentz the Nobel Prize of 1902.

To explain this effect, a third quantum number, called *magnetic quantum number* (m) was introduced. In a magnetic field, each level with given n and l would split further into (2l+1) sublevels. Thus each level of electron would have to be defined by three numbers n, l and m. Quantum number (n) and magnetic number (m) were denoted by integers while orbital moment (l) by s, p, d, f, ...etc. These numbers define stationary orbits. External fields like electric or magnetic field can alter motion of electron and would split in energy levels. This would be reflected in the structure of light signal emitted by the atom and thereby in splitting of spectral lines.

In an unexcited sodium atom, electron remains in state 3s. When it is excited to 3p, dark D-line appears in the spectra. In the reverse process of 3p → 3s, the atom should emit energy and bright yellow D-line should appear. Here we should get single line in the spectra. But D-line was found to split into two closely spaced components, D1 and D2 (in absence of magnetic field). In case of transition from 3p → 3s in magnetic field, the upper level 3p should split into 3 components while lower level 3s in 1, according to Sommerfeld's theory. But D1-line was found to split into 4 components and D2 into 6. Scientists were to explain - why these happened?

The Austrian physicist, **Wolfgang Pauli** (1900-1958), then a student of Sommerfeld, conceived another quantum number that made 3p level in the above example to split into two more levels. This new quantum number, denoted by (S), was described as 'non-classical two valuedness' of electron. It can have only two values $+\frac{1}{2}$ and $-\frac{1}{2}$. This speculation made by Pauli in 1924, led to the idea of *electron spin.*
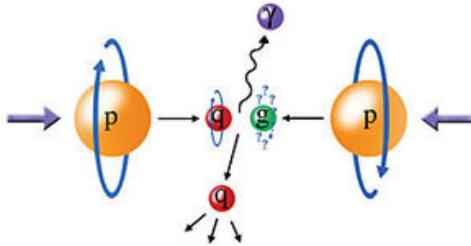
Fig:4.10. The head-on collision of a quark (the red ball) from one proton (the orange ball) with a gluon (the green ball) from another proton with opposite spin; spin is represented by the blue arrows circling the protons and the quark. The particles ejected from the collision are a shower of quarks and one photon of light (the purple ball).

Pauli later proposed his 'exclusion principle', to account for the way the two or more electrons in an atom arrange themselves in successive shells. This was found important for explaining chemical valency.

The Dutch physicists **George Eugene Uhlenbeck** (1900-1988) and **Samuel Abraham Goudsmit** (1902-1978), clarified the above 'non-classical two valuedness' of electron (1925). It was proposed that the electron has inherent to it a kind of intrinsic angular momentum, called **spin** (S) that equals to $\pm^1/_2$, in addition to orbital angular momentum (l). This spin is not be like spinning top or an axially-rotating Earth. It is a property that would only appear in quantum interactions, for example, in splitting of spectral lines. This idea finally explained intricacies of spectral lines.

Total angular momentum (J) would be the result of intrinsic angular momentum (S) and orbital angular momentum (l) so that J may be either J1 ($= l - ^1/_2$) or J2 ($= l + ^1/_2$). Armed with this idea, we may check the sodium spectrum, first split into two lines and then into 10. The atomic spectrum no longer remained a simple one and grew more and more complex.

How then Bohr's atomic model developed at this stage?

First there was only one level, in case of sodium atom. Then came two levels, 3p and 3s, for two quantum numbers. With the idea of spin, 3p again splits into $3p_{1/2}$ and $3p_{3/2}$. Finally in a magnetic field, we get a system of levels and transitions between them. In this way, there emerged finer details of atomic structure.

This points out how finer observations reveal finer truths and they can be explained only by higher theory. It does not mean that the first one is entirely false and the last one is right. It means that

truths have enriched into more details and perhaps into more complexities with higher knowledge.

The new structure of atom hereon emerged poor in description and simplicity but fine in explaining finer spectrum results. Any line in the spectra can be defined by four initial level of quantum numbers (n_i , l_i , m_i , S_i) and four final level numbers (n_k , l_k , m_k , S_k).

As radiation of electrons occurred in different wavelengths, each set was called either *K-series* or *L-series* or *M-series* etc. Scientists began to construe that electrons are arranged in different shells around the nucleus. Electrons filling the innermost shell would emit the most energetic radiation of shortest wavelengths in K-series. Electrons of next innermost shell produced L-series of radiation and so on. The shells were henceforth called K-, L-, M-, N-, O-, P-shell. In 1916, the American scientist **Gilbert Newton Lewis** (1875-1946), studied properties and chemical behaviour of elements on the basis of shell structure.
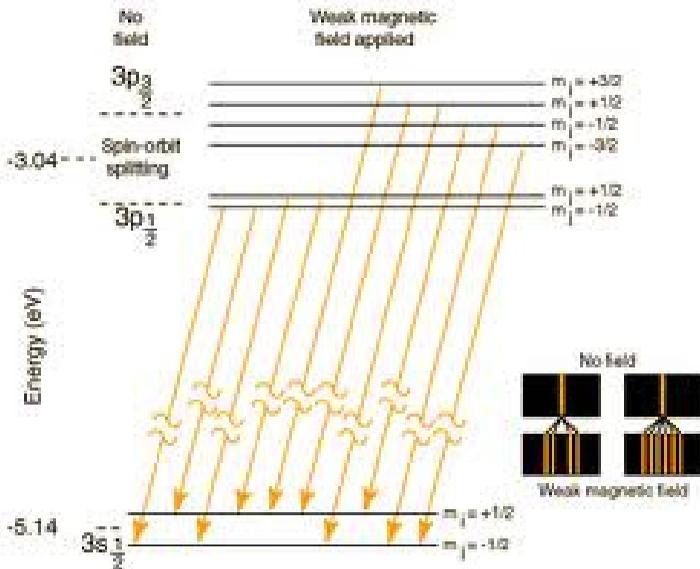

Fig:4.11. Sodium-Zeeman effect (source: website - hyperphysics.phy-astr.gsu.edu/hbase/quantum/Sodzee.html)

From researches of **Irving Langmuir** (1881-1957) in 1919 and of Bohr and **Charles Bury** (1890-1968) in 1921, it became known that maximum possible number of electrons rotating in each orbit around nucleus, are fixed. Number of electrons moving in outermost orbit would mainly determine the physical and chemical properties of the element. Based on this, Mendeleyev's periodic table was reset. It also became clear that radioactivity, fission and isotopes etc. depend on characteristics of nucleus. *Permissible maximum number of electrons in a shell followed the guideline* $2n^2$. The capacity of K-shell would be only 2 electrons, L-shell 8, M-shell 18 and N-shell 32. Even that shell model was not enough. Atoms are found to have more complexity.

In June, 1922, Bohr gave a series of lectures at the University of Gottingen. There he presented *theory of the periodic table of elements.* Energy states of electrons called shells, were made of sub-shells (s-, p-, d- f- sub-shells) at slightly different energy. In each succeeding shell, the spread of sub-shells was greater and overlapping. Due to this, outermost sub-shell of M-shell might be farther from the centre than the innermost sub-shell of N-shell. It would then fill the inner sub-shell of N-shell before outer sub-shell of M-shell. Outermost shell usually would not exceed 8 electrons. Detailed study of spectrum of elements supported the view.
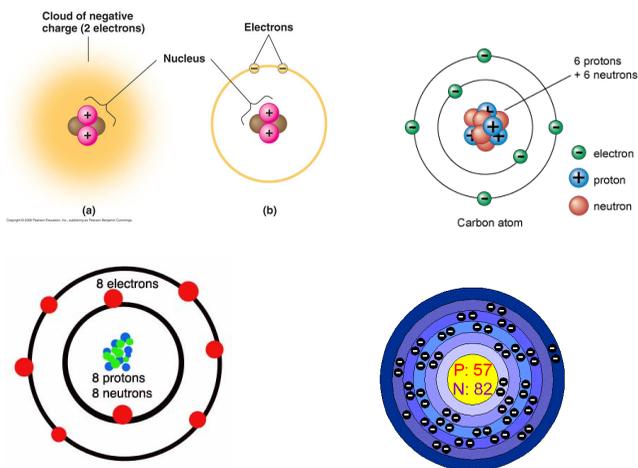

Fig:4.12. helium, carbon, oxygen and lanthanum atom.

K-shell has only one set with 2 electron-seats, as in helium.

L-shell has 2 sub-shells s and p of 2 and 6 seats. Neon with 10 electrons fill up all sub-shells of K- and L-shell.

M-shell got three sub-shells s, p and d of 2, 6 and 10 electrons. Argon with 18 electrons, fill up K-shell with 2 electrons, L-shell with 8 electrons, and M-shell's two inner sub-shell s and p with 2 and 6 electrons.

Table:4.x. shell, subshell & electron capacity

	s	p	d	f	g	total
K	2					2
L	2	6				8
M	2	6	10			18
N	2	6	10	14		32
O	2	6	10	14	18	50

But potassium with 19 electrons fill up innermost sub-shell s of N-shell before filling up outermost sub-shell d of M-shell. The chemical behaviour of potassium with 1 electron in the N-shell is like 11-electron sodium with 1 electron in the M-shell. Calcium with 20 electrons has 2 electrons on the N-shell and is like magnesium with 2 electrons in the M-shell. Scandium with 21 electrons would fill up 2 electrons of N-shell to occupy outermost sub-shell of M-shell. The picture below shows electron sub-shells of lanthanum atom where fourth sub-shell of N-shell is empty.
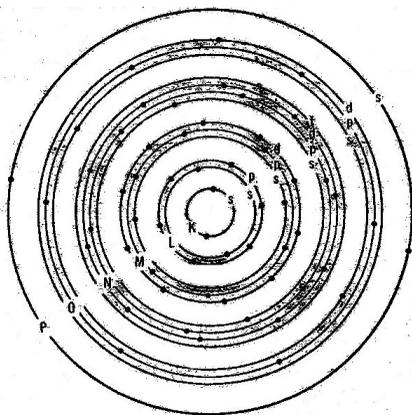

Fig:4.13. electron subshells of lanthanum atom. (source: p/257, Asimov)

Thus electron's shell and sub-shell system overlap. The properties of element depend upon outermost shell position. Where inner sub-shells vary providing outer sub-

shell unchanged, variations in properties were less pronounced. This would go long way to explain why rare earth lanthanides resemble one another.

4.10. NEUTRON

It would be natural to think that nucleus (A) with twice the charge compared to another nucleus (B) should have twice the number of protons and twice the mass compared to B. But surprisingly such a relation was not observed. As early as 1920, Rutherford and Harkins predicted that some neutral particles should occur inside the nucleus in order to explain extra mass. The popular idea was that the nucleus contained protons in twice the number of orbiting electrons. Half of the protons are neutralised by electrons and their positive charges did not show up. Extra nuclear mass was due to these neutralised protons. In the phenomena of beta decay, electrons emerged from nucleus. This supported the idea that electrons also occur inside the nucleus. The theory could only be checked if nucleus could be broken.

In 1928, the Russian scientist **George Gammow** (1904-1968) and two American scientists **Edward Condon** (1902-1974) and **Ronald Garni** (1899-1953) separately said that less powerful charged particles would on collision break the nucleus. Meanwhile two American scientists, Arnest Orlando Lawrence (1901-1958) and Stanley Livingstone (1905-1986) learnt from a Norway-publication that charged particles could be accelerated through a circular path. In 1930 AD, they developed one circular *Particle Accelerator* at Berkeley, California. In the same year, the German scientist **Walther Wilhelm Georg Bothe** (1891-1957) and **Herbart Becker** released from the nucleus a mysterious radiation. They did it by colliding beryllium atoms with alpha particles. The penetrating radiation passed through 25 mm thick layer of lead: $\alpha + {}^{9}Be_4 \rightarrow$

${}^{12}C_6$ +n. Two years later Frederic Joliot and Irene Curie, used this new radiation to bombard paraffin (rich in hydrogen) and knocked off high energy proton. They thought new rays might be gamma rays. Actually they were neutron rays and Irene and Frederic missed the chance to identify neutron.

The English scientist **James Chadwick** (1891-1974) did the same experiment by

bombarding beryllium-9 with alpha particles that produced a new radiation. When boron was bombarded with this new radiation, its nucleus transformed and increased in mass. The radiation was not detected in the cloud chamber. So it would be neutral in character. Chadwick realised that he hit upon a new particle and named it **neutron,** the third particle of atom. The year was 1932. Chadwick was rewarded with the Nobel Prize three years later.

Neutron is a chargeless particle with mass about 1840 times to that of electron. The stable nuclei of smaller atomic weight (such as helium, carbon, oxygen) have equal number of proton and neutron. Heavier atoms contain more neutrons than protons. For example uranium-238 contains 96 protons and 142 neutrons. Neutron is then the key to the store of intra-nuclear energy. In a free state, it disintegrates quickly in half-life of 10.7 minutes into proton, electron and antineutrino ($n^0 \rightarrow p^+ + e^- +$ antineutrino). Every now and then a neutron decays and protons remain inside emitting electron and electron anti-neutrino. Beta rays of radio-active elements comprise of these electrons. Marie Curie and her husband Pierre Curie discovered Polonium by beta decay process of Bismuth ($Bi \rightarrow Po + e^-$).

4.11. NUCLEAR STRUCTURE

With the discovery of two nuclear particles, scientists had to explain the structure of the nucleus. In 1936, Neils Bohr suggested *liquid drop model* according to which nuclear particles were held together tightly like a liquid drop oscillating around its spherical shape. The spherical nucleus may be distorted likea dumbshell and divide at the neck into two nearly equal bidies. The model could account for phenomena of alpha-emission and nuclear fission.

The *shell model* suggested that nucleus occupied shell and subshell structure. It was developed byEugene Paul Wigner(1902-1995), **Maria Goeppert Mayer** (1906-1972) and **Johannes Hans Daniel Jensen** (1907-1973). Their idea was that nucleons had different energies when it would spin in the same or opposite sense around the nucleus-centre. A strong coupling occurred between the spin and orbital momentum of each nucleon. Two vectors tend to be parallel. In the shell model, nucleons were assumed to move in orbits arranged in shells. Here the spin and orbital-momentum coupling could predict correctly the magic numbers corresponding

to nuclei of greatest stability. The abnormal stability was found to occur for neutron-proton numbers 2 (helium), 8 (oxygen), 20 (calcium), 28 (nickel), 50 (tin), 82 (lead) and 126. (Refer to fig:4..11. above)

4.12. REMARKS

All material bodies of Nature are built with atoms. Different elements have different atoms. The idea of atom as ultimate thing was old but experimentally established only in last 200 years. All atoms, be it carbon or iron, are constituted of three atomic particles – electron, proton and neutron. The last two form the compact nucleus. The atomic structure appeared like planetary system, as if the basic structural plan for minutes and macros were the same.

The configuration of electrons outside nucleus determines character of element. Thus elements differ from one another due to different number and arrangement of atomic particles. The grand Nature produced three particles in true universal style. Simply due to these trio, some hundred varieties of elements were created. Who made it so? None, but Nature itself? Gold and iron differ in properties, only because they differ in number of electrons-protons-neutrons. The property of iron or gold is created by the assembly of some particles. Can we say that properties of matter are created as a result of its material structure in specific arrangement? The properties of iron or gold are not present in its constituents. They emerge because of some arrangement inside those bodies? Is it fact that some properties of matter can be created out of some other properties just by reorientation of its constituent structure? It appears like that.

Some new rays such as X-ray, alpha ray, beta radiation, and gamma ray, were discovered. Some strange matter were found to produce spontaneous rays and get transformed into another matter, without any external influence. Uranium changes into lead on its own. It is a property of uranium.

However the structure of atom is not yet fully clear. We have not learnt enough of the nucleus. The Grand Nature is going to be more and more complex in micro-structures. To understand more about it, we need to know quantum theory. Before that let us take up another discovery, relativity. Relativity and quantum theory are two basic tools to unfold the mystery of our Grand Nature in both macro and micro world.

TABLES & CHARTS

I. TABLE OF SPECTRUM OF VISIBLE LIGHT
(Wave length in nanometer and frequency in hertz)

Colour	wave length (10^{-9} m)	frequency (10^{14})	colour	wave length (10^{-9} m)	frequency (10^{14})
Red	647 - 700	4.634 - 4.284	Green	491.2 - 575	6.100 - 5.21
Orange	585 - 647	5.125 - 4.634	Blue	424 - 491.2	7.115 - 6.10
Yellow	575 - 585	5.210 - 5.215	Violet	400 - 424	7.495 - 7.115

II. TABLE FOR SPECTRUM OF ELECTROMAGNETIC RADIATION

wavelength (meter)	type of rays	frequency in kHz
10^{-17} to 3×10^{-13}	Cosmic ray	5×10^{22} to 10^{19}
3×10^{-13} to 10^{-11}	Gamma ray	10^{20} to ?
3×10^{-11} to 3×10^{-9}	X-ray	10^{18} to 10^{20}
3×10^{-9} to 4×10^{-7}	Ultraviolet ray	7.5×10^{14} to 10^{18}
4×10^{-7} to 8×10^{-7}	Visible Light	3.7×10^{14} to 7.5×10^{14}
8×10^{-7} to 3×10^{-7}	Infrared ray	10 to 3.7×10^{8}
10^{-3}	EHF radio	
	SHF	
	UHF	
to	VHF	
	HF	
	MF	
	LF	
10^{5}	VLF	1

III. TABLE OF ELEMENTS

At. No level	Element & symbol	At.wt.	Mass No	K L M N O P Q (Energy)
1	Hydrogen (H)	1.008	1	1
2	**Helium (He)**	**4.003**	**4**	**2**
3	Lithium (Li)	6.939	7	2 1
4	Beryllium (Be)	9.012	9	2 2
5	Boron (B)	10.811	11	2 3
6	Carbon (C)	12.011	12	2 4
7	Nitrogen (N)	14.007	14	2 5
8	Oxygen (O)	15.999	16	2 6
9	Fluorine (Fl)	18.998	19	2 7
10	**Neon (Ne)**	**20.183**	**20**	**2 8**
11	Sodium (Na)	22.990	23	2 8 1
12	Magnesium (Mg)	24.312	24	2 8 2
13	Aluminium (Al)	26.982	27	2 8 3
14	Silicon (Si)	28.086	28	2 8 4
15	Phosphorus (P)	30.974	31	2 8 5
16	Sulfur (S)	32.064	32	2 8 6
17	Chlorine (Cl)	35.453	35	2 8 7
18	**Argon (Ar)**	**39.948**	**40**	**2 8 8**
19	Potassium (K)	39.102	39	2 8 8 1
20	Calcium (Ca)	40.080	40	2 8 8 2
21	Scandium (Sc)	44.956	45	2 8 9 2
22	Titanium (Ti)	47.900	48	2 8 10 2
23	Vanadium (V)	50.942	51	2 8 11 2
24	Chromium (Cr)	51.996	52	2 8 13 1
25	Manganese (Mn)	54.938	55	2 8 13 2
26	Iron (Fe)	55.847	56	2 8 14 2
27	Cobalt (Co)	58.933	59	2 8 15 2
28	Nickel (Ni)	58.710	58	2 8 16 2
29	Copper (Cu)	63.540	63	2 8 18 1
30	Zinc (Zn)	65.370	65?	2 8 18 2
31	Gallium (Ga)	69.723		2 8 18 3
32	Germanium (Ge)	72.610		2 8 18 4
33	Arsenic (Ar)	74.922	75	2 8 18 5
34	Selenium (Se)	78.960	79	2 8 18 6
35	Bromine (Br)	79.909	79	2 8 18 7
36	**Krypton(Kr)**	**83.800**		**2 8 18 8**
37	Rubidium (Rb)	85.468	85	2 8 18 8 1
38	Strontium (Sr)	87.620		2 8 18 8 2
39	Yttrium (Y)	88.905		2 8 18 9 2
40	Zirconium (Zr)	91.224		2 8 18 10 2

41	Niobium (Nb)	92.906	2 8 18 12 1
42	Molybdenum (Mo	95.940	2 8 18 13 1
43	Technetium (Tc)	98.910	2 8 18 13 2
44	Ruthenium (Ru)	101.070	2 8 18 13 1
45	Rhodium (Rh)	102.905	2 8 18 15 1
46	Palladium (Pd)	106.420	2 8 18 18
47	Silver (Ag)	107.868	2 8 18 18 1
48	Cadmium (Cd)	112.411	2 8 18 18 2
49	Indium (In)	114.820	2 8 18 18 3
50	Tin (Sn)	118.710	2 8 18 18 4
51	Antimony (Sb)	121.757	2 8 18 18 5
52	Tellurium (Te)	127.600	2 8 18 18 6
53	Iodine (I)	126.904	2 8 18 18 7
54	**Xenon (Xe)**	**131.290**	**2 8 18 18 8**
55	Cesium (Cs)	132.905	2 8 18 18 8 1
56	Barium (Ba)	137.327	2 8 18 18 8 2
57	Lanthanium (La)	138.905	2 8 18 18 9 2
58	Cerium (Ce)	140.115	2 8 18 20 8 2
59	Prasodymium (Pr)	140.907	2 8 18 21 8 2
60	Neodymium (Nd)	144.240	2 8 18 22 8 2
61	Promethium (Pm)	145.000	2 8 18 23 8 2
62	Samarium (Sm)	150.360	2 8 18 24 8 2
63	Europium (Eu)	151.965	2 8 18 25 8 2
64	Gadolinium (Gd)	157.250	2 8 18 25 9 2
65	Terbium (Tb)	158.925	2 8 18 27 8 2
66	Dysprosium (Dy)	162.500	2 8 18 28 8 2
67	Holmium (Ho)	164.930	2 8 18 29 8 2
68	Erbium (Er)	167.260	2 8 18 30 8 2
69	Thulium (Tm)	168.934	2 8 18 31 8 2
70	Ytterbium (Yb)	173.040	2 8 18 32 8 2
71	Lutetium (Lu)	174.970	2 8 18 32 9 2
72	Hafnium (Hf)	178.490	2 8 18 32 10 2
73	Tantalum (Ta)	180.948	2 8 18 32 11 2
74	Tungsten (W)	183.850	2 8 18 32 12 2
75	Rhenium (Re)	186.200	2 8 18 32 13 2
76	Osmium (Os)	190.200	2 8 18 32 14 2
77	Iridium (Ir)	192.200	2 8 18 32 15 2
78	Platinum (Pt)	195.080	2 8 18 32 17 2
79	Gold (Au)	196.967	2 8 18 32 18 1
80	Mercury (Hg)	200.590	2 8 18 32 18 2
81	Thallium (Tl)	204.383	2 8 18 32 18 3
82	Lead (Pb)	207.190	2 8 18 32 18 4
83	Bismuth (Bi)	208.980	2 8 18 32 18 5
84	Polonium (Po)	209.000	2 8 18 32 18 6
85	Astatine (Al)	210.000	2 8 18 32 18 7
86	Radon (Rn)	222.000	2 8 18 32 18 8

87	Francium (Fr)	223.000	2 8 18 32 18 8 1
88	Radium (Ra)	226.025	2 8 18 32 18 8 2
89	Actinium (Ac)	227.030	2 8 18 32 18 9 2
90	Thorium (Th)	232.038	2 8 18 32 18 10 2
91	Protactinium (Pa)	231.036	2 8 18 32 20 9 2
92	Uranium (U)	238.030	2 8 18 32 21 9 2
93	Neptunium (Np)	237.050	2 8 18 32 22 9 2
94	Plutonium (Pl)	244.000	2 8 18 32 24 8 2
95	Americium (Am)	243.000	2 8 18 32 25 8 2
96	Curium (Cm)	247.000	2 8 18 32 25 9 2
97	Berkelium (Bk)	247.000	2 8 18 32 27 8 2
98	Californium (Cf)	251.000	2 8 18 32 28 8 2
99	Einsteinium (Es)	252.000	2 8 18 32 29 8 2
100	Fermium (Fm)	257.000	2 8 18 32 30 8 2
101	Mendelevium (Md)	258.000	2 8 18 32 31 8 2
102	Nobelium (No)	259.000	2 8 18 32 32 8 2
103	Lawrencium (Lr)	260.000	2 8 18 32 32 9 2
104	Rutherfordium	261.000	2 8 18 32 32 10 2
105	Hahnium	262.000	

 [NOTES: Nearly all elements found in Nature are mixture of isotopes. There occur more than 1000 isotopes, both natural and artificial of which at least 320 are found in Nature, 40 in radioactive state, some 280 are relatively stable. Rare Earth elements or Lanthanides occur from 58 to 71 and Actinides from 90 to 103.]