Government of Tamilnadu

Department of Employment and Training

Course : TNPSC Group II Exam

Subject : Physics

Topic : **Atomic & Nuclear Physics**

ATOMIC & NUCLEAR PHYSICS

ATOMIC PHYSICS

The charge of an electron was found to be 1.602×10^{-19} coulomb.

Properties of Cathode rays

Cathode rays have the following properties:

1. They travel in straight lines.
2. Cathode rays possess momentum and kinetic energy.
3. Cathode rays produce heat, when allowed to fall on matter.
4. Cathode rays produce fluorescence when they strike a number of crystals, minerals and salts.
5. When cathode rays strike a solid substance of large atomic weight, X-rays are produced.
6. Cathode rays ionize the gas through which they pass.
7. Cathode rays affect the photographic plates.
8. The cathode rays are deflected from their straight line path by both electric and magnetic fields. The direction of deflection shows that they are negatively charged particles.
9. Cathode rays travel with a velocity upto $(1/10)^{th}$ of the velocity of light.
10. Cathode rays comprises of electrons which are fundamental constituents of all atoms.

Properties of Canal rays

1. They are the streams of positive ions of the gas enclosed in the discharge tube. The mass of each ion is nearly equal to the mass of the atom.
2. They are deflected by electric and magnetic fields. Their deflection is opposite to that of cathode rays.
3. They travel in straight lines.
4. The velocity of canal rays is much smaller than the velocity of cathode rays.
5. They affect photographic plates.

6. These rays can produce fluorescence.
7. They ionize the gas through which they pass.

Atom models

1803, Dalton, showed that the matter is made up of extremely small particles called atoms. Prout (1815), suggested that all elements are made up of atoms of hydrogen

Thomson atom model

An atom is a sphere of positive charge having a radius of the order of 10^{-10}m. The positive charge is uniformly distributed over the entire sphere and the electrons are embedded in the sphere of positive charge. The total positive charge inside the atom is equal to the total negative charge carried by the electrons, so that every atom is electrically neutral

Rutherford's α - particle scattering experiment

The scattering of the α - particles by a thin gold foil in order to investigate the structure of the atom. An α-particle is a positively charged particle having a mass equal to that of helium atom and positive charge in magnitude equal to twice the charge of an electron.

a. Atom may be regarded as a sphere of diameter 10^{-10}m, but whole of the positive charge and almost the entire mass of the atom is concentrated in a small central core called nucleus having diameter of about 10^{-14}m.
b. The electrons in the atom were considered to be distributed around the nucleus in the empty space of the atom. If the electrons were at rest, they would be attracted and neutralized by the nucleus. To overcome this, Rutherford suggested that the electrons are revolving around the nucleus in circular orbits, so that the centripetal force is provided by the electrostatic force of attraction between the electron and the nucleus.
c. As the atom is electrically neutral, the total positive charge of the nucleus is equal to the total negative charge of the electrons in it.

Bohr atom model

a. An electron cannot revolve round the nucleus in all possible orbits. The electrons can revolve round the nucleus only in those allowed or permissible orbits for which the angular momentum of the electron is an integral multiple of h 2π (where h is Planck's constant = 6.626×10^{-34} Js).

- These orbits are called stationary orbits or nonradiating orbits and an electron revolving in these orbits does not radiate any energy. If m and v are the mass and velocity of the electron in a permitted orbit of radius r then angular momentum of electron = $mvr = \frac{nh}{2\pi}$, where n is called principal quantum number and has the integral values 1,2,3 ... This is called Bohr's quantization condition.

b. An atom radiates energy, only when an electron jumps from a stationary orbit of higher energy to an orbit of lower energy. If the electron jumps from an orbit of energy E_2 to an orbit of energy E_1, a photon of energy $h\nu = E_2 - E_1$ is emitted. This condition is called Bohr's frequency condition.

$$r_1 = 0.53\text{Å}$$

This is called Bohr radius.

Spectral series of hydrogen atom

Electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference in energies of the two levels is emitted as a radiation of particular wavelength. It is called a spectral line. As the wavelength of the spectral line depends upon the two orbits (energy levels) between which the transition of electron takes place, various spectral lines are obtained.

(i) Lyman series

When the electron jumps from any of the outer orbits to the first orbit, the spectral lines emitted are in the ultraviolet region

$$\mathbf{n_1 = 1, n_2 = 2, 3...}$$

(ii) Balmer series

When the electron jumps from any of the outer orbits to the second orbit, we get a spectral series called the Balmer series. All the lines of this series in hydrogen have their wavelength in the visible region.

$$\mathbf{n_1 = 2, n_2 = 3, 4...}$$

(iii) Paschen series

This series consists of all wavelengths which are emitted when the electron jumps from outer most orbits to the third orbit This series is in the infrared region

Formula for H2 Series

Wave number $\bar{\lambda} = \left[\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right]$

(iv) Brackett series

The series obtained by the transition of the electron from $n_2 = 5$, 6… to $n_1 = 4$ is called Brackett series. The wavelengths of these lines are in the infrared region.

(v) Pfund series

The lines of the series are obtained when the electron jumps from any state $n_2 = 6, 7…$ to $n_1=5$. This series also lies in the infrared region.

Excitation and ionization potential of an atom

The energy required to raise an atom from its normal state into an excited state is called excitation potential energy of the atom. Hydrogen atom, the energy required to remove an electron from first orbit to its outermost orbit($n=\infty$) 13.6-0=13.6eV. This energy is known as the ionization potential energy for hydrogen atom

Sommerfeld atom model

In order to explain the observed fine structure of spectral lines, Sommerfeld introduced two main modifications in Bohr's theory.

(i) According to Sommerfeld, the path of an electron around the nucleus, in general, is an ellipse with the nucleus at one of its foci.

(ii) The velocity of the electron moving in an elliptical orbit varies at different parts of the orbit. This causes the relativistic variation in the mass of the moving electron

X–rays

A German scientist, Wilhelm Roentgen, in 1895, discovered X–rays X-rays are electromagnetic waves of short wavelength in the range of 0.5 Å to 10 Å. Roentgen was awarded Nobel prize in 1901 for the discovery of X–rays

Production of X–rays – Modern Coolidge tube

X–rays are produced, when fast moving electrons strike a metal target of suitable material. The basic requirement for the production of X–rays are: (i) a source of electrons, (ii) effective means of accelerating the electrons and (iii) a target of suitable material of high atomic weight.

Soft X–rays and Hard X–rays

X–rays are of two types : (i) Soft X–rays and (ii) Hard X–rays

(i) Soft X–rays

X–rays having wavelength of 4Å or above, have lesser frequency and hence lesser energy. They are called soft X – rays due to their low penetrating power. They are produced at comparatively low potential difference.

(ii) Hard X–rays

X–rays having low wavelength of the order of 1Å have high frequency and hence high energy. Their penetrating power is high, therefore they are called hard X–rays. They are produced at comparatively high potential difference.

Properties of X–rays

1. X–rays are electromagnetic waves of very short wave length. They travel in straight lines with the velocity of light. They are invisible to eyes.
2. They undergo reflection, refraction, interference, diffraction and polarisation.
3. They are not deflected by electric and magnetic fields. This indicates that X-rays do not have charged particles.
4. They ionize the gas through which they pass.
5. They affect photographic plates.
6. X–rays can penetrate through the substances which are opaque to ordinary light e.g. wood, flesh, thick paper, thin sheets of metals.
7. When X–rays fall on certain metals, they liberate photo electrons (Photo electric effect).
8. X-rays have destructive effect on living tissue. When the human body is exposed to X-rays, it causes redness of the skin, sores and serious injuries to the tissues and glands. They destroy the white corpuscles of the blood.
9. X–rays do not pass through heavy metals such as lead and bones. If such objects are placed in their path, they cast their shadow

Applications of X–rays

X–rays have a number of applications. Some of them are listed below:

Medical applications

- ❖ X–rays are being widely used for detecting fractures, tumours, the presence of foreign matter like bullet etc., in the human body.
- ❖ X–rays are also used for the diagnosis of tuberculosis, stones in kidneys, gall bladder etc.
- ❖ Many types of skin diseases, malignant sores, cancer and tumours have been cured by controlled exposure of X-rays of suitable quality.
- ❖ Hard X–rays are used to destroy tumours very deep inside the body.

Industrial applications

a. X–rays are used to detect the defects or flaws within a material

b. X–rays can be used for testing the homogeneity of welded joints, insulating materials etc.

c. X-rays are used to analyse the structure of alloys and the other composite bodies.

d. X–rays are also used to study the structure of materials like rubber, cellulose, plastic fibres etc.

Scientific research

1. X–rays are used for studying the structure of crystalline solids and alloys.
2. X–rays are used for the identification of chemical elements including determination of their atomic numbers.
3. X–rays can be used for analyzing the structure of complex molecules by examining their X–ray diffraction pattern.

Laser

Some sources have been developed, which are highly coherent known as LASER. The word ‘Laser’ is an acronym for Light Amplification by Stimulated Emission of Radiation.

Characteristics of laser

The laser beam (i) is monochromatic. (ii) is coherent, with the waves, all exactly in phase with one another, (iii) does not diverge at all and (iv) is extremely intense

Applications of laser

Due to high coherence, high intensity, laser beams have wide applications in various branches of science and engineering.

Industrial applications

a. The laser beam is used to drill extremely fine holes in diamonds, hard sheets etc.,
b. They are also used for cutting thick sheets of hard metals and welding.
c. The laser beam is used to vapourize the unwanted material during the manufacture of electronic circuit on semiconductor chips.
d. They can be used to test the quality of the materials.

Medical applications

a. In medicine, micro surgery has become possible due to narrow angular spread of the laser beam.
b. It can be used in the treatment of kidney stone, tumour, in cutting and sealing the small blood vessels in brain surgery and retina detachment.
c. The laser beams are used in endoscopy.
d. It can also be used for the treatment of human and animal cancer.

Scientific and Engineering applications

1. Since the laser beam can stay on at a single frequency, it can be modulated to transmit large number of messages at a time in radio, television and telephone.
2. The semiconductor laser is the best light source for optical fiber communication.
3. Narrow angular spread of the laser beam makes it a very useful tool for microwave communication. Communication with earth satellites and in rocketry. Laser is also used in accurate range finders for detecting the targets.
4. The earth-moon distance has been measured with the help of lasers.
5. It is used in laser Raman Spectroscopy.

6. Laser is also used in holography (three dimensional lensless photography)
7. Laser beam can determine precisely the distance, velocity and direction as well as the size and form of the objects by means of the reflected signal as in radar.

Holography

- A three dimensional image of an object can be formed by holography. In ordinary photography, the amplitude of the light wave is recorded on the photographic film. In holography, both the phase and amplitude of the light waves are recorded on the film. The resulting photograph is called hologram.

MASER

- The term MASER stands for Microwave Amplification by Stimulated Emission of Radiation. The working of maser is similar to that of laser.

NUCLEAR PHYSICS

Nuclear Physics

- The atomic nucleus was discovered by Earnest Rutherford in 1911. Rutherford's experiment on scattering of alpha particles proved that the mass of the atom and the positive charge is concentrated in a very small central core called nucleus. The dimension of nucleus is much smaller than the overall dimension of the atom. The nucleus is surrounded by orbiting electrons.

Nucleus

- The nucleus consists of the elementary particles, protons and neutrons which are known as nucleons. A proton has positive charge of the same magnitude as that of electron and its rest mass is about 1836 times the mass of an electron. A neutron is electrically neutral, whose mass is almost equal to the mass of the proton. The nucleons inside the nucleus are held together by strong attractive forces called nuclear forces.
- A nucleus of an element is represented as $_{Z}X^{A}$, where X is the chemical symbol of the element. Z

represents the atomic number which is equal to the number of protons and A, the mass number which is equal to the total number of protons and neutrons. The number of neutrons is represented as N which is equal to A–Z. For example, the chlorine nucleus is represented as $_{17}Cl^{35}$. It contains 17 protons and 18 neutrons.

Classification of nuclei

(i) Isotopes

- Isotopes are atoms of the same element having the same atomic number Z but different mass number A. The nuclei $1H1$, H^2 and H^3 are the isotopes of hydrogen. In other words isotopes of an element contain the same number of protons but different number of neutrons. As the atoms of isotopes have identical electronic structure, they have identical chemical properties

(ii) Isobars

- Isobars are atoms of different elements having the same mass number A, but different atomic number Z. The nuclei $_8O^{16}$ and $_7N^{16}$ represent two isobars. Since isobars are atoms of different elements, they have different physical and chemical properties.

(iii) Isotones

- Isotones are atoms of different elements having the same number of neutrons. $_6C^{14}$ and $_8O^{16}$ are some examples of isotones.

General properties of nucleus

Nuclear size

- measure of nuclear radius, which is approximately 10^{-15}m.

  (1 Fermi, F = 10^{-15}m)

Nuclear density

The nuclear density is calculated as 1.816×10^{17} kg m^{-3}

Nuclear charge

Proton has a positive charge equal to 1.6×10^{-19}C.

Atomic mass unit

- One atomic mass unit is considered as one twelfth of the mass of carbon atom 6C12. Carbon of atomic number 6 and mass number 12 has mass equal to 12 amu.

$$1 \text{ amu} = 1.66 \times 10^{-27}\text{kg}$$

The mass of a proton, mp = 1.007276

$$\boxed{1 \text{ amu} = 931 \text{ MeV}}$$

Binding energy

Explanation of binding energy curve

- The binding energy per nucleon increases sharply with mass number A upto 20. It increases slowly after A = 20. For A<20, there exists recurrence of peaks corresponding to those nuclei, whose mass numbers are multiples of four and they contain not only equal but also even number of protons and neutrons. Example: $He4$, ${}_{4}Be^{8}$, C^{12}, ${}_{8}O^{16}$, and ${}_{10}Ne^{20}$. The curve becomes almost flat for mass number between 40 and 120. Beyond 120, it decreases slowly as A increases.
- The binding energy per nucleon reaches a maximum of 8.8 MeV at A=56, corresponding to the iron nucleus (${}_{26}Fe^{56}$). Hence, iron nucleus is the most stable.
- The average binding energy per nucleon is about 8.5 MeV for nuclei having mass number ranging between 40 and 120. These elements are comparatively more stable and non radioactive.
- For higher mass numbers the curve drops slowly and the BE/A is about 7.6 MeV for uranium. Hence, they are unstable and radioactive.
- The lesser amount of binding energy for lighter and heavier nuclei explains nuclear fusion and fission respectively. A large amount of energy will be liberated if lighter nuclei are fused to form heavier one (fusion) or if heavier nuclei are split into lighter ones (fission).

Nuclear force

1. Nuclear force is charge independent. It is the same for all the three types of pairs of nucleons (n−n), (p−p) and (n−p). This shows that nuclear force is not electrostatic in nature
2. Nuclear force is the strongest known force in nature.
3. Nuclear force is not a gravitational force. Nuclear force is about 10^{40} times stronger than the gravitational force.
4. Nuclear force is a short range force. It is very strong between two nucleons which are less than 10^{-15} m apart and is almost

negligible at a distance greater than this. On the other hand electrostatic, magnetic and gravitational forces are long range forces that can be felt easily. Yukawa suggested that the nuclear force existing between any two nucleons may be due to the continuous exchange of particles called mesons, just as photons, the exchange particle in electromagnetic interactions. However, the present view is that the nuclear force that binds the protons and neutrons is not a fundamental force of nature but it is secondary.

Radioactivity

- Radioactivity was discovered by Henri Becquerel in 1896 The phenomenon of spontaneous emission of highly penetrating radiations such as α, β and γ rays by heavy elements having atomic number greater than 82 is called radioactivity and the substances which emit these radiations are called radioactive elements The radioactive phenomenon is spontaneous and is unaffected by any external agent like temperature, pressure, electric and magnetic fields etc.

Properties of α–rays

1. An α - particle is a helium nucleus consisting of two protons and two neutrons. It carries two units of positive charge.
2. They move along straight lines with high velocities.
3. They are deflected by electric and magnetic fields.
4. They produce intense ionisation in the gas through which they pass. The ionising power is 100 times greater than that of β-rays and 10,000 times greater than that of γ–rays.
5. They affect photographic plates.
6. They are scattered by heavy elements like gold.
7. They produce fluorescence when they fall on substances like zinc sulphide or barium platinocyanide.

Properties of β – rays

1. β–particles carry one unit of negative charge and mass equal to that of electron.Therefore, they are nothing but electrons.
2. The β–particles emitted from a source have velocities over the range of 0.3 c to 0.99 c, where c is the velocity of light.
3. They are deflected by electric and magnetic fields.
4. The ionisation power is comparatively low
5. They affect photographic plates.
6. They penetrate through thin metal foils and their penetrating power is greater than that of α–rays
7. They produce fluorescence when they fall on substances like barium platinocyanide.

Properties of γ – rays

1. They are electromagnetic waves of very short wavelength.
2. They are not deflected by electric and magnetic fields.
3. They travel with the velocity of light.
4. They produce very less ionisation.
5. They affect photographic plates.
6. They have a very high penetrating power, greater than that of β-rays.
7. They produce fluorescence.
8. They are diffracted by crystals in the same way like X–rays are diffracted.

Half life period

❖ Since all the radioactive elements have infinite life period, in order to distinguish the activity of one element with another, half life period and mean life period are introduced. The half life period of a radioactive element is defined as the time taken for one half of the radioactive element to undergo disintegration.

From the law of disintegration

$$\boxed{N = N_0 e^{-\lambda t}}$$

The half life and mean life are related as

$T_{1/2} = \frac{0.6931}{\lambda}$

$T_{1/2} = 0.6931\tau$

Neutron

Chadwick in the discovered that the emitted radiation consists of particles of mass nearly equal to proton and no charge.

$${}_4Be^9 + {}_2He^4 \rightarrow {}_6C^{12} + {}_0n^1$$

where ${}_0n^1$ represents neutron

Properties of neutrons

1. Neutrons are the constituent particles of all nuclei, except hydrogen.
2. Neutrons are neutral particles with no charge and mass slightly greater than that of protons. Hence, they are not deflected by electric and magnetic fields.
3. Neutrons are stable inside the nucleus. But outside the nucleus they are unstable. The free neutron decays with an emission of proton, electron and antineutrino, with half life of 13 minutes. ${}_0n^1 \rightarrow {}_1H^1 + {}_{-1}e^0 + \bar{\nu}$
4. As neutrons are neutral, they can easily penetrate any nucleus.
5. Neutrons are classified according to their kinetic energy as (a) slow neutrons and (b) fast neutrons. Both are capable of penetrating a nucleus causing artificial transmutation of the nucleus. Neutrons with energies from 0 to 1000 eV are called slow neutrons. The neutrons with an average energy of about 0.025 eV in thermal equilibrium are called thermal neutrons. Neutrons with energies in the range between 0.5 MeV and 10 MeV are called fast neutrons. In nuclear reactors, fast neutrons are converted into slow neutrons using moderators.

Artificial radioactivity

- Artificial radioactivity or induced radioactivity was discovered by Irene Curie and F. Joliot in 1934. This is also known as man-made Radioactivity

Applications of radio-isotopes

Medical applications

- In medical field, radio-isotopes are used both in diagnosis and therapy. Radio cobalt (Co^{60}) emitting γ–rays is used in the treatment of cancer. Gamma rays destroy cancer cells to a greater extent. Radio-sodium (Na^{24}) is used to detect the presence of blocks in blood vessels, to check the effective functioning of heart in pumping blood and maintaining circulation. Radio-iodine (I^{131}) is used in the detection of the nature of thyroid gland and also for treatment. Radioiodine is also used to locate brain tumours. Radio-iron (Fe^{59}) is used to diagnose anaemia. An anaemic patient retains iron in the blood longer than normal patient. Radio-phosphorous (P^{32}) is used in the treatment of skin diseases.

(ii) Agriculture

- ❖ In agriculture, radio-isotopes help to increase the crop yields. Radio-phosphorous (P^{32}) incorporated with phosphate fertilizer is added to the soil. The plant and soil are tested from time to time. Phosphorous is taken by the plant for its growth and radio-phosphorous is found to increase the yield.
- ❖ Sprouting and spoilage of onions, potatoes, grams etc. are prevented by exposure to a very small amount of radiation. Certain perishable cereals remain fresh beyond their normal life span when exposed to radiation.

(iii) Industry

- ❖ In Industry, the lubricating oil containing radio-isotopes is used to study the wear and tear of the machinery.

(iv) Molecular biology

- ❖ In molecular biology radio-isotopes are used in sterilizing pharmaceutical and surgical instruments.

(v) Radio-carbon dating

- ❖ In the upper atmosphere, C_{14} is continually formed from N_{14} due to the bombardment by neutrons produced from cosmic rays.

$$_7N^{14} + {}_0n^1 \rightarrow {}_6C^{14*} + {}_1H^1$$

- ❖ The C_{14} is radioactive with half life of 5570 years. The production and the decay of C_{14} are in equilibrium in atmosphere. The ratio of C_{14} and C_{12} atoms in atmosphere is $1 : 10^6$. Hence, carbon dioxide present in the atmosphere contains a small portion of C_{14}.
- ❖ Living things take C_{14} from food and air. However with death, the intake of C_{14} stops, and the C_{14} that is already present begins to decay. Hence the amount of C_{14} in the sample will enable the

calculation of time of death i.e, the age of the specimen could be estimated. This is called radio-carbon dating. This method is employed in the dating of wooden implements, leather clothes, charcoal used in oil paintings, mummies and so on.

Biological hazards of nuclear radiations

- When γ-ray or any high energy nuclear particle passes through human beings, it disrupts the entire normal functioning of the biological system and the effect may be either pathological or genetic. The biological effects of nuclear radiation can be divided into three groups

(i) Short term recoverable effects

(ii) Long term irrecoverable effects and

(iii) Genetic effect

The extent to which the human organism is damaged depends upon

(i) The dose and the rate at which the radiation is given and

(ii) The part of the body exposed to it.

Smaller doses of radiation exposure produce short term effects such as skin disorder and loss of hair. If the exposure is 100 R*, it may cause diseases like leukemia (death of red blood corpuscle in the blood) or cancer. When the body is exposed to about 600 R, ultimately it causes death. Safe limit of receiving the radiations is about 250 milli roentgen per week. The genetic damage is still worse. The radiations cause injury to genes in the reproductive cells. This gives rise to mutations which pass on from generation to generation. The following precautions are to be taken for those, who are working in radiation laboratories.

1. Radioactive materials are kept in thick–walled lead container.
2. Lead aprons and lead gloves are used while working in hazardous area.
3. All radioactive samples are handled by a remote control process.
4. A small micro–film badge is always worn by the person and it is checked periodically for the safety limit of radiation.

The radiation exposure is measured by the unit called roentgen (R). One roentgen is defined as the quantity of radiation which produces 1.6×10^{12} pairs of ions in 1 gram of air.

Nuclear fission

- In 1939, German scientists Otto Hahn and F. Strassman discovered that when uranium nucleus The process of breaking up of the nucleus of a heavier atom into two fragments with the release of large amount of energy is called nuclear fission.

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$$

- Atom bomb is based on the principle of uncontrolled fission chain reaction. Natural uranium consists of 99.28% of U^{238} and 0.72% of U^{235}. U^{238} is fissionable only by fast neutrons. Hence, it is essential in a bomb that either U^{235} or Pu^{239} should be used, because they are fissionable by neutrons of all energies

Nuclear reactor

- A nuclear reactor is a device in which the nuclear fission reaction takes place in a self sustained and controlled manner. The first nuclear reactor was built in 1942 at Chicago USA

Fissile material or fuel

- The fissile material or nuclear fuel generally used is $_{92}U^{235}$. But this exists only in a small amount (0.7%) in natural uranium. Natural uranium is enriched with more number of $_{92}U^{235}$ (2 – 4%) and this low enriched uranium is used as fuel in some reactors. Other than U^{235}, the fissile isotopes U^{233} and Pu^{239} are also used as fuel in some of the reactors.

Moderator

- The function of a moderator is to slow down fast neutrons produced in the fission process having an average energy of about 2 MeV to thermal neutrons with an average energy of about 0.025 eV, which are in thermal equilibrium with the moderator. Ordinary water and heavy water are the commonly used moderators Graphite is also used as a moderator in some countries. In fast breeder reactors, the fission chain reaction is sustained by fast neutrons and hence no moderator is required.

Neutron source

- A mixture of beryllium with plutonium or radium or polonium is commonly used as a source of neutron

Control rods

- The control rods are used to control the chain reaction. They are very good absorbers of neutrons. The commonly used control rods are made up of elements like boron or cadmium In our country, all the power reactors use boron carbide (B_4C), a ceramic material as control rod.

The cooling system

- The cooling system removes the heat generated in the reactor core. Ordinary water, heavy water and liquid sodium are the commonly used coolants. A good coolant must possess large specific heat capacity and high boiling point. Liquid sodium boiling point is about 1000^o C.

Neutron reflectors

Neutron reflectors prevent the leakage of neutrons to a large extent, by reflecting them back

Uses of reactors

a. Nuclear reactors are mostly aimed at power production, because of the large amount of energy evolved with fission.
b. Nuclear reactors are useful to produce radio-isotopes
c. Nuclear reactor acts as a source of neutrons, hence used in the scientific research

Nuclear fusion

- Nuclear fusion is a process in which two or more lighter nuclei combine to form a heavier nucleus. The mass of the product nucleus is always less than the sum of the masses of the individual lighter nuclei. The difference in mass is converted into energy. The fusion process can be carried out only at a extremely high temperature of the order of 10^7 K

The nuclear fusion reactions are known as thermo-nuclear reactions

Hydrogen bomb

- The principle of nuclear fusion is used in hydrogen bomb. It is an explosive device to release a very large amount of energy by the fusion of light nuclei.

$$_1H^3 + {}_1H^2 \rightarrow {}_2He^4 + {}_0n^1 + \textbf{energy}$$

Elementary particles

The study of the structure of atom reveals that the fundamental particles electron, proton and neutron are the building blocks of an atom. But the extensive studies on cosmic rays have revealed the existence of numerous new nuclear particles like mesons. These particles are classified into four major groups as photons, leptons mesons and baryons.

The heavy water project is located at Tuticorin.