Atomic Physics is a branch of Physics which deals with the structure and the properties of atoms of elements.

An atom consists of negatively charged electron revolving round the positively charged nucleus.

The atomic nucleus is a cluster of charged protons and uncharged neutrons occupying a small region at the centre of the atom with a diameter of the order of $10^{-14}$ Protons and neutrons in the nucleus are called nucleons.

Nuclear physics is the study of structure of nucleus and nuclear processes such as radioactivity and nuclear reactions.

In this chapter we shall study the electromagnetic waves, the radio activity and the production of nuclear energy.

**Electromagnetic Radiation**

- Ordinary waves like ocean waves and the waves created by the wind in a flag are visible mechanical waves.
- Sound waves is another mechanical wave which cannot be seen. All these mechanical waves need a material medium to propagate.
- There are other kinds of waves known as electromagnetic waves which do not need material medium to propagate.
- Electromagnetic waves consist of a magnetic field and an electric field vibrating at right angles to each other.
- Energy changes in atoms or electrons produce electromagnetic waves.

**1. Classification of electromagnetic waves**

- Electromagnetic waves cover a wide range of frequencies or wave lengths.
- The behaviour of an electromagnetic wave is determined by its wavelength and hence it is useful to group electromagnetic waves according to their wave lengths. Electromagnetic waves are classified into seven types, viz.,
  - Gamma rays
  - X-rays
  - Ultra violet rays
  - Visible rays
  - Infra red rays
  - Micro waves
  - Radio waves
All the electromagnetic waves have the following common properties

- All electromagnetic waves travel at the same speed ($3 \times 10^8$ ms$^{-1}$) in vacuum or through space. The speed of electromagnetic waves is given by $c = \gamma \lambda$
- where $\gamma$ is the frequency and $\lambda$ is the wavelength of electromagnetic waves. They do not need any material medium to propagate.
- All are transverse waves.
- All exhibit the basic wave properties, reflection, refraction, interference and diffraction etc.,
- They carry no electric charge.
- They transfer energy from one place to another. They can be emitted and absorbed by matter.

2. X-rays

- X-rays were discovered first by W. Roentgen in the year 1895. As the nature of radiation was unknown at that time he called them X-rays. These rays are also called as Roentgen rays.

Production of X-rays
7. Atomic and Nuclear Physics

• **Principle**: When fast moving electrons fall on a target of high atomic weight X-rays designed by Coolidge.

• It consists of highly evacuated (~0.0001 mm of Hg pressure) hard glass tube containing a cathode and an anode.

• Molybdenum metallic cylinder (M) and tungsten filament (F) together act as cathode. The anode is a block of copper in which the target tungsten is embedded.

• Tungsten has high atomic weight and high melting point as well as very good electrical and thermal conductivities.

• The tungsten filament F is heated by a low voltage battery (4 V) to emit electrons. These electrons are highly accelerated and focussed by Molybdenum metallic cylinder on to the anode by applying a high potential difference of about 1,00,000 V between the cathode and the anode.

• As the fast moving electrons strike the solid tungsten in the anode X-rays are emitted. In order to save the target from melting it is constantly cooled by running water.

• The intensity of X-rays depends on the number of electrons striking the target per second. By adjusting the filament current the intensity of X-rays can be controlled. The quality of X-rays depends on the energy of electrons. Hence the quality of X-rays can be controlled by adjusting the voltage between the cathode and anode.

**Properties of X-rays**
• X-rays are electromagnetic waves having a wavelength range from $10^{-9}$ m to $6 \times 10^{-12}$ m.
• X-rays travel with the velocity of light.
• X-rays are not deflected by electric and magnetic fields since they are not charged. They produce fluorescence in certain materials like Zinc Sulphide and Barium Platino- cyanide.
• They affect photographic plates strongly.
• They ionise the gases through which they pass.
• They can pass through substances like glass, flesh, wood etc. But they cannot pass through bones and heavy elements such as gold and lead. Bones contain large amount of calcium which is a heavy element and hence they are good absorbers of X-rays. But soft tissues of flesh contain lighter elements like hydrogen, carbon, nitrogen, oxygen and hence they are poor absorbers of X-rays. Hence X-rays can pass through flesh.
• An exposure to a large dose of X-rays may cause enough destruction to produce sickness or death.

Applications of X-rays

• X-rays play an important role in medicine, industry, scientific research and forensic Sciences.

Medical Applications

• Radiography : X-ray photographs are used to detect fracture and dislocation of bones. They are used to locate the foreign body in digestive track or lungs and the bullet embedded in a limb.
• Radiotheraphy : They are used to destroy malignant tumours and cure some skin diseases.
Industrial and Scientific applications

- They are used to find whether a given gem is genuine or artificial.
- X-rays are used to detect the defects in tennis balls, rubber tyres, etc. They are used for the detection of cracks and flaws in metal castings and welded joints in machinery parts etc.
- The X-rays are used to study the effect of heat treatment and the formation of alloys.
- X-rays are used to study the structure of crystals, organic and biological molecules.

Applications in Forensic Science

- X-ray examination, screening and radiographs can be used in crime detection.
- If a person is suspected to have swallowed jewel, the object would be revealed in a X-ray radiograph.
- The hidden gold, opium and explosive in a luggage can be identified using X-rays with a fluorescent screen.
- Very soft X-rays are used for the detection of counterfeit currency and forgery in documents.

3. Infrared Rays (IR rays)
Electromagnetic radiation with wavelengths a little longer than that of red light is called infrared radiations.

- This covers wavelengths from $10^{-3}$ m to $7.8 \times 10^{-7}$ m. These waves are produced by molecules of hot bodies.
- Sun is the natural source of infra red rays. Electric lamp, fire, molecules of hot bodies are the artificial sources of infra red radiations.
- Human body gives off IR radiation with a wavelength of $1/10$ mm to $1/100$ mm. The human eye cannot detect IR radiation but we can feel it on our skin as warmth. Some snakes have specially designed sense organs which make good use of this ability.
- They are situated in pit on either side of their head, and they use them to ‘see’ a warm object, such as a mouse in the dark.

### Uses of IR rays

- Infra-red radiations are not absorbed by air or thick fog. Hence infra-red rays are used to take photographs where visible light cannot penetrate.
- Infra red can penetrate deep into the human body than visible light. These IR rays enlarge blood vessels which increase the blood circulation.
- In physio-theraphy IR is used to relieve pain from muscles and joints. They are used in the determination of molecular structure.
- They are used to dry newly painted and enamelled surfaces within a short time. During second world war infra-red lamps were fitted to military vehicles for night driving.
- As water absorbs IR radiation, satellite pictures of lakes and rivers would appear black. Hence IR radiation can be used to identify the water sources on the earth. Infra red satellite pictures of the earth are used in weather forecasting.
- IR satellite photos reveal diseased crops.

### 4. Microwaves
Shorter wave length radio waves with wavelengths from 1 mm to 10 cm are known as microwaves.
Microwaves are generated by special electronic devices such as, magnetron, klystron and travelling wave tube.

Applications

• Telephone links between cities are achieved by microwaves. Microwaves are used in satellite communication and radar.
• Microwaves are used for cooking. A microwave oven produces electromagnetic waves with a wave length of about 12 cm. These waves transmit energy to cook the food.
• Microwaves can be used to kill insects in grain stores and also used to kill bacteria in food without heating the food so much.
• Microwaves are used in the field of radio astronomy. They are used to study atomic and molecular structures.

5. Radio waves

• Electromagnetic waves with longest wavelengths are called radio waves. They have a wavelength range from 0.3 m to a few kilometer.
• Radio waves are produced by stars and galaxies. They are also produced by vibrating electrons using electronic circuits.
• They are used in Radio and Television communication systems.

Radioactivity
Radioactivity was discovered by Henry Becquerel in the year 1896. He found that uranium and some of its salts emit spontaneously some invisible penetrating radiations which affected the photographic plate.

This phenomenon of spontaneous emission of highly penetrating radiations by heavy elements is called radioactivity.

The elements which emit radioactive radiations are called radioactive elements or radioelements.

These radiations are called Becquerel rays or radioactive rays.

Later investigations by Madame Curie, and her husband Pierre Curie, Rutherford and others showed that the phenomenon was exhibited by heavy elements of atomic weights greater than 206 like Uranium, Polonium, Radium, Thorium etc.,

The radio activity is not affected by physical or chemical conditions like variations of temperature or pressure.

1. Experimental study of Radioactivity

- A small quantity of some radioactive material is placed at the bottom of a small hole drilled in a lead block.
- Lead is the best absorber of all kinds of radiations. Hence radiations in all other directions will be absorbed by lead.
- A photographic plate is placed at a short distance above the lead block.
- The whole arrangement is enclosed inside an evacuated chamber and placed in a dark room.
- A strong magnetic field is applied at right angles to the plane of the diagram.
- After a long exposure, the photographic plate is developed. Three distinct spots are found on the photographic plate.
- It is observed that the beam of radiations coming out of the hole splits into three parts.
- The first part which bends towards the left end is called a- particles, the second part which bends towards the right end is called b particles, while the third part which goes straight without bending is called g-rays.
- By applying Fleming’s left hand rule it may be seen that a- particles are positively charged, b particles are negatively charged while g-rays are uncharged or neutral.
Distinction between Y rays and X-rays.

- γ rays and X-rays are both electromagnetic radiations which differ from each other as given in table 5.2.

Comparision of Y rays with X-rays.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Y rays</th>
<th>X-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>γ rays are produced due to the spontaneous emission of radiation from the nucleus. (nuclear origin)</td>
<td>rays are produced due to the transition of electrons from higher to lower energy orbits of atoms (atomic origin).</td>
</tr>
<tr>
<td>2.</td>
<td>The wavelength of γ rays is much shorter than that of X-rays</td>
<td>Shorter wavelength</td>
</tr>
</tbody>
</table>

Radioactive decay:

- When a radioactive nucleus disintegrates by emitting a or b particles a new element is formed.
- α- decay: When a radioactive nucleus disintegrates by emitting an α - particle its atomic number decreases by two and its mass number decreases by four.
- where Z-atomic number, A-mass number X-parent element, Y-daughter element

\[ XA \quad z \quad \rightarrow \quad 2 \ Y A - 4 \ + \ 2 He 4 \]

2He4- α particle.

Example: Uranium decays to thorium by a emission.

92 U238 \rightarrow 90Th234 + 2He4
• **β - decay**: When a radioactive substance disintegrates by emitting a β - particle there is no change in its mass number but its atomic number increases by one.

• **Example**: Radium decays to actinium by β emission.

\[
\begin{align*}
88 \text{Ra}_{228} & \rightarrow 89 \text{Ac}_{228} + -1e0
\end{align*}
\]

• **γ emission**: When a radioactive substance emits a γ-ray there is no change in both atomic number and mass number. Only the energy level of the nucleus undergoes a change.

### Nuclear Fission and Nuclear fusion:

2. **Nuclear fission**

- In 1939 Otto Hahn and Strassman in Germany bombarded uranium by neutrons.
- It exploded into two nearly equal fragments of lighter elements such as Barium and Krypton and enormous amount of energy.
- Since this process somewhat resembles fission of cells in biology this phenomenon of nuclear disintegration is called **nuclear fission**.
- The process of breaking up of the nucleus of a heavy atom into two nearly equal fragments with the release of a large amount of energy is known as **nuclear fission**. When uranium is bombarded with slow neutrons, the uranium nucleus becomes unstable. This unstable uranium nucleus splits into two nearly equal fragments.
- Two or three free neutrons are also released in this process.

\[
\begin{align*}
92 \text{U}_{235} + 0n1 & \rightarrow 92 \text{U}_{236}
\end{align*}
\]

\[
\begin{align*}
56 \text{Ba}_{141} + 36 \text{Kr}_{92} + 3 0n1 + Q
\end{align*}
\]

• Here Q is the amount of energy released.
2. Energy released in Nuclear Fission

- During nuclear fission enormous amount of energy is released. This energy is produced because the original mass of the nucleus is greater than the sum of the masses of the end products.
- The excess mass appears as energy in accordance with the Einstein’s mass energy relation \( E = mc^2 \).
- In order to calculate the energy released let us consider the above fission reaction.
- Mass of \(^{92}\text{U}235\) nucleus = 235.045733 a.m.u. (a.m.u means atomic mass unit) = 200.5 MeV
- (MeV = Million electron volt)
- Thus when one nucleus of uranium undergoes fission 200 MeV energy is released. The energy released by the fission of one gram of uranium is \(5.128 \times 10^{23}\) MeV, which is equivalent to \(2.26 \times 10^4\) kilowatt hour. Since large amount of energy is released in fission the nuclear energy is being used for the generation of electricity.

3. Chain Reaction:
The chain reaction is a process in which the nuclear fission of an atom induces nuclear fission in another atom which again induces fission in another atom and so on.

During fission process neutrons are emitted which attack other atoms causing fission.

The number of neutrons goes on multiplying rapidly during fission process till the whole of the fissionable material is disintegrated.

Let us consider the chain reaction in uranium (U235).

When uranium nucleus is bombarded by slow neutrons the nucleus is broken into two parts viz. Barium and Krypton.

The process is accompanied by the emission of three neutrons. Nearly 200 MeV energy is released per fission.

The neutrons thus produced in this process further attack other uranium nuclei and produce further fission.

Now more number of neutrons are released and an enormous amount of energy is produced.

This process continues and the series of fission reaction is called a chain reaction. If the number of neutrons produced in a nuclear fission is not controlled a large amount of energy is released in a violent explosion within a very short interval of time.

This is called uncontrolled chain reaction, which is the basic principle of the atom bomb.

4. Nuclear Reactor
A nuclear reactor is a device in which nuclear fission is produced under a self sustaining controlled nuclear chain reaction.

The following are the essential components of a nuclear reactor.

- **Fuel**: The material containing fissile isotope is called reactor fuel. U 235, Pu239 and U233 are used as fuel in the reactor. The fuel is sealed in aluminium cylinder and kept in the form of rods. Natural uranium contains 99.28% of U238 and only 0.72% of fissile U235. The fissile U235 fuel is called enriched uranium.

- **Moderator**: The moderator is a material which is used to slow down the neutrons produced by nuclear fission. Graphite, heavy water (D2O), Berillium and its oxides are used as a good moderator should have high boiling point and low atomic number.

- **Control Rods**: In order to control the chain reaction, control rods are used. These rods are made up of neutron absorbing materials. Cadmium, boron or Hafnium rods are used as control rods. When the control rod is completely pushed into the fuel, the neutrons are absorbed and hence the chain reaction stops. If the rods are withdrawn stronger will be the chain reaction.

- **Coolant**: A material used to absorb the heat generated in chain reaction is called coolant. The heat carried by coolant is used to convert water into steam which in turn runs the turbines to produce electricity. Ordinary water, heavy water, air, carbon-dioxide, helium gas and liquid sodium are used as coolants. Heavy water serves both as moderator and as coolant. A pump is provided to pump the coolant into the reactor. The coolant should have high boiling point and high specific heat.

- **Neutron reflector**: Neutron reflector is a material surrounding the fuel and moderator. It is used to reflect the escaping neutrons back into the reactor. This minimises the leakage of neutrons.

- **Shielding**: The radiations emitted during nuclear fission reactions are very dangerous and harmful to living beings. To protect the people operating the reactor it is surrounded by thick lead lining and concrete wall of thickness about 2 to 2.5 metre.

### 5. Nuclear Fusion
The process of combining two or more lighter nuclei to form a heavier and stable nucleus with the release of a large amount of energy is known as nuclear fusion. The mass of the single nucleus formed in fusion is always less than the sum of the mass of the individual light nuclei.

- The difference in mass is converted into energy according to Einstein’s mass energy relation \( E = mc^2 \).
- For example when two deuterium nuclei fuse together a helium nucleus is formed

\[
1H_2 + 1H_2 \rightarrow 2He_4 = 23.84 \text{ MeV}
\]

Since the process of nuclear fusion requires a very high temperature, the nuclear fusion reactions are called the thermonuclear reactions and the energy released is termed as the thermonuclear energy.

- Bethe has given a detailed theory of nuclear reactions in the sun and stars. He proposed a carbon-nitrogen cycle as one of the most important nuclear reactions for the release of energy from the sun.
- In this cycle four protons fuse together to give a helium nucleus two positrons and energy equal to 24.7 MeV.

\[
4\, ^1H_1 \rightarrow 2He_4 + 2\, ^1e_0 + \text{energy}
\]

- Stars which are hotter than the sun get their energy from the carbon-nitrogen cycle. Stars which are cooler than the sun get their energy through another cycle called proton-proton cycle.
- In the proton-proton cycle also four protons fuse together to give a helium nucleus. Carbon acts as a catalyst in the carbon-nitrogen cycle and there is no catalyst in the proton-proton cycle.
- Fusion is the process which powers the sun and stars where temperatures are very high.

**Advantages of using nuclear fusion:**

- The required fuels like hydrogen, deuterium and lithium nuclei are in plentiful supply in the sea.
- There are no nuclear waste materials left in fusion.
Differences between nuclear fission and fusion:

<table>
<thead>
<tr>
<th>Nuclear Fission</th>
<th>Nuclear Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A heavy nucleus is split up into two fragments</td>
<td>Two lighter nuclei fuse</td>
</tr>
<tr>
<td>It produces harmful energy. Hence nuclear fission energy is not a clean energy.</td>
<td>It does not produce any harmful radiations. Hence fusion energy is called a clean energy.</td>
</tr>
<tr>
<td>This process is possible even at room temperature</td>
<td>This process is only possible at very high temperature (~107 K)</td>
</tr>
<tr>
<td>The links of this process are neutrons</td>
<td>The links of this process are protons.</td>
</tr>
<tr>
<td>The energy produced per nucleon is 0.85 MeV.</td>
<td>The energy produced per nucleon is 6.75 MeV.</td>
</tr>
<tr>
<td>This principle is used in the explosion of Atom Bomb</td>
<td>This principle is used in the explosion of Hydrogen Bomb</td>
</tr>
</tbody>
</table>

Advantages and hazards of nuclear energy and safety measures

2. Advantages of nuclear energy
• **Nuclear power stations** have many advantages over thermal power stations.
• Nuclear power stations do not produce gases like carbon dioxide and sulphur oxides. So they do not pollute the atmosphere.
• Their fuel uranium will not run out even after the available fossil fuels are used up completely.
• Some reactors called breeder reactors actually produce nuclear fuel while they are in operation.
• The nuclear reactors generate power for the propulsion of ships and submarines. They produce radio isotopes and neutron beam for medical and nuclear research applications.

### 2. Hazards of nuclear energy

• Inspite of all these advantages there are many disadvantages also. People all over the world are always exposed to radiation. α, β and γ radiations are all ionizing radiations.
• They knock electrons away from atoms when they pass through them. This causes a change in the structure and behaviour of molecules in cells.
• If an organism receives a large dose of radiation, then many molecules may get damaged.
• This affects all the processes taking place in the body and the person feels ill. This is known as radiation sickness.
• If a nuclear reactor runs out of control large amounts of radiation may be released into air.
• This happened at the nuclear station in Chernobyl, Russia, in 1986. Hence the radiation spreaded into air and blown by winds into the Central Europe thousands of kilometers away.
• Some farmers in Britain were not able to sell their lambs for meat because of radioactive contamination of the soil from the Chernobyl accident even after five years.
• The unit of radiation exposure is roentgen.
• One roentgen (R) is a quantity of radiation which produces $1.61 \times 10^{15}$ ion pairs in one kilogram of air.
Effects of radiation

<table>
<thead>
<tr>
<th>Dose in roentgen</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>no observable effect</td>
</tr>
<tr>
<td>25-50</td>
<td>slight blood changes</td>
</tr>
<tr>
<td>50-100</td>
<td>vomiting and fatigue</td>
</tr>
<tr>
<td>100-200</td>
<td>hemorrhage</td>
</tr>
<tr>
<td>200-400</td>
<td>permanent damage in the body</td>
</tr>
<tr>
<td>400</td>
<td>50% chances of death</td>
</tr>
<tr>
<td>600</td>
<td>100% chances of death</td>
</tr>
</tbody>
</table>

- Workers in nuclear power stations, mines and X-ray laboratories wear photographic film badges.
- If the wearer is exposed to radiation, it will affect the film. The badges are collected regularly and the film is developed to check if the wearer is being exposed to radiation.

3. Safety measures

- The following precautions are taken in radiation laboratories: Radioactive materials are kept in thick walled lead containers.
- Lead aprons and gloves are used while working in hazardous places.
- A small micro-film badge is always worn by the person and it is checked periodically for the safety limit of radiation.

4. Indian Nuclear Energy Programme
Energy plays an important role in determining the development of a country. Electricity can be produced by different methods such as hydroelectric, thermal and nuclear generations.

Even though there are many disadvantages of electric power generation from nuclear energy, a large amount of electricity can be generated even with a small amount of nuclear fuel.

Industrialised countries like Belgium, Germany, Japan, Taiwan and Spain generate more than 30% of their total electric power by using many nuclear reactors.

There is a major programme for the production of nuclear power in India. However, it is still about 4% of the total power being generated in our country.

A number of nuclear reactors Dr. Homi Bhabha, the pioneer of nuclear power programme in India took efforts to start the first and major nuclear reactor in India. This nuclear research centre located at Trombay in Mumbai is called Bhabha Atomic Research Centre (BARC). Apsara, Cirus, Zerlina, Purnima and Dhruva are the research reactors located at BARC.

Nuclear Power Corporation of India Ltd. (NPCIL) is the public sector company which owns, constructs and operates nuclear power plants in India.

NPCIL has a plan to put up a total installed nuclear power capacity of 20,000 MWe (Megawatt energy) by the year 2020.

India’s nuclear power programme has 14 reactors in operation and eight power reactors under construction.

Some important operating nuclear power reactors and power reactors which are under construction are shown in the tables 5.5 and 5.6 respectively.

## Operating Nuclear Power Reactors

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Capacity (in MWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarapur</td>
<td>Boiling Water Reactor</td>
<td>2 x 160</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>Pressurised Heavy water reactor</td>
<td>1 x 100, 1 x 200 and 2 x 220</td>
</tr>
<tr>
<td>Kalpakkam</td>
<td>Pressurised Heavy water reactor</td>
<td>2 x 170</td>
</tr>
<tr>
<td>Narora</td>
<td>Pressurised Heavy water reactor</td>
<td>2 x 220</td>
</tr>
<tr>
<td>Kakrapar</td>
<td>Pressurised Heavy water reactor</td>
<td>2 x 220</td>
</tr>
</tbody>
</table>
### Nuclear Power Reactors under construction

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Capacity (in MWe)</th>
<th>Expected date of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarapur (3 and 4)</td>
<td>Pressurised Heavy Water reactor</td>
<td>2 X 540</td>
<td>unit 3 : July 2006 unit 4: October 2005</td>
</tr>
<tr>
<td>Kaiga (3 and 4)</td>
<td>Pressurised Heavy water Reactor</td>
<td>2 X 220</td>
<td>unit 3 : December 2006 unit 4 :June 2007</td>
</tr>
<tr>
<td>Rajasthan (5 and 6)</td>
<td>Pressurised Heavy water Reactor</td>
<td>2 X 220</td>
<td>unit 5 : May 2007 unit 6 :November 2007</td>
</tr>
<tr>
<td>Kudankulam (Tamil Nadu)</td>
<td>—</td>
<td>2 X 1000</td>
<td>unit 1 : 2007 unit 2 : 2008</td>
</tr>
</tbody>
</table>