UNIVERSITY OF TRADITIONAL MEDICINE

DEPARTMENT OF PHYSICS

Departmental Objectives

At the end of the course, the learners should be able to:

Knowledge

- have acquired the basic concepts and fundamental principles in physics.
- know about the laws of physics in their study of traditional medicine appropriately

Skill

- apply the principles of physics in teaching, learning and practice of traditional medicine

Attitude

- appreciate the applied aspects of medically oriented physics.
- have acquired essential habits of applying scientific methods in approaching solving problems.
- accept the hazards encountered habits in the content of the environment in relation to pressure, vibration, heat, sound, light, electricity and radiation.

There are six portions in physics subject for first year B.M.T.M

- Mechanics
- Heat
- Light
- Wave motion
- Electricity and magnetism
- Modern physics

In this PDF file, only four portions are described.

CHAPTER – III

LIGHT

Most objects we see are visible because they reflect light into our eyes. In this chapter, we introduce only some applications of reflection.

Applications of Plane Mirrors

(1) Nose and throat examination

Two mirrors, the laryngeal and postnasal mirrors for nose and throat examinations as shown in Fig:3.1. The light rays reflected in accordance with the laws of reflection.

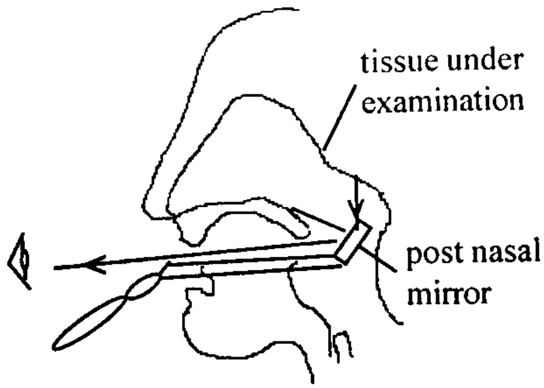
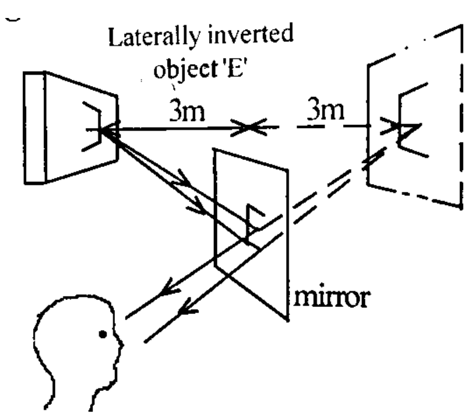


Fig: 3.1 Nose and throat examination

(2) Eye testing

The patient sees the letters in the mirror, the image being at the same distance behind the mirror as the object is in front of it, hence giving a total distance of 6 meters.

Fig: 3.2
Eye testing. The image is at a distance behind the mirror equal to the distance of the object in front of the mirror.

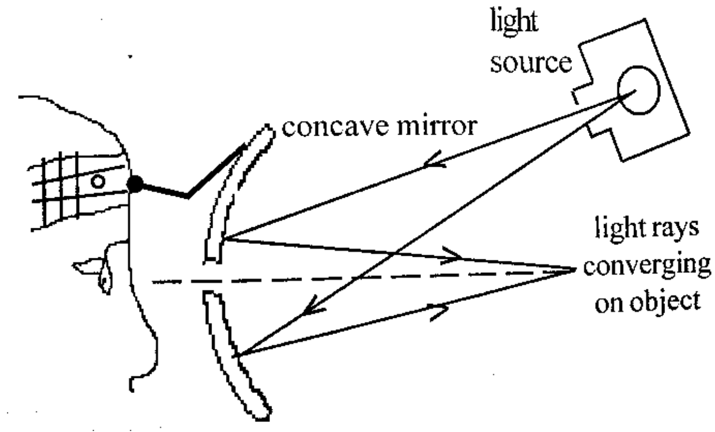


3.1 Applications of Concave and Convex Mirrors

The converging or concave mirror is a useful magnifier for a closer examination of tissues hidden from normal direct paths of vision.

The postnasal and laryngeal mirrors have small concave mirrors which give the surgeon and enlarged, erect image of the area under examination.

The head mirror is a concave mirror with a viewing hole in its centre. The purpose of this mirror is to provide a converging beam of light to illuminate the dark interior of the ear, nose or throat.



s **Fig: 3.3 Head mirror**

The convex mirror is used in a cosmetic compact in order to give an overall view of the face and hair. Driving mirrors in cars give an expended view of the road and traffic coming behind the car.

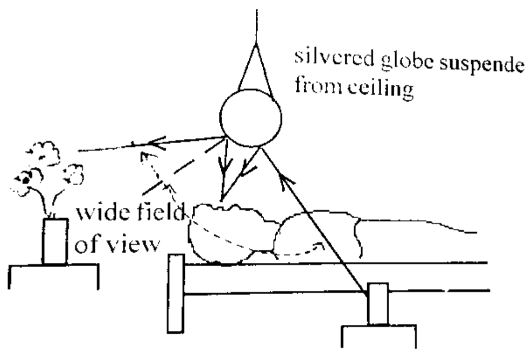


Fig: 3.4 Extended view for recumbent patient

A large slivered globe or spherical mirror can be suspended above the patient to give him an extended view of his surroundings, a view which can be altered by slight head movements.

3.2 The Physics of Vision

The human eye is sensitive to electromagnetic waves in a certain narrow frequency range. Such waves are called light or "visible light" to distinguished them from the wide range of electromagnetic waves. This chapter is devoted to the discussion of visible light and the vision process. The use of lenses for vision correction and the principles of simple optical instruments are considered.

Refraction

The bending of light rays at interfaces where the speed of light changes is referred to as refraction.

Refractive Index

The optical property of a medium is usually specified in terms of the index of refraction, n, which is defined by :

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in that medium}}$$

(or)

$$n = \frac{c}{v} \quad (\text{i.e; } n \propto \frac{1}{v})$$

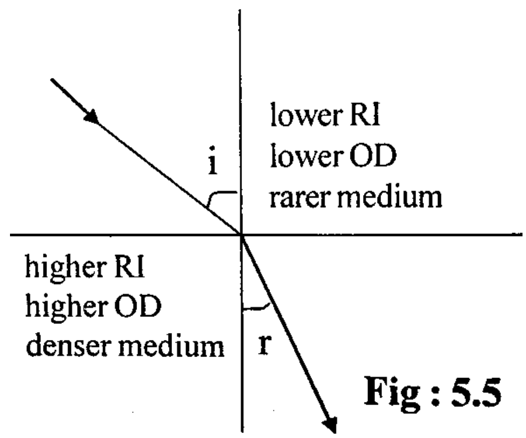


Fig : 5.5

Refractive Index (By using Snell's Law)

By Snell's law, the ratio $\frac{\sin i}{\sin r}$ is a constant for that material and for that wavelength of light. This constant is defined as the refractive index of the material for that wavelength of light. In defining the refractive index, the light ray is passing from vacuum into that medium.

By definition, the refractive index, n, is

$$n = \frac{\sin i}{\sin r}$$

The refractive index of any material is always greater, than unity. Thus in passing from vacuum or air into a material the light ray will bent toward the normal. The medium with higher refractive index has a higher optical density.

When a light ray passes through a slab with parallel sides, situated in vacuum, the incident and the emergent rays are parallel.

The rays AB and CD are parallel, i.e. total angular deviations is zero. Emergent ray is shifted to one side by an amount depending on the thickness of the slab.

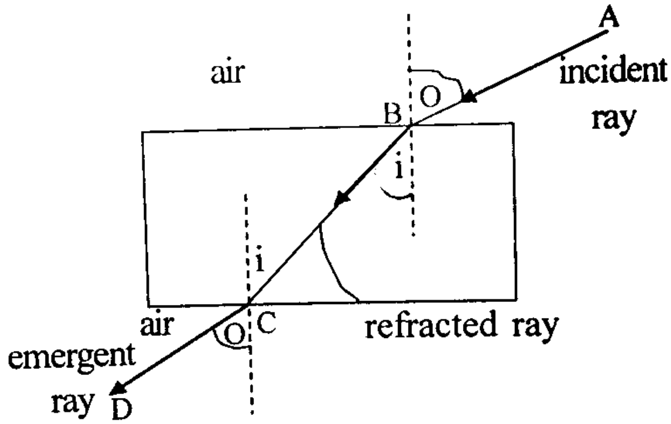


Fig: 3.6 Refraction of light rays through air and glass

Applications of Total Internal Reflection

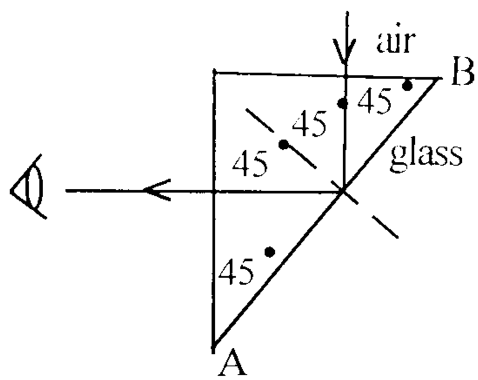


Fig: 3.7 Total internal reflection in a prism of glass

(1) Prismatic Spectacles

Isosceles prism in spectacles allows the patient to read in a horizontal position without raising the head.

(2) Endoscopes

The endoscope for looking into eye is called an opthalmoscope.

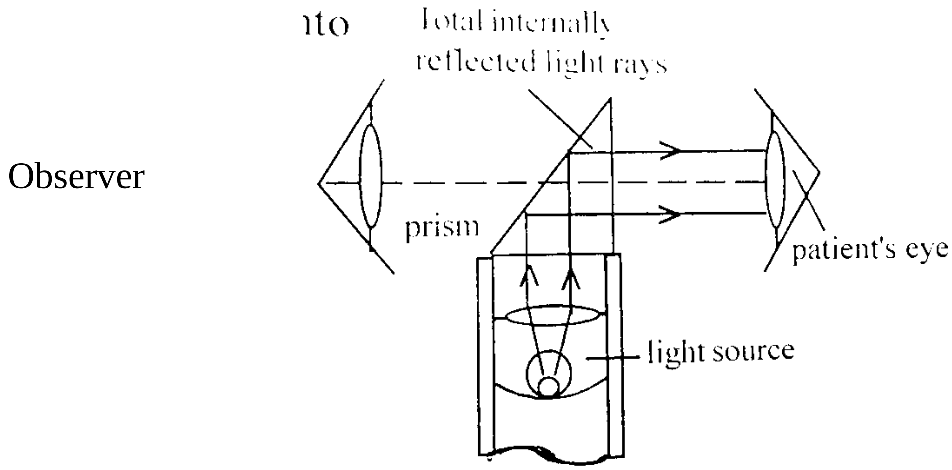


Fig: 3.8 Use of a prism for illuminating the interior of the eye

(3) Flexible Light Guides

Flexible light guides, consisting of thousands of parallel glass fibres allow light rays to be transmitted along the fibres by total internal reflection emerging through the highly polished opposite end to illuminate the dark interior of the stomach or lung.

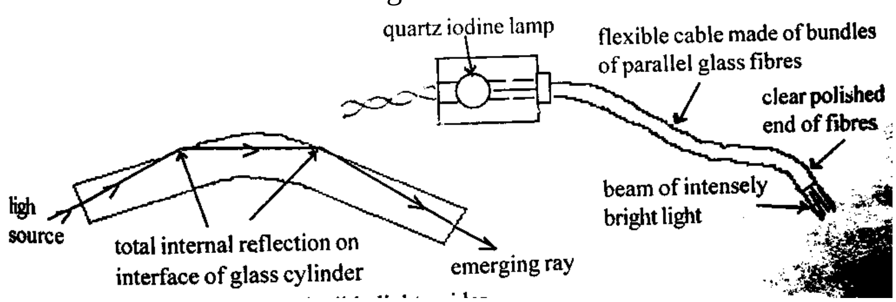


Fig: 3.9 Flexible light guides

Lenses

A transparent material which can diverge or converge rays of light is called a lens. A thin lens is usually circular, and its two faces are portions of sphere. The thin lens equations come from an analysis of the triangles in ray tracing: we simply state them here:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$m = \frac{II'}{OO'} = -\frac{v}{u}$$

where,

u	=	the object distance
v	=	the image distance
OO'	=	the size of object
II'	=	the size of image

Power of a Lens

Opticians use to specify spectacle lenses in terms of power, rather than a focal length in metre, and its units is the dioptre (D). Thus the power is expressed as.

$$P = \frac{1}{f(m)}\ D \text{ or } P = \frac{100}{f(cm)}\ D$$

Up to this point it has been assumed that the lenses considered were thin and symmetric and with ideal optical properties.

In practice, images formed by lenses are not perfect. The failure of a lens to produce an image

Chromatic Aberration

It is due to the fact that the refractive index of the lens material varies with the colour, or wavelength of the light. Therefore various colours in white light do not all focus at the same point. The violet and blue focus nearer the lens i.e., bent most. The red and orange focus farthest away from the lens i.e., bent least.

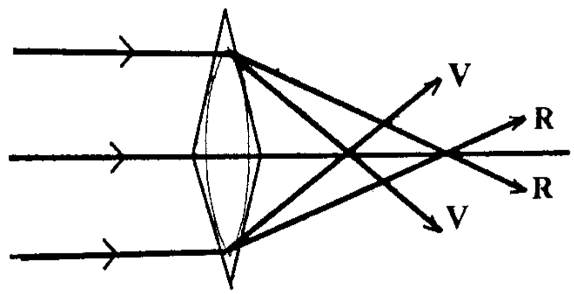


Fig: 3.10

Correction (Achromatic lenses)

A double lens of crown glass converging lens and flint glass diverging lens corrects chromatic aberration and is called achromatic. Focal lengths of two lenses are so chosen that they combine to give a desired focal length.

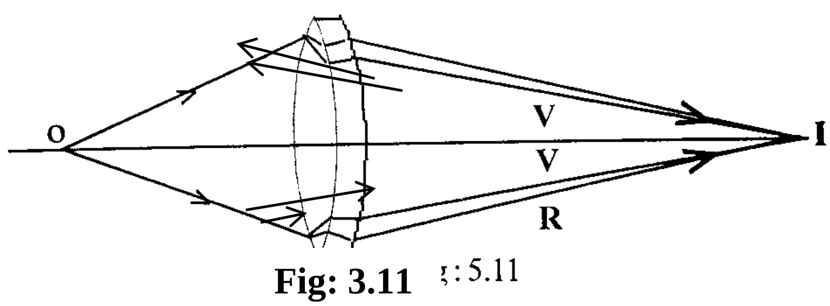


Fig: 3.11

The doublet lens, still behaves as a converging lens, though not as strong lens as the converging component by itself.

Spherical Aberration

In spherical aberration light striking the outer part of the lens will focus at a slightly different point than the light striking the centre of the lens, resulting in a slightly blurred image.

Correction

The clarity of the image can be improved by inserting a small aperture in front of the lens so that the light passes through only a small portion of the centre of the lens. Lens defects are more pronounced in dim light because more of the lens area is being used to form the image on the retina.

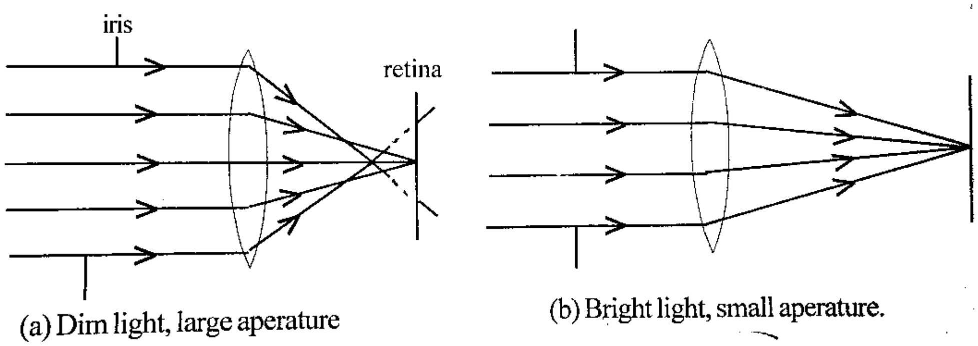


Fig: 3.12

Optical Instruments

The purpose of most optical instruments is to give larger and clearer images. Some common optical instruments are the microscope, telescope, binoculars and the camera. Since optical instruments are concerned with vision, we consider the eye also as an optical instrument.

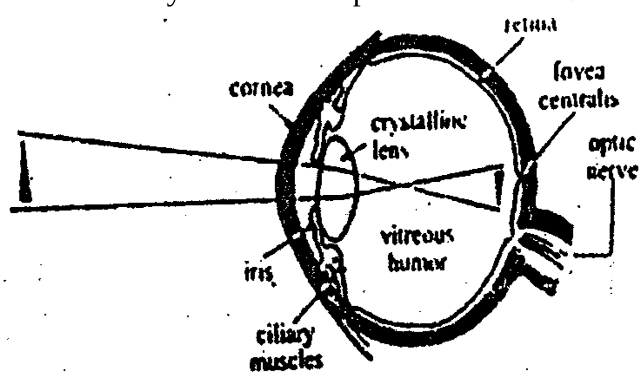


Fig: 3.13 Image formation by the eye

3.3 Image Formation by the Eye

When light from an object strikes the eye, it passes through the cornea, the crystalline lens, and the transparent vitreous humor (refracting medium of the eye) to form an image on the retina. The ending in the retina transmits electrical impulses to the brain via the optic nerve. The image formation is accomplished by refraction in the cornea and crystalline lens; a focused real inverted image is formed on the retina. The brain, however, sees it as an upright object.

When looking at a very near object, the rays are divergent and to make then converge on the retina, the crystalline lens must have a short focal length. This requires the ciliary muscle contract, loosening the crystalline lens to take on a more rounded shape.

For a distant object, the rays entering the eyes are not very divergent and for proper focus the lens must be flattened to increases the focal length. In this position ciliary muscles are relaxed.

The process of changing the shape of the lens to meet the needs of far and near vision is called accommodation, and it is performed by the ciliary muscles which control the lens.

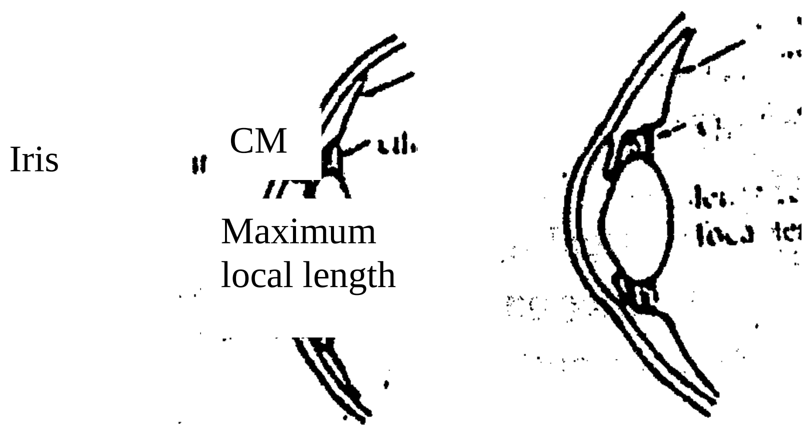


Fig: 3.14 Accommodation of focus

Although the eye is two-lenses system, it is instructive to consider a simplified model in which the two lenses act together as a single lens to form images on the retina. The effective position of this single lens is about 2.2 cm from the retina in the average human eye. The effective focal length of the eye when viewing distant objects must be about 2.2 cm, the distance to the retina.

Thus, the strength of the eye's lens in diopters is

$$S = \frac{1}{f} = \frac{1}{0.022\ \text{meter}} = 45D$$

When the object viewed is closer to the eye, the image is no longer formed at the focal length of the lens but at the position given by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Since the image distance is fixed, the focal length of the lens must change to produce a focused image on the retina

$$\frac{1}{f_{eye}} + \frac{1}{f_{lens}} = \frac{1}{f_{corrected}}$$

or equivalently, $S_{eye} + S_{lens} = S_{corrected}$

Good approximation for their lenses which are placed very closed together, and is reasonably accurate for calculating prescriptions for eye glasses.

$$\frac{1}{f_{corrected}} = \frac{1}{d}$$

where, d = effective distance from the eye's lens to the retina for viewing distant object.

The correction is normally calculated for the distant vision case when the eye lens is completely relaxed and f_{eye} is maximum focal length for the eye.

Visual defects

There are four common visual defects.

1. Myopia (short-sightedness)
2. Hyperopia (long-sightedness)
3. Presbyopia or loss of accommodation
4. Astigmatism

Common Vision Defects

If the focal length of the eye's lens is too short as shown in the figure, the light rays will focus before they reach the retina, resulting in a blurred image on the retina. This condition is referred to as myopia or nearsightedness. It can be corrected by inserting a diverging or negative lens in front of the eye to cause the rays to diverge slightly before entering the eye.

If the focal length of the eye lens is too long (hyperopia or farsightedness) then the light will focus only at a distance greater than the distance to the retina. A converging lens will correct this defect?

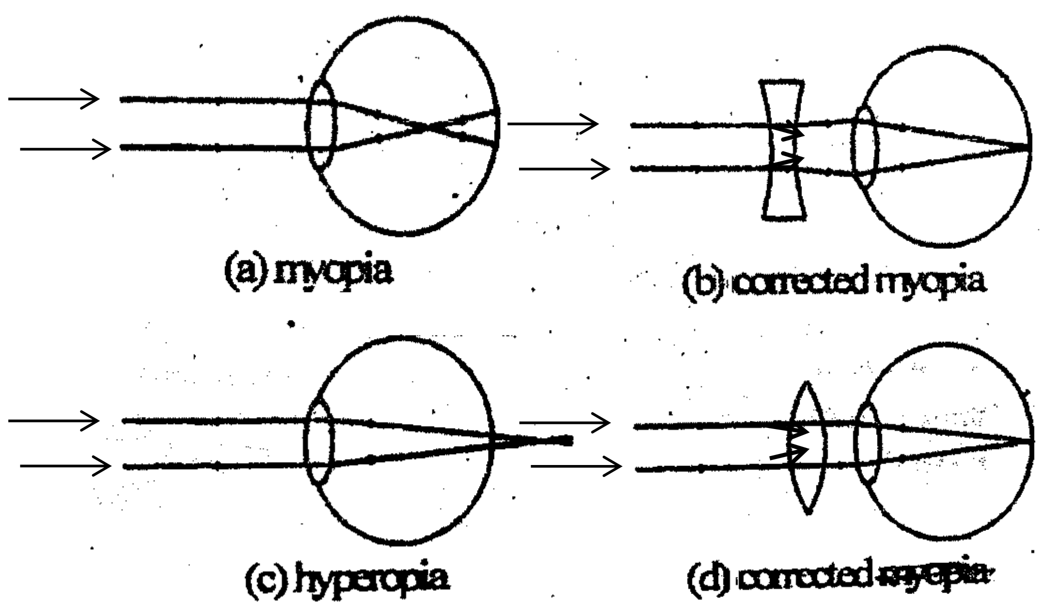


Fig: 3.17 The use of lenses to correct common eye defects

Astigmatism

For human eye, the common eye defects known as astigmatism is due to eye's lens not having equal curvature in all directions i.e., there were some cylindrical curvature in addition to spherical curvature.

The corrections for astigmatism is spectacles with cylindrical curvature arranged to cancel the cylindrical curvature of the eye.

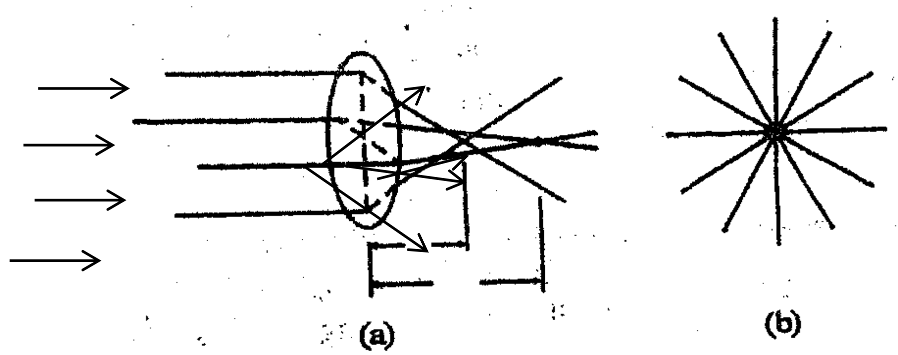


Fig: 3.18 Astigmatism

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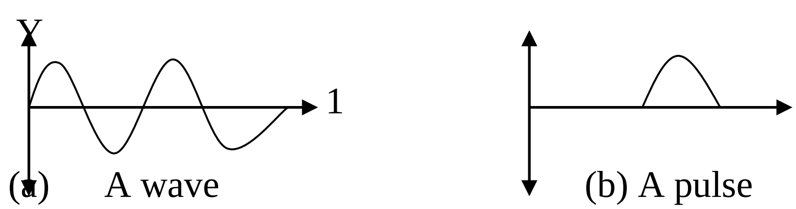
CHAPTER –IV
WAVE MOTION

Energy propagation by means of the motion of a change in a medium is called wave motion and its occurs in many forms in nature.

Wave : A wave is a periodic disturbance of relatively long duration.

Pulse : A pulse is a single disturbance of relatively short duration.

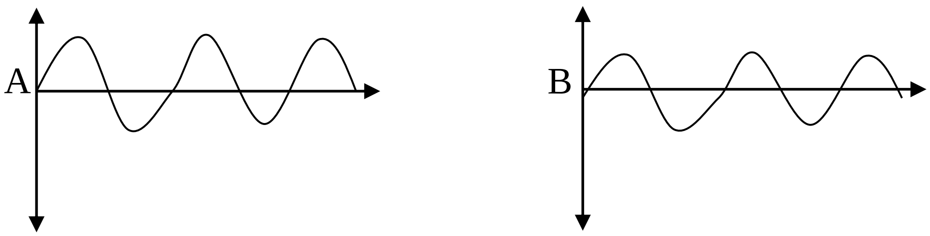


4.1 Types of waves

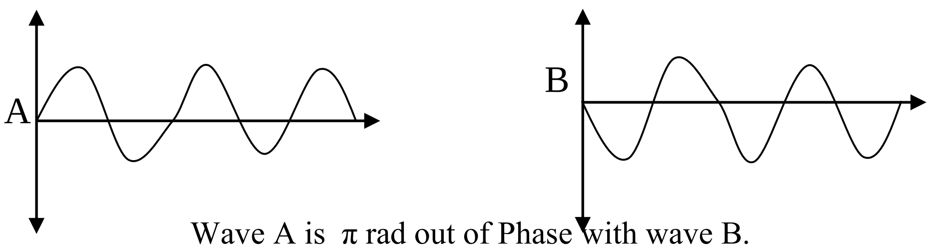
1. Transverse wave
2. Longitudinal wave

Phase

The phase of the particle in wave determines the position and direction of motion of the particle.



Wave A is in phase with wave B.



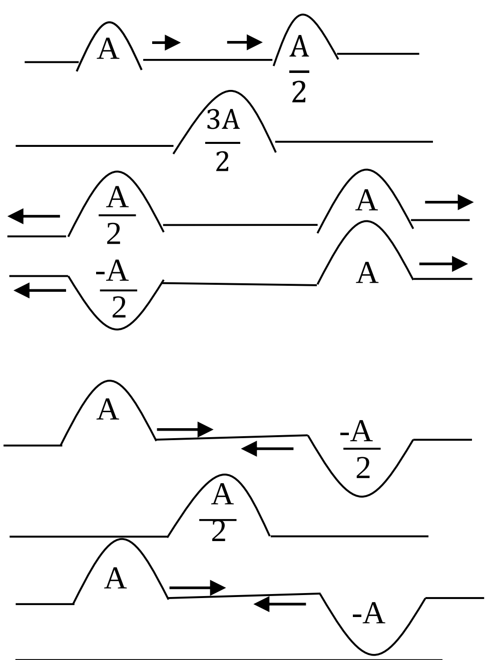
Wave A is π rad out of Phase with wave B.

Phase difference is simply the amount of lead or lag of one wave over another, it is usually stated in radians or in fractions of a wavelength.

$\lambda = 360°$ $\frac{1}{2}\lambda = 180°$ $\frac{1}{4}\lambda = 90°$

Superposition Principles

Whenever waves coincide, their displacements are added vectorically.



Two wave pulses approach each other and meet. The resultant wave has amplitude the sum of the amplitudes of the components.

They then separate out from each other and continue on their way unchanged.

Wave pulses with a crest and trough superpose.

Wave pulses with identical amplitudes but one being a crest and the other a trough, meet and superpose.

Behaviours of Waves

1. Reflection
2. Refraction
3. Interference and
4. Diffraction

SOUND

4.2 Wave properties of Sound

Sound is a travelling pressure wave which may be propagated through the air or through solid or liquid materials. It cannot travel through a vacuum. This travelling wave phenomenon said to be in the audible range when its frequency is between 20 and 20,000Hz.

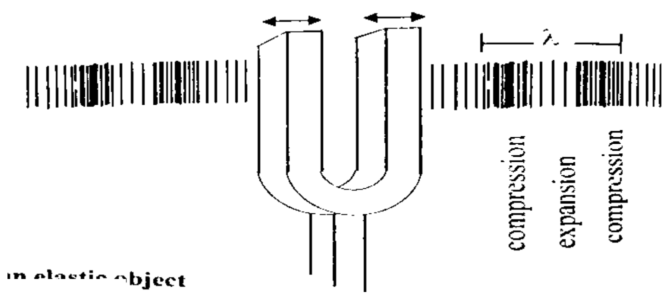


Fig : 4.1 The vibration of an elastic object produces sound waves

The Wave Equation

Whether we consider water waves, sound waves or electromagnetic waves, wave velocity is related to both the frequency and wavelength by

$$v = f \lambda$$

This equation shows that wavelength is inversely proportional to frequency.

The Speed of Sound

The speed of sound is determined by the medium through which it is traveling. The speed of sound in air at 0°C is 331.5 ms^{-1} (1087 fts^{-1}) and it increases about 0.6ms^{-1} for each degree Celsius above 0°C. The speed of sound in solids and liquids is considerably higher than the speed in air, but the frequency or pitch will remain the same since it is determined by the sound source.

$$v_T = 331+0.6\,T$$

Interference and Standing Waves

Interference refers to the addition of two or more waves which pass the same point in space.

Constructive (or) additive interference and Destructive interference

If the two waves combine in such a way that crests meet crests and troughs meet troughs, the displacements due to the two waves add, and the resultant is a wave of double the original amplitude. These two waves give rise to constructive interference. If the two waves given rise to constructive interference. If the two waves combine in such a way that crest meets trough and trough meets crest, that cancel one another and we have destructive interference.

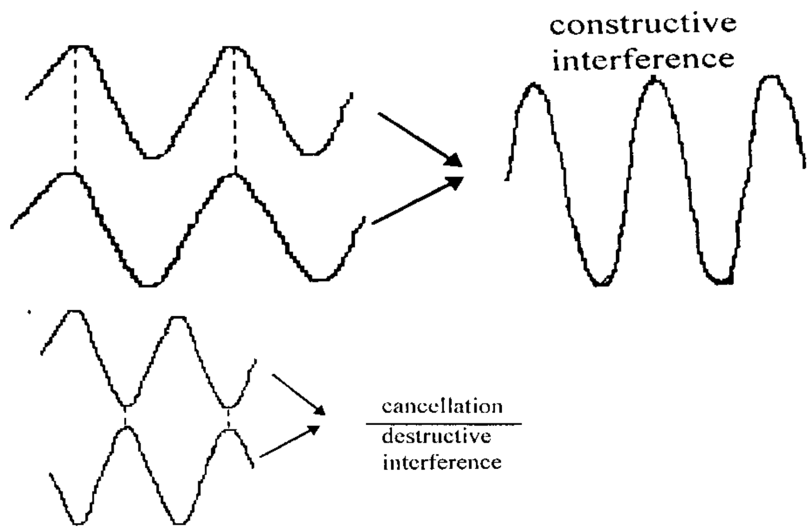
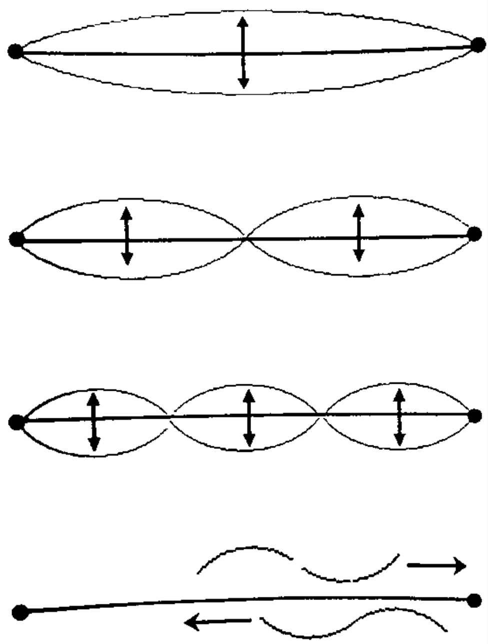


Fig: 4.2 Constructive and destructive interference of waves

Standing waves

When a wave is produced in an elastic medium like a stretched guitar string, the wave will reflect at the end of the string and return. The reflected wave may interfere constructively or destructively with the incident wave. When the length of the string corresponds to a half-wave length or an integer multiple of half-wavelength ($\frac{\lambda}{2}$, λ, $3\frac{\lambda}{2}$, 2λ , $5\frac{\lambda}{2}$, etc) then the interference between reflected waves will cause the condition known as a standing wave. It is called a standing wave because the string will appear to vibrate up and down in fixed segments as shown in fig 4.3. The frequencies corresponding to the standing waves are said to be natural frequencies or "resonant" frequencies.

When a guitar string is plucked, it produces not only the fundamental frequency corresponding to the fundamental standing wave mode show in fig but also the higher resonant frequencies. These higher "overtones" are integer multiples of "harmonics" of the fundamental frequency.



Fundamental mode frequency=f_1

$L = \frac{\lambda}{2}$, $f_1 = \frac{V}{2L}$

2ndFundamental mode frequency=$2f_1$

$L = \lambda$, $f_2 = \frac{2V}{2L}$

3rdFundamental mode frequency=$3f_1$

$L = \lambda\frac{3}{2}\lambda$, $f_3 = \frac{3V}{3L}$

The interference of travelling waves in the string produces the standing wave pattern

Fig: 4.3 Resonant ''standing waves'' produced in a stretched sting by interference

For any string, the natural frequencies are in the ratio 1:2:3 …….. The velocity v of the waves set up in the vibrating string is given by the equation

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{m/l}}$$

Where, T = tension of the string express in Newton.

$\mu = \frac{m}{l}$ is the mass per unit length of the string expressed in kgm^{-1}.

The fundamental vibration frequency of the string can be raised by increasing the tension in the string. A heavier string with the same tension and length will have a lower fundamental frequency.

Applications

Although the vocal cords of a human are more like membranes than strings the analogy with the guitar string can be used to some extent. When the tension of the vocal cords is increased or shortening the cords by muscle action produces a high pitch, high frequency vibration note; reducing the tension or lengthening the cords produces a low pitch. Male voices are usually lower than female voices partly because the vocal cords are more massive.

Characteristics of Sound

The fundamental characteristics of sound are pitch, loudness and quality. They are related to the physical properties of waves.

The pitch of the sound depends upon the frequency of sound waves, the lower the frequency, the lower the pitch, and the higher the frequency, the higher the pitch.

Loudness is the sensation produced by sound and is a subjective quantity depending on the hearing ability of a person. A sound which is loud to one person may not be so to another. Loudness is measured in units called the 'phon' by mean of noise meters.

Sounds which have the same loudness and pitch may have very different qualities. The quality of a sound is determined by the number of overtones present. For example, if a piano and a trumpet play the note at the same loudness, it is easy to distinguish between them. The reason is that neither sound source produces a single frequency. Each sends out a group of frequencies, the fundamental as well as overtones. When two notes differ in quality, they differ in the frequencies and relative intensities of the various overtones.

Sound Intensity

The intensity of a sound wave is defined as the rate of flow of energy per unit area perpendicular to the direction of the wave.

It can be shown that the intensity is proportional to the density of air, the square of the frequency and the square of the amplitude. For the sound of given frequency, the most important factor is the square of the amplitude since the density of the air has to be taken as it is.

The unit of intensity is the Wm^{-2}. One joule of energy per second flows through a $1m^2$ surface perpendicular to the path of a wave whose intensity is $1Wm^{-2}$. The minimum intensity a sound wave must have in order to be audible is about $10^{-12}\,Wm^{-2}$.

Inverse Square Law

The intensity of sound is proportional to the square of the distance from the source.

$$I \, \alpha \, \frac{1}{d^2}$$

$$I_1 d_1^2 = I_2 d_2^2$$

Where I_1 and I_2 are the intensities of the same source at two different distance d_1 and d_2 respectively.

The human ear does not respond linearly to sound intensity doubling the intensity of a particular sound produces the sensation of somewhat louder sound, but one that seems far less than twice as loud. For this reason the scale used to measure the intensity level of a sound is logarithmic. The unit is a bel, or much more commonly, the decibel (dB), which is 1/10 bel. Sound which is barely audible ($I_0 = 10^{-12}\,Wm^{-2}$) is assigned a value of 0dB. This is also known as threshold of hearing.

The intensity level in decibels, of a sound whose intensity is $I(Wm^{-2})$ is given by

$$\beta \text{ (in dB)} = 10 \log \frac{I}{I_0}$$

Where I_0 is the intensity of some reference level. Usually taken as threshold of hearing intensity at 1000 Hz. The logarithm is the base 1_0. For sound of intensity level 10 decibels.

$$10 = 10 \log \frac{I}{I_0}$$

$$1 = \log \frac{I}{I_0}$$

$$10^1 = \frac{I}{I_0}$$

$$I = 10\, I_0$$

Thus, for the sound of intensity level 10 decibels, the intensity is 10 times of 0 dB sound. For the case of intensity level 20 dB.

$$20 = 10 \log \frac{I}{I_0}$$

$$2 = \log \frac{I}{I_0}$$

$$10^2 = \frac{I}{I_0}$$

$$I = 100 I_0$$

Similarly, for 30dB, the intensity will be 1000 times that of 0dB.

Typical Decibel Levels for Normal Sounds

Decibel level at 1000Hz

160 dB Bursting of ear drum

140 dB Severe pain

120 dB Damage to hearing after prolonged exposure, factory for close observer

80 dB Class lecture, loud radio

60 dB Conversational speech

40 dB Very soft music, typical living room

20 dB Very quiet room

0 dB Threshold of hearing

Example (1) Find the intensity in decibels if the sound intensity is equal to the threshold of hearing intensity. Then calculate the corresponding decibel levels associated with intensities 10,000 times and 40 times the threshold intensity.

For the threshold level,

For $I = I_0$

$$\beta \text{ (dB)} = 10 \log \frac{I}{I_0} \qquad = 10 \log 1 = 0\text{dB}$$

For $I = 10{,}000\, I_0$

$$\beta\,(dB) = 10 \log \frac{10{,}000 I_0}{I_0} = 40\ dB$$

For $I = 40\ I_0$

$$\beta\,(dB) = 10 \log \frac{40 I_0}{I_0} = 16dB$$

Example (2) A siren for a certain factory has an intensity level of 120dB. Express the intensity on terms of Wm^{-2}.

For β =120 dB

$$\beta\,(dB) = 10 \log \frac{I}{I_0}$$

$$120 = 10 \log \frac{I}{I_0}$$

$$12 = \log \frac{I}{I_0}$$

$$10^{12} = \frac{I}{I_0}$$

$$I = 10^{12}\, I_0$$

But $I_0 = 10^{-12}\ Wm^{-2}$

$$I = 10^{12} \times 10^{-12} = 1Wm^{-2}$$

Interference and Beats

When two bodies vibrate with slightly different frequencies, the two wave emitted by them will interfere with each other. At some instant the two waves will be in the same phase and there will be a reinforcement of the waves resulting in a wave of increased amplitude. At some other instant the two waves will be completely out of phase, a compression and a rarefaction will meet, resulting in a decreased amplitude, producing a sound of very low intensity. At other times they will get in phase again.

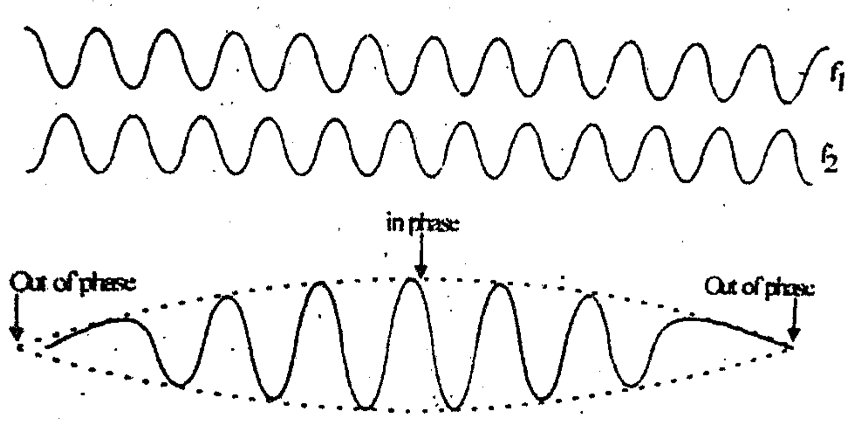


Fig : 4.4

The addition of two waves of slightly different frequencies is illustrated in fig above. If one wave has a frequency f_1 and the other a frequency f_1 and the other a frequency f_2, the number of times there waves will get in phase per second is f_1-f_2. This number is the same as the number of times the waves will get out of phase per second. When the waves are out of phase the faintest sound (or silence) is heard. These variations of loudness are called beats. **Thus, the fluctuations in intensity or loudness when two sound waves of slightly different frequencies interfere with each other are called beats.** The beat frequency is the difference between the two original frequencies.

For example, if one tuning fork is emitting 256 Hz and the other is emitting 260 Hz, 4 beats will be heard each second.

Example

Two tuning forks are vibrating and make 4 beats per second. One tuning fork is vibrating at 256 Hz. A small piece of wax is places on the other fork and frequency of the beats decrease. What is the frequency of the second fork?

Science the beat frequency is 4 beats per second, f_1-f_2 = 4.

Frequency of one tuning fork = 256 Hz

After placing a small piece of wax on the other fork the beat frequency decreases.

Frequency of the second fork = 256+4 = 260 or 252 Hz.

When the wax is placed on a fork, the frequency will be reduced. Since the beat frequency decreases after placing the wax, the frequency of the second fork must be 260Hz.

4.3 The Doppler Effect

When a motor car, traveling at high speed and sounding its horn, passes you, a noticeable drop in the pitch of sound will be observed as the car passes. When a source of sound is moving toward an observer, or an observer toward a sound source the pitch of the sound heard is higher than the normal pitch. When the sound source moves away from the observer, or the observer away from the source, the pitch is lowered. This phenomenon is known as Doppler Effect and occurs for all types of waves. The apparent change in frequency of a sound brought about by the relative motion between the source and the observer is called the Doppler Effect.

Example:

A 5000 Hz sound wave is directed toward an object moving 3.3 ms^{-1} toward the source. What is the frequency of the reflected wave?

There are actually two Doppler shifts in this situation. First, the object acts like a moving observer and detects a sound wave of frequency.

$$f' = \frac{v+v_0}{v} f = \frac{330+3.3}{330} \times 5000 = 5100 \text{ Hz}$$

Second, the object acts like a moving source in reemitting (reflecting) the sounds, so the reflected frequency is

$$f' = \frac{v}{v-v_s} f = \frac{330}{330-3.3} \times 5000 = 5100\text{Hz}$$

Thus the frequency shifts by 100Hz.

Thus incident wave and reflected wave, when mixed together, interfere with one another and beats are produced. The beat frequency is equal to the difference in the two frequencies, and in the above example would be 100Hz.

The Doppler techniques used in a variety of medical application, usually with ultrasonic, waves in the megahertz frequency range. For example, ultrasonic waves reflected from red blood cells can be used to determine the velocity of the blood flow. Similarly, the technique can be used to detect the movement of the chest of a young fetus and also to monitor its heart beat.

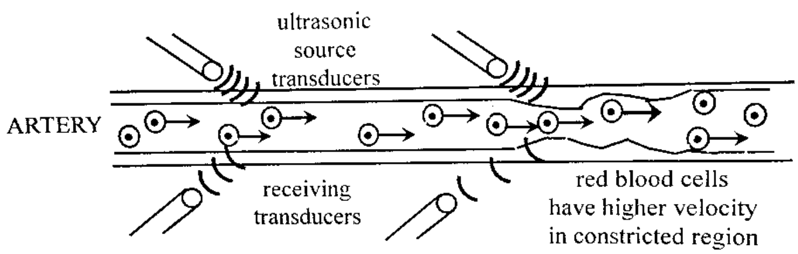


Fig:4.5 Doppler ultrasound techniques detect vascular constrictions by measuring the velocity of blood flow

Figure: 4.5 is a simplified diagram of how Doppler ultrasound techniques might be used in vascular studies. Both the sources and the detectors of the ultrasound are called transducers. A transducer is a device that converts energy from one form to another, the source transducer converts electrical energy into ultrasound and the receiving transducer coverts ultrasound back into an electrical signal, which can be processed for display.

4.4 Ultrasonic Sound

Ultrasonic sound consists of the frequencies above the range of human hearing, beginning about 20,000Hz and going upward without a definite upper limit. Frequencies as high as 15 million cycles/sec (15MHz) are routinely used in medical applications.

Most of the diagnostic uses of ultrasonic sound make use of echo techniques analogous to the SONAR echo-location of underwater object by submarines and fishing vessels.

When ultrasonic waves are directed into the body, reflections occur at interfaces between different tissues of fluids. A reflection will occur at any interface when the speed of sound changes. The speed of sound in tissue is primarily dependent upon density, so the outlines produced are largely outlines of density changes. The pattern of reflections produces a visualization of interior body tissue structures. Low intensity (about $10^{-2}Wm^{-2}$) ultrasound is used for medical diagnostics to avoid tissue damage.

Most of the energy carried in by the ultrasonic wave in converted to thermal energy, but 10^{-2} Wm^{-2} causes negligible heating of tissue, unlike x-rays which always do some tissue damage. Ultrasound is therefore often used in obstetrical applications.

Ultrasound of considerably higher intensity in used for the therapeutic purposes. Ultrasonic diathermy is deep heating using ultrasound of intensity of 1-10 W m^{-2}.

Intensity of 10^3 Wm^{-2} is used to in some medical procedures to destroy cancerous tissues or gallstones.

The smallest detail observable when using a wave as probe is one wavelength.

Ultrasound wavelengths can be small enough to see needed detail. Therefore ultrasound is used in diagnostic rather than audible sound. One drawback, however, is that ultrasound is absorbed and is **useful only to depths as great as 200 wavelengths.**

Example

Ultrasound has a speed of 1500 m/sec in tissue. (a) Calculate the smallest detail visible with 2.0 MHz ultrasound. (b) To what depth can the sound probe effectively? (c) How long does it take the echo to return to the probe from the depth of 0.10 m?

(a) The smallest detail visible has a size about equal to one wavelength of the sound. the relationship between propagation speed, frequency, and wavelength is

$v = 1500\ ms^{-1}$

$f = 2.0\ MHz = 2 \times 10^6\ Hz$

$v = f\lambda$

$\lambda = \frac{v}{f}$

$\lambda = \frac{1500}{2.0\times10^6} = 750 \times 10^{-6}\ m$

(b) The effective depth is 200 wavelengths. Therefore,

$200\lambda = 200\ (750 \times 10^{-6}) = 0.15\ m$

This is sufficient to probe a normal size person.

(b) The time for an echo to return is the time for its round trip.

$S = 0.10 \times 2\ m = 0.2\ m$

Since $s = vt$

We obtain

$t = \frac{s}{v}$

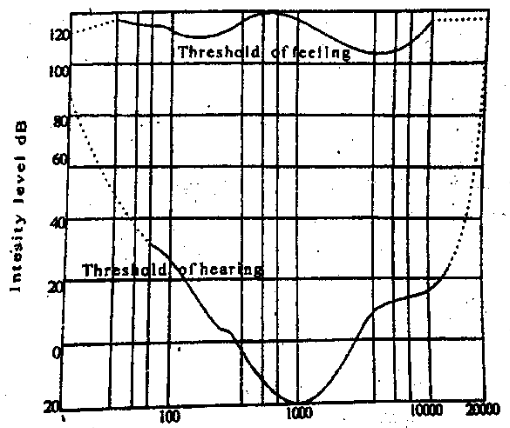
$= 1.3 \times 10^{-4} sec$

Human Audiogram

Hearing tests are recorded in the form of a graph called the audiogram where the sound intensity is plotted vertically and the sound frequency, horizontally. The figure given below is the audiogram for a normal hearing person. The lower curve gives the faintest sounds that can be heard, and the upper curve the loudest that can be heard without pain. It will be noted that the ear is most sensitive to frequencies between 2000Hz and 4000Hz and that the sensitivity diminishes rapidly at higher and lower frequencies.

To see how intensity affects the frequency limits of audibility, consider the horizontal line at 20 dB.

At this intensity level, with a few of energy 100 times that necessary to hear the faintest 1000 Hz note, frequencies below about 200Hz.



The amplitude of the sound waves at the threshold of hearing (audibility) at 1000Hz has been determined and found to be about 1 -10 m. This is about the diameter of a H_2 atom and gives some idea of the enormous sensitivity of the human ear. When a sound becomes so loud that it is painful to the ear, the amplitude is of the order of 1- 2 mm.

Hearing Aids

A spectacles correct defects in sight, so the hearing aid seeks to correct defects in hearing; both are prosthetic devices for the disabled.

A hearing aids basically consists of three functions parts: (a) the microphone, which gathers the sound waves, and changes sound energy into electrical energy, (b) the amplifier, an electronic device which increases the intensity of the sound received, (c) the loudspeaker, which produces sound energy from electric current, is either inserted into the external ear opening for air conduction or placed behind the ear lobe for bone conduction in the form of a transducer.

CHAPTER – V

INTRODUCTION TO ELECTRICITY AND MAGNETISM

5.1 Static Electricity

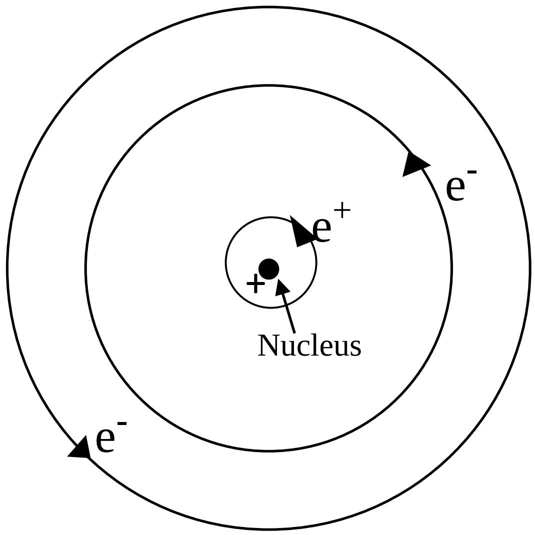


Fig: 5.1 A simplified view of the atom showing electrons in orbit around the nucleus. Thus view is called the planetary model of the atom in analogy to the way. Planets orbit the sun.

One of the first electrical phenomena studied was static electricity. Fig: 5.1 shows simplified view of an atom with electrons orbiting a tiny nucleus much as planets orbit the sun. When objects are rubbed together, surface atoms come into contact with one another and some electrons may be transferred between objects. If this happens, both objects will exhibit the ability to attract dust, feathers, or bits of paper and are said to be charged.

Charge is a basic physical property carried by certain sub atomic particles, such as electrons. Experiments have shown that charge has the following properties.

1. There are two types of charge.

Electrons carry negative charge, and particles called protons carry positive charge. Electrostatic force results from the separation of positive and negative charges.

2. Charge is conserved

That is, charge can be separated. but they can neither be created nor destroyed Neutral object contains equal numbers of positive and negative charges.

3. Like charges repel, unlike charges attract

For example, negative electrons orbit positive atomic nuclei because of their mutual attraction, much as planets orbit the sun because of gravitational attraction.

Static electricity in a hospital and Antistatic precautions Humidity in operating theatres

The anesthetic gasses used in surgery tend to escape into the air of the theatre. Many of these gases are inflammable, an electric spark will cause them to ignite and explode. The patient may produce static electricity by friction with the woolen blankets or a spark may be produced in pulling a rubber tube off a metal connector. In order to overcome this danger the air in the theatre is made electrically conducting by making the atmosphere moist or humid in order to drain any accumulating electric charges to earth as soon as they form.

Dry blankets and bedding

Friction of the persons hands against the blankets and sheets produces charges of static electricity. Charges acquired during bed making can become considerable and can be transmitted to a patient causing a slight unpleasant shock. To overcome this the person should occasionally touch water taps, pipes or radiators to drain away the acquired static electricity to earth.

Antistatic precautions

Antistatic flooring

Antistatic flooring with tiles of conducting carbon and steel wire mesh in operating theatres can be used.

Antistatic rubber

Antistatic rubber for the anesthetic masks, gas tubing, trolley wheels stool seats and for the rubber boots and shoes are worn in the theatre.

Gowns

Gowns worn in the theatre should be silicone treated and are called antistatic theatre gowns. Outer clothing should be of one type, (e.g. cotton) and never contrasting (e.g nylon next to wool, or terylene next to cotton such combinations produce static electricity.

Silicone rubber

Silicone rubber or antistatic rubber connections to gas apparatus are preferable to ordinary rubber

Humidity

Humidity should be high to drain away accumulated charges. Central heating system tend to produce a dry atmosphere; therefore air conditioning systems giving air of the right humidity should also be used.

Oxygen tents

Oxygen tents should be associated with antistatic precautions, for example the nurse should discharge her personal charge of static electricity by touching water taps or radiator pipes.

Electric Force

The quantitative expression for the force between stationary charges is named Coulomb's law and is written

$$F = K\frac{q_1 q_2}{r^2} \quad \text{………………} \; 5.1$$

where, F is the Coulomb force between charges q_1 and q_2, r is the distance between the charges, and K is a constant determined by experiment.

Electric Field

A useful concept of electric field was introduced by Michael Faraday. Electric field is a region in which electrical forces are acting. The presence of an electric field at a given point can be tested with a test charge placed at that point.

Electric Field Intensity

The electric field intensity at a point is defined as the force per unit positive test charge placed at that point.

$$\text{Thus,} \quad \vec{E} = \frac{\vec{F}}{q} \qquad \text{………....} \quad 5.2$$

Where, $\vec{F}$ is the force on the test charge +q and $\vec{E}$ is the electric field intensity. The magnitude of the electric field intensity $\vec{E}$ is called electric field strength and its direction is the same as the direction of force acting on the positive charge.

The SI unit of electric field intensity is newton per coulomb (NC^{-1}). It could also be expressed as volt per meter (Vm^{-1}).

The electric field strength drops off rapidly with the distance from the charge This can be seen by applying equation 5.2 to calculate the electric field due to a point charge Q,

$$E = \frac{KQ}{r^2} \quad \text{or} \quad E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2} \quad \text{(for a point charge)}$$

Electric Potential

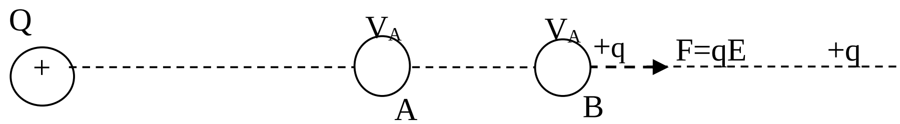


Fig: 5.2

The electric potential at a point is, therefore the amount of work done in moving a unit positive charge from a point of zero electric potential (a point at infinity or the earth's surface) to that point.

It is clear that the work done in moving a unit positive charge from point B to point A is equal to the electric potential difference between A and B. Potential difference between A and B is

$$V_A - V_B = \frac{\text{W.D in moving charge+q from B to A}}{q}$$

$$\text{or } V_{AB} = V_A - V_B = \frac{W_{BA}}{q}$$

The SI unit of electric potential or potential difference is joule per coulomb (JC^{-1}), but this unit has been given the name volt.

$$1 \text{ volt} = 1 \frac{\text{Joule}}{\text{coulomb}}$$

The electric potential at a distance r from a point charge Q can be expressed as

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

of there are many point charges Q_1, Q_2, Q_3, … the electric potential at a point is the sum of the potentials due to each charge i.e.

Potential Gradient and Intensity

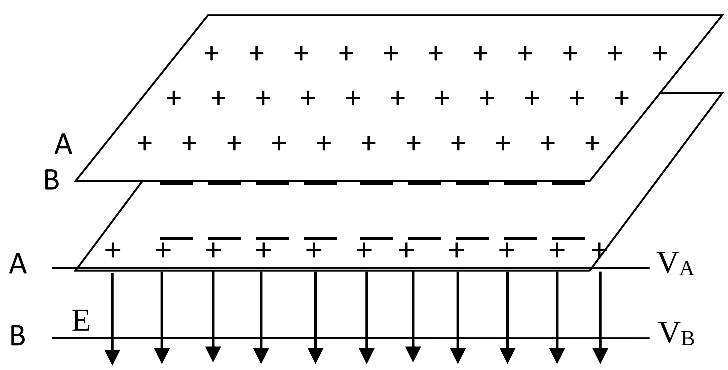


Fig: 5.3 Charged metal plates

The work done in bringing a unit positive charge from B to A against the electric force is

$$W = E.d$$

By definition

$$W = V_{AB}$$

$$\therefore V_{AB} = E.d$$

$$\text{or } E = \frac{V_{AB}}{d}$$, where d = distance between two plates.

The quantity $\frac{V_{AB}}{d}$ is the rate at which the potential rises with distance and is called the potential gradient. Since E = $\frac{V}{d}$, E is usually given in units of Vm^{-1} or NC^{-1}.

The parallel charged plates are introduced here because there are many applications of electricity which make use of this configuration. Parallel plates can be used to store electric charge in a state of elevated electric potential energy (i.e, high voltage). The stored charge can then be released to do work. In this content the set of parallel plates is referred to as a capacitor and has wide applications in electronics as an electrical storage device. The capacitance is defined as the charge which can be stored per volt of electric potential.

$$C = \frac{Q}{V}$$

Where Q is the charge coulombs stored on either plate, and V is the voltage difference between the two plates. The unit of capacitance is the coulomb / volt, which is called a farad.

5.2 Electric current

It is defined as the amount of charge passing through a cross-sectional area of a conductor in one second.

The SI unit of current is the ampere (A). $1A=1Cs^{-1}$

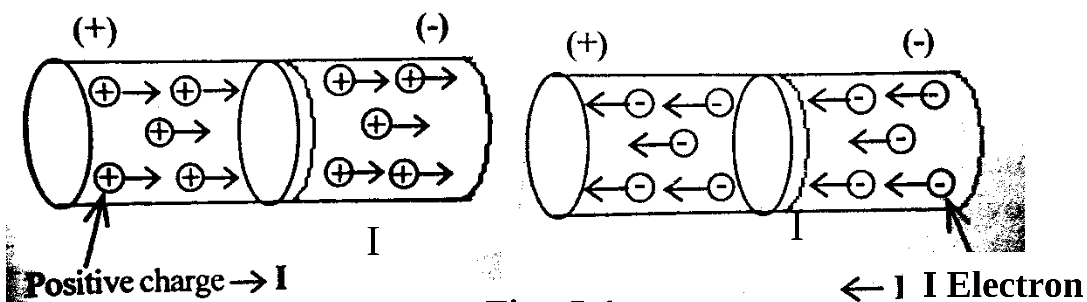


Fig: 5.4

Potential Difference and Current

The flow of current is basically related to the existence of a potential difference. A steady current will flow through the conductor if a steady potential difference is maintained between its ends.

A device which has two terminals and can transform some other form of energy into electrical energy and maintains a potential difference between its terminals is called a source of electromotive force (emf).

Car batteries, torchlight batteries, solar cells and electric generators are source of emf. In batteries, chemical energy is transformed into electrical energy. In generators, mechanical energy provided externally, is transformed into electrical energy. A solar cell converts radiant energy from the sun into electrical energy.

The ability of a source of emf to produce an electric current depends on its emf. The emf of a source is defined as the work done in moving a unit positive charge from its negative terminal to positive one.

or $\varepsilon = \frac{\text{energy transformed}}{\text{charge transferred through the source}}$, $\varepsilon = \frac{W}{q}$

Unit $1JC^{-1}$ = 1 volt

An alternative definition of emf is the potential difference between the two terminals of a source when there is no current following through it.

All sources of emf have a certain internal resistance. Due to this internal resistance a certain voltage drop occurs within the source of emf when a current is passing through it. If the internal resistance of a source when a current is passing through it. If the internal resistance of a source of emf is **r** and the current through it is **I**, the voltage drop to the internal resistance is **Ir**. Thus, the potential difference across the terminals, when the battery is supplying a current **I** is

$$V = \varepsilon - Ir$$

when there is no current through the battery, (I = 0), we have

$$V = \varepsilon$$

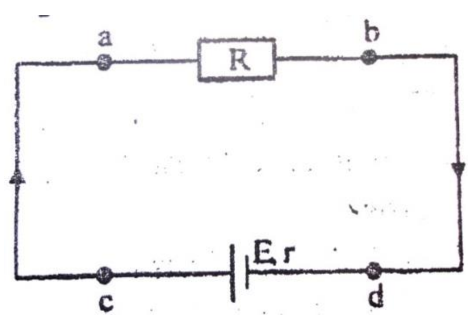


Fig: 5.5

Ohm's Law

It states that the current flowing through a conductor is directly proportional to the potential difference between the ends of the conductor provided that the temperature is kept constant.

In symbol, $I \propto V$

$I = \frac{V}{R}$ or $V = IR$

where, V - potential difference across the conductors or voltage producing current.

I - the current flowing through the conductor,

and R - the resistance of the conductor

Resistivity

The resistivity is defined as the resistance of a conductor of one unit cross-sectional area and one unit length.

$$\rho = \frac{RA}{l}$$

where, ρ = resistivity

R = resistance

A = area

L =length

SI unit = ohm metre (Ωm)

Variation of Resistance with Temperature

The resistivity of all materials change when the temperature is changed.

The resistivity at temperature t is:

$\rho_t = \rho_0 (1+\alpha t)$ where α is the temperature coefficient.

Since $R \alpha \rho$

$R_t = R_0 (1+\alpha t)$

Eg. The heating element of a hot plate is made of nichrome wire of resistance 50 Ω at 300 K. What is its resistance when it is red hot at 800 K? ($\alpha = 4\times10^{-4}K^{-1}$ for nichrome)

Resistance in Series and Parallel

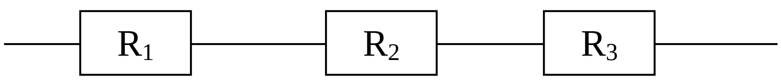


Fig: 5.6

For series combination, the equivalent resistance$R = R_1 + R_2 + R_3 + \ldots$..

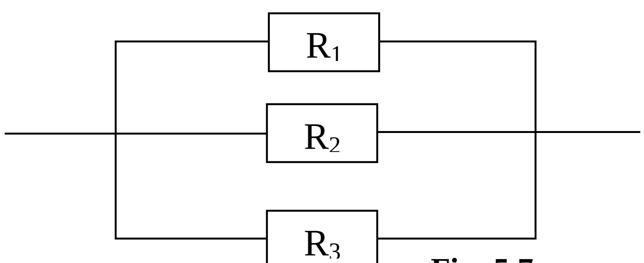


Fig: 5.7

For parallel combination, the equivalent resistance is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots..$$

Joule's Law

The amount of heat produced in a resistor due to a current flowing through it is directly proportional to the square of the current, the value of resistance and the time taken by the current to pass through the resistor. $H = \frac{I^2 R t}{J}$

Where, H = the amount of heat

I = Current

R = resistance

t = time taken

J = Joule mechanical equivalent of heat ($J=4.2\ Jcal^{-1}$)

5.3 Effect of Current in Human Bodies

The harmful effects of electricity are dependent mainly upon the amount of electric current which flows through the body, the duration of the current, and the path it flows through the body. A current that passes through vital organs such as the heart and brain is especially serious, for it can interfere with their operation. A current heat tissue and can cause burns, particularly on the skin, where the resistance is high. Also current stimulates the nerves and muscles of the body. We feel a "shock" because our muscles contract.

The serious ness of shock, depends on the resistance of the body. Living tissue has quite a low resistance, since the fluid of cells contains ions that can conduct quite well. However, the outer layers of skin, when dry offer considerable resistance. The resistance of a human body when the skin is dry is in the range $10^4\ \Omega$ to $10^6\ \Omega$. When the skin is wet, the resistance may be 1000Ω or less. A person in good contact with the ground who touches a 120V line with wet hands can suffer a current.

$$I = \frac{120}{1000} = 120\ mA$$

This could be lethal.

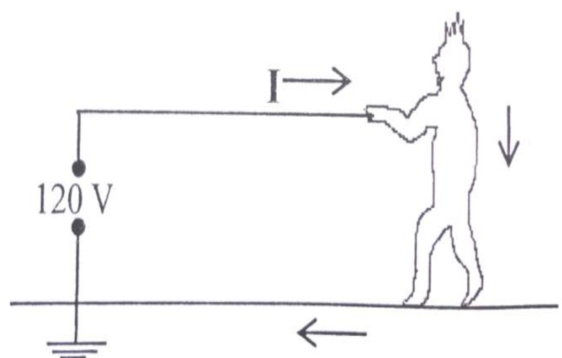


Fig: 5.8

A person receives an electric shock when the circuit is completed.

To avoid shocks, the body must not become part of a circuit by allowing different parts of the body to touch objects at different potential, commonly one part of the body may be touching ground and another part a high or low potential.

Table 5.1 The Physiological Effects of 60Hz AC Current Through Intake Skin into the Body Trunk

Current (1 Second Contact)	Physiological Effect	Voltage Required to Produce the Current with Assumed Body Resistance 10.000 ohms	1000 ohms
1 milliampere 5 milliamperes	- Threshold of feeling - Accepted as maximum harmless current	10 V 50 V	1 V 5 V
10-20 milliamperes	- Beginning of sustained, muscular contraction (can't let go current)	100-200 V	10-20 V
50 milliamperes	-Pain, possible, fainting and exhaustion. Heart and respiratory functions continue	500 V	50 V
100-300 milliamperes	- Ventricular fibrillation, fatal if continued Respiratory function continues	1000-3000 V	100-300 V
6 amperes	- Sustained ventricular con traction followed by normal heart rhythm (defibrillator). Temporary respiratory paralysis and possibly burns.	60,000 V	6000 V

****

1.4 Electromagnetism

Magnets and Magnetic Fields

Simple magnets have two poles which are designated as north and south poles. The poles are the regions where magnetic property is most concentrated. It is well known that like poles repel and unlike poles attract each other.

Magnetic field is represented by lines of force.

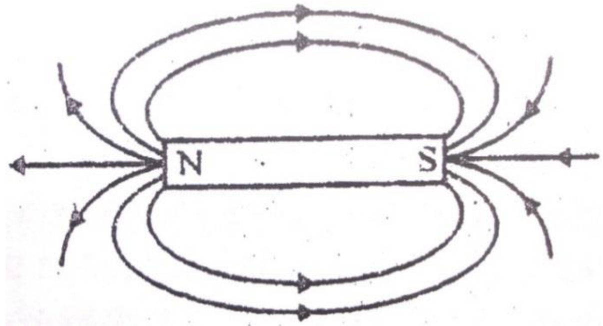
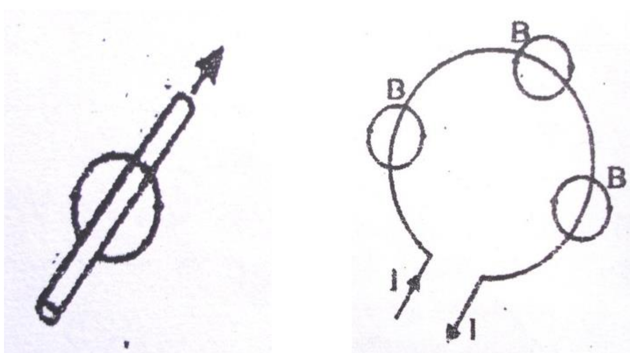


Fig: 5.9 The magnetic field of a bar magnetic

The Magnetic Field of a Current

The connection between electricity and magnetism was discovered in 1820 by Hans Christian Oersted, a Danish scientist. He found that a magnetic field could be produced not only magnets but also with electric currents.

The observations show that an electric current always produces a magnetic field.



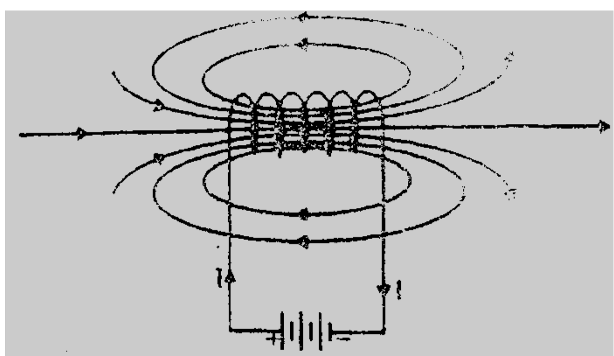


Fig: 5.10

If an electric current. I, flows through a straight wire, the magnetic field will be produced by that current. The direction of the magnetic field associated with any current may be determined by the "right hand rule". The rule states that if a current-carrying wire is held in the right hand, with the thumb pointing in the direction of the current, then the fingers point in the direction of the magnetic field (lines of force).

If the current-carrying wire is bent into a loop, the magnetic field add together inside the loop to give a stronger magnetic field. A further strengthening of the magnetic field can be obtained by winding a long coil of wire called solenoid. Note that the magnetic field configuration is like that of the bar magnet. The solenoid can be called an electromagnet and could be used for the same function as a bar magnet.

Practical electromagnets are made by adding an iron core to the solenoid.

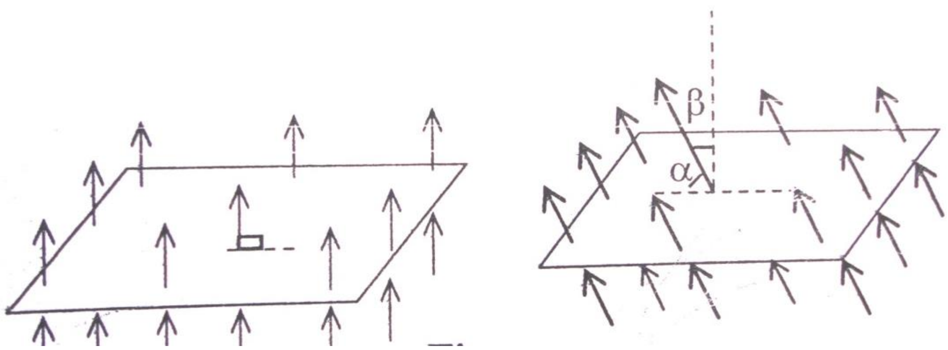
Magnetic Flux (ϕ)

The total magnetic lines of force passing normally through a surface (either plane or curved) is called the magnetic flux.

Its unit is tesla metre square. (Tm^2)

Magnetic Flux Density (B)

The total number of lines of force passing normally through a surface of unit area is called the magnetic flux density. (or) The intensity of the magnetic field is proportional to a quantity called the magnetic flux density, which is a vector denoted by B. Its unit is tesla (T). $B = \frac{\Phi}{A}$



$\Phi = BA$ **$\Phi = B A \cos\beta = BA \sin\alpha$**

Fig: 5.11

Where, β is the angle between the magnetic field and the normal to the surface.

α = angle between field and the surface area.

5.5 Electromagnetic induction

(The Interaction between Electricity and Magnetism)

(a) The Magnetic Force on a Moving Charge

If a positive charge q moves into the field B or a magnet with a velocity v, it will experience a force that is perpendicular both to the velocity and to the magnetic field.

The magnitude of the force is $F = q v B$ ($v \perp B$) = $q v B \sin\theta$

(only the magnetic field perpendicular to the velocity exerts a force on the charge.) (θ = the angle between v and B)

A magnetic field exerts no force on a charge at rest or a charge that is moving exactly parallel to the magnetic field.

The magnetic force provides the centripetal force necessary to move the charge in a circle of radius r.

(b) The Magnetic Force on a current-carrying wire

Any current-carrying wire in a magnetic field will experience a force perpendicular to the wire.

If a straight wire of length(l) with a current I in it is place perpendicular to the magnetic field, the magnitude of the force on the wire is given by $F = BIL$ $(I \perp B)$

If the length of the wire makes an angle ϕ with the field direction the force is $F = BIL \sin\theta$. (θ = the angle between I and B)

The direction of the force is given by the left hand rule. The rule stated that: If the thumb, the forefinger and the middle finger of the left hand are stretched out perpendicular to each other, such that the forefinger points in the direction of the field, and the middle finger points in the direction of the current, then the thumb points in the direction of the force.

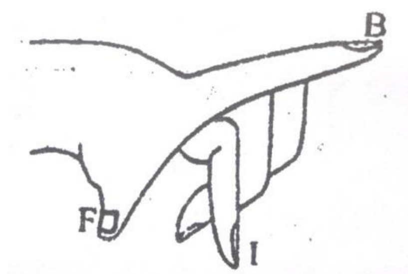
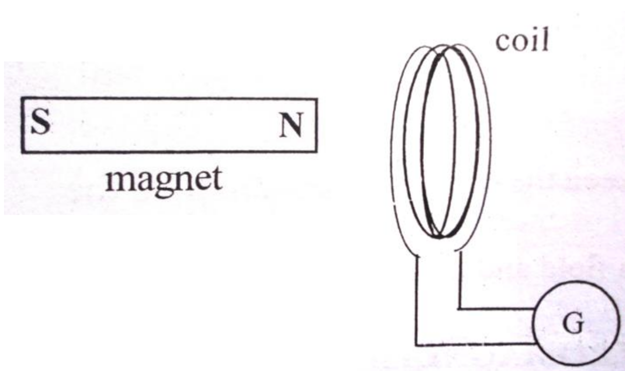


Fig: 5.12

(c) When a wire is forced to move through a magnetic field in a direction perpendicular to the wire, the magnetic field generates a voltage (emf) in the wire. This is the generator principle by which probably 95% of the world's electricity is generated.

Faraday's Experiment



Galvanometer

Fig: 5.13

The production of an electric current in a circuit by moving coils or magnets or by changing currents is called electromagnetic induction.

The current so produced is called an induced current. When there is a current, an emf is always associated with it, and the emf produced by electromagnetic induction is called an induced emf.

Faraday's Law

The emf induced in a circuit is proportional to the rate of change of magnetic flux linked with the current.

$\varepsilon \propto \frac{\Delta\phi}{\Delta t}$ where is the induced emf and $\Delta\phi$ is the change in flux during a time Δt.

Lenz's Law

The direction of the emf or the current induced in the circuit is given by Lenz's law.

The direction of the induced emf or current is such that it opposes the change that produces it.

$\varepsilon = -N \frac{\Delta\phi}{\Delta t}$ (N= number of turns)

The minus sign is present to take into account the fact that the direction of ε is to oppose the change in ϕ.

Since $\phi = BA \cos\beta$, it is clear that ϵ could be changed by changing B or A or ϕ, β could be changed by rotating the coil.

Alternating Current

Current flowing through a system powered by a battery is also steady and is called direct current (DC). However, nearly all electricity that is transmitted from power plants to homes and businesses fluctuate periodically in time, Fig: 5.14. Compares voltage as a function of time for DC and AC power. When the voltage alternates smoothly between positive and negative, the current through a device also alternate in the direction it flows. This current is called alternating current.

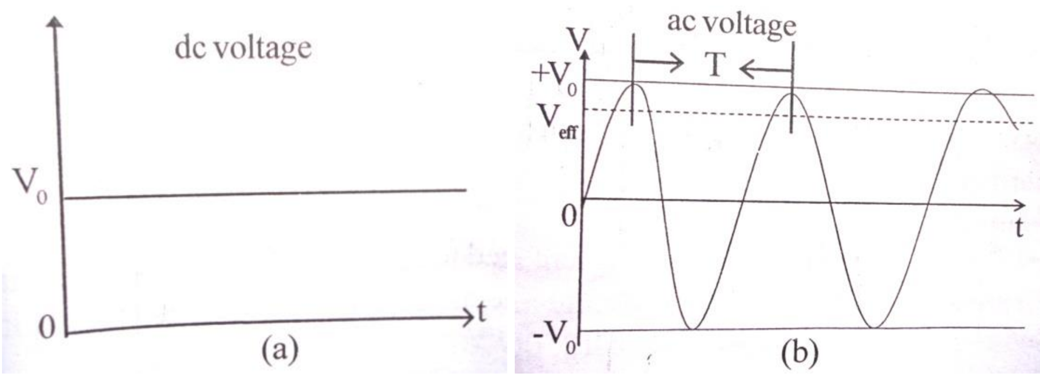


Fig: 5.14 (a) DC voltage is constant in time: (b) AC voltage oscillates in time with a period T, V is the effective voltage; V_0 is the speak voltage.

$V = V_0 \sin 2\pi ft$, $I = I_0 \sin 2\pi ft$

Meaningful effective voltage and effective current for AC are given by

$V_{rms} = V_{eff} = V_0 / \sqrt{2} = 0.7071\ V_0$

$I_{rms} = I_{eff} = I_0 / \sqrt{2} = 0.7071\ I_0$

Where V_0 and I_0 are the peak voltage and peak current, respectively.

It can be assumed that the values given for AC voltage, current and power are effective values unless otherwise stated.

Example

Calculate the peak voltage V_0 for 120V AC electricity. The effective voltage is 120V. To Find the peak voltage.

$V_{eff} = V_0 / \sqrt{2}$

$V_0 = \sqrt{2}\ V_{eff} = (1.414)(120) = 170\ V$

Thus, common household electricity swings from +170 to -170 V and back 60 times per second, producing and effective voltage of 120V.

AC electricity is used because it can be transmitted over large distances with greater case and efficiency. This is because of the relative ease with which ac voltage can be increased or decreased. It is necessary to raise the voltage of electricity sent large distances and to reduce it again at the user's site. This is most easily done with AC. (It is relatively difficult to change the voltage of DC electricity.)

The higher the voltage used, the less heat is generated in the wires carrying a given amount of power. (Although all wires have been assumed to have negligible resistance, cross – country wires are very long.)

Example

(a) Calculate the amount of current need to transmit 1.0 MW of power at a voltage of 120V.

(b) Calculate the amount of current needed to transmit 1.0 MW of power at a voltage of 12,000 V.

(a) From equation P = IV, and solving for the current, I = P / V given

$$I = \frac{1.0 \times 10^6\ W}{120\ V} = 8.33 \times 10^3\ A$$

(b) Similarly,

$$I = P / V$$

$$= 1.0 \times 10^6\ W / 12{,}000\ V$$

$$= 83.3\ A$$

Much less current is needed to transmit the same amount of power at a higher voltage.

5.6 Bioelectricity

The Living Cell as an Electric Source

Bioelectricity refers to the electrical phenomena in living tissue. The membrane of the living cell can maintain a voltage difference between the inside and outside of the cell.

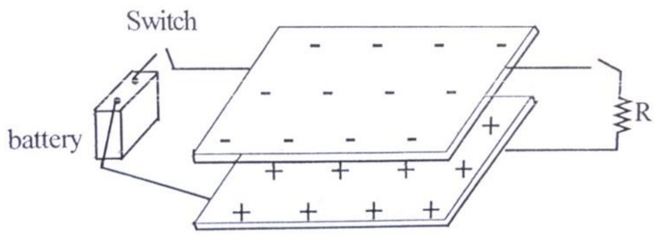


Fig: 5.15

This is analogous to the charged parallel plate arrangement discussed previously. If unlike charges are placed on parallel conducting plates as shown in figure, a voltage will exist between the plates. Energy is required from a battery or other source to establish this unequal charge distribution.

Charge the plate by the battery ----- polarized (high energy state)

Switch closed, discharged through R---------- depolarized

This would be somewhat analogous to the production of an electrical impulse by a nerve cell. When a living cell is in its normal or "rest" state, it maintains a voltage of about 70 to 90 millivolts between the inside and outside of the cell. The inside of the cell is negative with respect to the outside. This voltage across the cell membrane is referred to as the "membrane potential" or "rest Potential" of the cell.

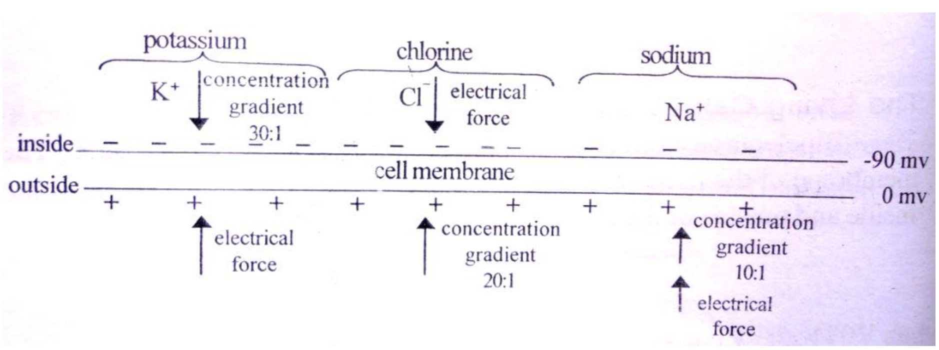


Fig: 5.16. The cell membrane with a rest potential of -90mv on the inside of the cell.

The resting state of the cell membrane is a result of the balancing of opposing influences, as illustrated in Fig: 5.16. Large concentration gradients exit across the membrane for each of the three electrolytes, Potassium ions are more concentrated inside the cell by a factor of roughly 30 to 1. The sodium and chloride ions are more concentrated outside, with concentration ratio roughly ten to one for Na^+ and twenty or more to one for Cl^{-1}.

The movements of mobile charge carriers through the cell membranes are government by the three main influences: (i) the tendency toward diffusion from a higher to a lower concentration (ii) the tendency to move away from like charges and toward unlike charges, and (iii) the permeability of the membrane to the particular ion.

If the cell wall is uncharged, the potassium beings to diffuse outward through the permeable membrane because of the large concentration gradient. This leaves a net negative charge near the interior of the cell membrane and contributes a net positive charge on the outside. This charge build up opposes further potassium migration so that after a brief diffusion period, on the order of milliseconds, a stable equilibrium voltage is established and no further net diffusion occurs.

The Action Potential

When a membrane of a nerve cell is sufficiently stimulated, it "fires" or releases some of the stored energy. The interior potential of the cell quickly rises from about 90 mill volts to about +20 to +30 mill volts. This process is called depolarization. The repolarization process begins immediately. The voltage pulse produced by the depolarization repolarization process is referred to as the action potential. The depolarization process is closely related to the conduction of sodium ions into the cell. During depolarization the cell, driving the potential positive. The threshold requirement for stimulating a cell involves increasing the permeability to Na+ sufficiently for the influx to start. The lowered electrical force allows potassium ions to migrate outward. Within energy supplied by the cell, the potassium diffusion process takes control for the repolarization or "recharging" of the cell membrane when the membrane's permeability to sodium is turned off.

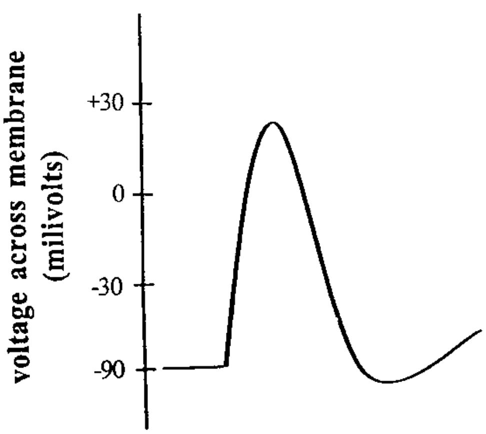


Fig: 5.17: Sequence of membrane events during an action potential

The propagation of the action potential pulses by nerve fibers and other cells produces measurable electrical voltages at all points in the body. The fact that these action potential can be measured at the surface of the skin provides the basis for many bioelectric measurements, such as the ECG and EEG.

The Electrocardiogram

The most widely used of the bioelectric measurements if the electrocardiogram (ECG). It is a direct measurement of voltage produced by the body and therefore does not involve a transducer. The action potentials produced in the heart result in measureable voltages at the skin which can be monitored by external electrodes. These are the largest action potential measured on the body, producing voltages on the order of 1mv between ECG leads.

The Electroencephalogram

The electroencephalogram (EEG) is a recording of electrical signals produced by the brain. Usually the measurements are made from electrodes placed on the scalp. The signal strengths involved are much lower than those involved in the ECG. The voltages measured are on the order of 50 micro volts, compared to about a mill volt for the ECG. Consequently, the signals must be amplified by factors of several thousand to be records. This of course makes the problems of stray signals and electrical noise much more severe than with the ECG.

The Electronic Pacemaker

Many physiological events could be stimulated by externally generated impulses. For example, a regularly produced electrical impulse, generated form an artificial pacemaker and applied to the myocardium, can cause the ventricles to contract when the normal biological pacemaker signal from the SA node is absent or blocked.

The artificial pacemaker is a battery-powered devices, which generates electrical stimuli at a predetermined rate. Typically, these pulses will be on the order of 10volts with duration of a few milliseconds and a repetition rate of 60 to 70 per minute.

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CHAPTER – VI
MODERN PHYSICS

6.1 Atomic Physics (X-rays, CT scan, NMR Scan)

In this chapter we shall study the methods of producing electrons and concept of the photon which are both important in modern physics.

Way of Getting Electrons out of Metals

There are four common ways of getting electrons out of metals:

(1) Thermionic emission
(2) Photoelectric emission
(3) High field emission
(4) Secondary emission

All of these methods have their important uses.

But we will discuss only first two in the present chapter.

(1) Thermionic Emission

The emission of electrons from a metal surface at high temperature is called thermionic emission.

When a metal is heated the atoms as well as the free electrons gain energy. Those electrons which have got enough could leave the metal.

The energy required to remove an electron from a metal surface is called the work function of the metal.

$$W = h\,\upsilon_0$$

(2) Photoelectric Emission

This effect is the emission of electron from a metal surface when light of short wavelength is incident on it. The electrons produced by photoelectric effect are called photoelectrons.

According to Planck's quantum theory, electromagnetic waves are radiated as small packets of energy called quanta. Each quantum carries an energy

$$E = h\nu$$

where ν is the frequency of the wave and h is a constant called Plank's constant and has a value 6.625 x10^{-34}Js. The basic unit of the energy of electromagnetic radiation was given the name quantum by planck, but Einstein called it a photon.

When radiation falls on a metal surface the energy $h\nu$ of a photon is transferred to an electron. The electron needs an energy W, the work function to get out of the metal surface. The remaining energy ($h\nu$-W) is carried away by the electron as kinetic energy. We can write

$$KE = \tfrac{1}{2} mv^2 = h\nu - W$$

Where, $\tfrac{1}{2} mv^2$ is the kinetic energy of the electron.

The minimum energy of an emitted electron is zero, and this corresponds to the threshold frequency ν_0 where

$$\nu_0 = \frac{W}{h}$$

Below this frequency, the radiation cannot produce photoelectrons.

The Production of X-rays

When a metal target is hit by high energy electrons, the atoms become ionized or some atomic electrons are raised to excited states. With sufficient energy, the electrons in the innermost orbits could be excited or ejected from the atom. Fig: 6.1 shows the ejection of an electron from a K-shell. When an electron site in the K-shell is vacant, an electron from the L-shell can jump down the emit an X-ray photon of energy

$$h\nu = E_f - E_i$$

where, E_f and E_i are the energies of the electron in the final and initial states.

An electron from the L-shell jumping to the K-shell also leaves a vacancy and an electron from the next shell. In this case, the M-shell can jump to the vacant site producing another photon. Thus there appears a cascade of transitions and corresponding photons. The transitions involving the inner shells have large energy changes and therefore produce high energy photons which are X-rays. The transitions among the outer shells produce visible light. Thus from a single atom, radiations of different wavelengths could be produced.

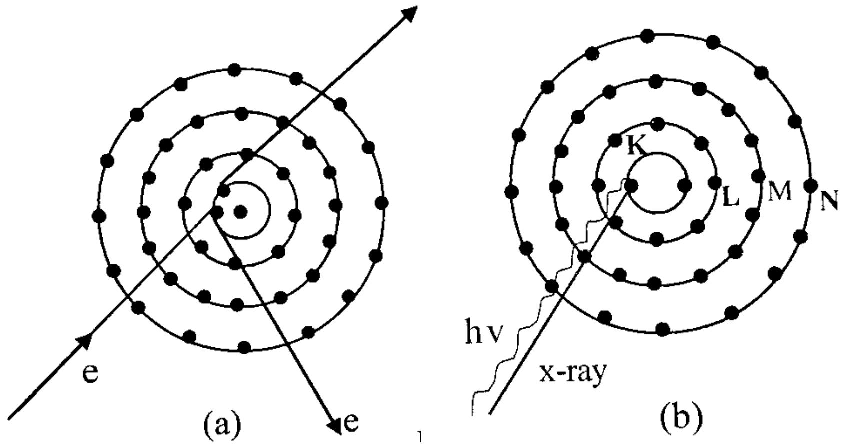


Fig : 6.1

The properties of X-rays

(1) X-rays travel in straight lines
(2) X-rays produce fluorescence in many materials, and like visible light, darken photographic plates.
(3) X-rays produce ionization in air, and also in solids, liquids and gases.
(4) X-rays have high penetrating power and the depth X-rays can penetrate depends on the density of the material.
(5) X-ray are electromagnetic waves like visible light, but with wavelength in the order of 10^{-10}m. (Because of this short wavelength it is very energetic, penetrating and ionization)

Danger of X-rays and their Prevention

X-rays have harmful effects as well as beneficial uses. They were rushed into use without the damaging effects of their penetration of the human body being fully appreciated. When X-ray strikes the chromosomes in the nucleus of a cell, changes mutations may result, and the cell or genes may even be destroyed. Radiation can cause sterility.

The hair of a radiation – sickness sufferer turns white before falling out. Early experimenters and operators of X-ray machines were often afflicted by this radiation sickness.

In view of the harmful nature of the X-rays, it is essential for radiography workers to be shielded from the X-rays apparatus by a wall of lead or by wearing a lead lined apron and impregnated rubber gloves.

Application of X-rays

(1) Radiography

X-rays are penetrating rays and pass easily through the soft tissues of the body but experience difficulty in penetrating opaque objects such as bone, metal and certain chemicals (a barium meal for example)

X-rays will cause fluorescence. During a radiographic examination, the fluorescent plate or photographic plate is placed behind the region to be examined. The fluorescent plate will produce an immediate image, in contrast to the photographic plate which must be developed chemically examination.

(2) Direct Fluoroscopy

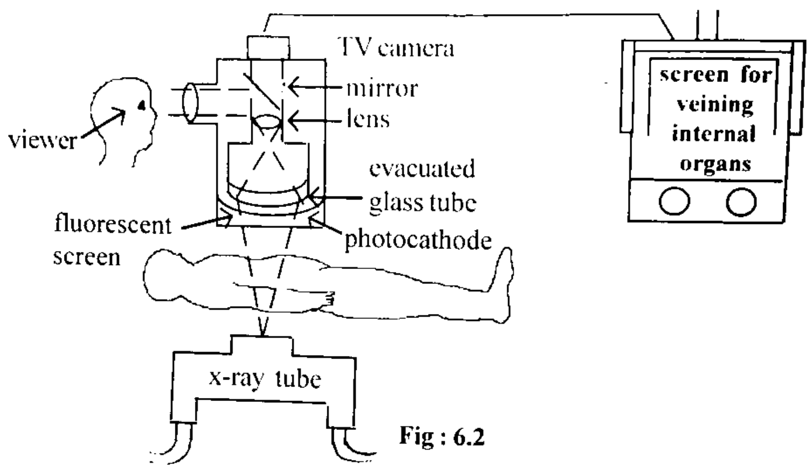


Fig : 6.2

Direct fluoroscopy is another method of X-ray examination, when it is necessary to observe the motion of internal parts of the body. The patient is placed between the X-ray source and a fluorescent screen. The rays pass through the body, causing the fluorescence of calcium tungstate, zinc sulphide or barium platinocyanide in an intensifying screen: the image is then viewed by the radiologist. This method of X-ray examination calls for protection for radiologists.

CT Scan

Major advances in X-ray diagnosis have been made with computer assisted scanning methods which produce a cross-sectional view of part of the body. Such techniques are generally called 'computed tomography' or CT scans.

NMR Scan

The nuclear magnetic resonance (NMR) scan is growing rapidly in clinical importance. This scanning technique produces sectional images with fineness of detail approaching that of the X-ray CT scans, although the scan time required in minutes compared to seconds for the X-ray methods.

Unit-roentgen.

The Nature of the Nucleus

Atomic number (Z)

It is number of protons present in a nucleus.

Neutron number

It is the sum of the neutrons present in a nucleus.

Mass number (A)

It is the number of all nucleus. (i.e the sum of protons and neutrons, A=Z+N)

Nuclide

A specification of an atom, characterized by its mass number, atomic number and nuclear energy state, it is commonly used in nuclear physics.

e.g $^{A}_{Z}X$

Isotopes

Nuclides having the same atomic number but different mass number.

Isobars

Nuclides having the same mass number but different atomic number.

Isomers

Nuclides having the same mass number and atomic number but different energy states.

Parent nuclide

It is a nuclide from which another nuclide is formed during a radioactive decay.

Daughter nuclide

A nuclide originated from a parent nuclide.

6.2 Nuclear physics

Radioactivity

In the development of both atomic and nuclear physics, radioactivity has played the most significant role. It is concerned with fission as well as fusion processes of the nuclei.

Radioactivity is a phenomenon in which the atomic nuclei spontaneously disintegrate and transform into new nuclei. In the process, the transforming nucleus emits either one or more of radiations known as alpha rays, beta rays and gamma rays.

The Three Types of Radioactive Rays

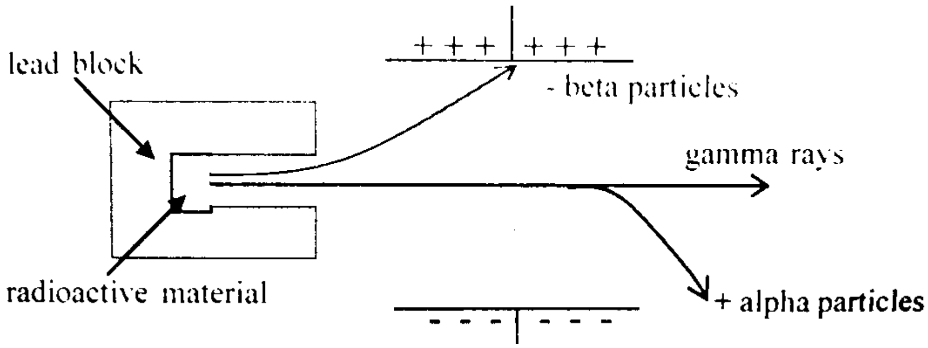


Fig: 6.3

A single radioisotope will not emit all three types of radiation, but a sample containing several radioactive species may produce the three beams. The three types of radiations were labeled alpha, beta, and gamma rays.

Type of radiation Physical nature and description of effects

Alpha

Composed of two protons and two neutrons, it is a nucleus of the element helium. Because of its very large mass (more than 7000 times the mass of the beta particle), it has a very short range. It is not suitable for radiation therapy since its range is less than a tenth of a millimeter inside the body. Its main radiation hazard comes when it is ingested into the body. It has great destructive power within its short range.

$^{A}_{Z}X$ ---------- $^{A-4}_{Z-2}Y$ + α ($^{4}_{2}He$)

$^{226}_{88}Ra$ ---------- $^{222}_{86}Rn$ + α

(radium) (radon)

Beta

An electron, it has a greater range of penetration than the heavier alpha particles, but is much less penetrating than gamma rays. It radiation hazard is greatest if it is ingested.

$^{A}_{Z}X$ ----------- $_{Z-1}^{\ A}$ Y + β^+ ($_{+1}^{0}e$)

$^{A}_{Z}X$ ----------- $_{Z+1}^{\ A}$ Y+ β^- ($_{-1}^{0}e$)

$^{214}_{82}Pb$ ----------- $^{214}_{83}$ Bi + β^-

lead bismuth

$^{30}_{15}P$ ----------- $^{30}_{14}$ Si + β^+

Phosphorus silicon

Gamma

Electromagnetic ray. It is distinguished from X-ray only by the fact that it come from the nucleus. Gamma rays are emitted by the nuclei themselves when they are left an excited state following alpha or beta emissions. Most gamma rays are somewhat higher in energy than X-rays and therefore are very penetration. It is the most useful type of radiation for therapy, but at the same time it is the most hazardous because of if ability to penetrate large thickness of material.

$$^{40}_{20}\text{Ca}^* \text{-----------------} \; ^{40}_{20}\text{Ca} + \Upsilon$$

Radioactive Series

An unstable nuclide will decay continuously until a stable nuclide is finally formed. The whole series is called a radioactive series. A typical example is the uranium series given below.

$^{238}_{92}$U ---- $^{234}_{90}$Th ---- $^{234}_{92}$U ---- $^{230}_{90}$Th------$^{226}_{88}$Ra-------$^{222}_{86}$Rn

(Uranium) (Thorium) (Radium) (Radon)

Law of Radioactive Decay

The number of parent nuclei in a radioactive material decreases with time because of radioactive disintegration. The disintegration is a statistical and random process.

The rate of radioactive disintegration is proportional to the number of nuclei that have not yet disintegrated at any instant.

$-\frac{dN}{dt} \propto N$

$\frac{dN}{dt} = -\lambda N_0$ (λ =decay constant)

$N= N_o e^{-\lambda t}$

N_0= the number of nuclei at time t = 0;

N= the number of nuclei at time t = t;

t = time interval

$N= \frac{N_0}{2^n}$

$n = \frac{t}{T_{1/2}}$

n = number of half-life, t= time interval

Activity

Activity is defined as the number of decays per unit time occurring in a radioactive source. The activity of a radioactive source depends on the number N of radioactive nuclei present and their half-life $T_{1/2}$.

$A = A_0 e^{-\lambda t}$

$A = \frac{A_0}{2^n}$

A_0 = activity at time t =0;

A = activity at time t =t;

Half-life $T_{½}$

The physical half-life T is the time required for the number of radioactive nuclei to decrease to one-half of the original number N_0,

When t, $T_{½}$, $\frac{N}{N_0} = \frac{1}{2}$.

With these values setting in equation (l) we obtain.

$$\frac{1}{2} = e^{-\lambda T_{½}}$$

We take logarithms of both sides and solve for $T_{½}$

$$T_{½} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

Biologic half-life

It is the time required to reduce the activity to one-half by natural biologic elimination processes.

Effective half-life

Physical and biologic half-lives may be thought of as representing two parallel path ways for reducing the amount of radioactive material.

Therefore, effective half-life is

$$T_{eff} = \frac{T_P T_B}{T_P + T_B}$$

Biological Effects of Ionization Radiation

The biological effects of nuclear radiation and X-rays are due to the ionization they produce. They are therefore considered together under the name ionizing radiation. Ionizing radiation can induce cancer and causes genetic defects. It can also cure cancer and is used routinely for medical diagnostic-purpose.

When X-rays or gamma rays enter tissue, they may give all their quantum energy to an electron in ejecting it from a molecule (photo ionization) or they give only a fraction of their energy to the electron and then ‘’scatter’ the remainder off in the form of a lower energy, lower frequency quantum of a radiation. In either case the ejected electron have very high speeds and enough to ionize many other atoms. They may act directly on cellular molecules or may interact with water molecules to dissociate

H_2O into chemically active H^+ and OH^- ions. The ionization resulting from any type of ionizing radiation produces very active chemical species which may disable cellular component or produce toxins.

Radiation Therapy

Ionizing radiation, particularly X-rays and gamma rays, has proved to be a useful therapeutic tool for the treatment of cancer. This may seem paradoxical after discussing hazards and the possibility of a radiation caused cancer, but recall that the rick of a cancer-causing mutation is quite small and that the most probable result of the interaction of radiation with a cell is that the cell will fail to reproduce.

Measurement of Radiation Exposure

Several types of units are used in the measurement of radiation.

1 **Curie (Ci)**

One curie is the activity of 1g radium.

$1Ci = 3.7 \times 10^{10}$ decays sec^{-1}

The curie (**Ci**) is the unit used for stating the "strength'' or "activity" of a given radioactive sample.

1 becquerel (Bq)

It is defined as one nuclear decay per second.

$1Ci = 3.7 \times 10^{10}$ Bq

The Becquerel (**Bq**) is the unit for source activity in the SI unit system.

1 roentgen (R)

It is the radiation intensity required to produce an ionization charge of 0.000258 coulomb per kilogram of air.

The roentgen (R) is a measure of radiation exposure for X-rays or gamma rays.

Measurement of Radiation Dosimetry

The red

It is defined as an absorbed dose of 0.01 joules of energy per kilogram to tissue.

The Gray (Gy)

It is the SI unit for absorbed radiation dose and is defined as 1 joule of absorbed energy per kilogram of tissue.

1 Gray = 100 rad.

The rem (roentgen-equivalent-man)

It is defined as the dose in rads multiplied by a "quality factor", which is an assessment of the biological effectiveness of that particular type and energy of radiation.

Diagnostic use of radioisotpe

Radioisotopes can be used to locate to track, or as a method of destroying tissue.

Tracers

Radioactive Iodine 132,131, or 125 are radioisotpes which can be included in a medicine and swallowed. The course of the iodine through the body can be "traced" by listening to the detector. Labelled compounds containing Cobalt 58, Chromium 51 and Iron 59 atoms are used as tracers for examining the blood. Technetium 99 is a radioisotope popular for many tracer diagnosis tests.

Location of tumour

Tumours and cancers are regions if active multiplication of body cells, if medicine containing radioactive labeled atom of sodium or mercury, is either injected or taken by mouth, the labeled isotopes will gather in the position of the tumour which can be specifically localized by scanning with a Geigar Muller counter.

Therapy

The use of radioactive isotopes for treatment and destruction of harmful tumours is quite well known. Healthy and cancerous tissue can be destroyed by the beta and gamma radiations of radioactive isotopes. The radioisotope is used in a sealed form, that is, it is contained with a metal tube of platinum, nickel or aluminum. The tubes can take the form of needles, bead or be in the wire form, all of which can be inserted nest to tumour, whilst the gamma radiation passes through the metal to attack the tissues.

How to Minimize your Exposure

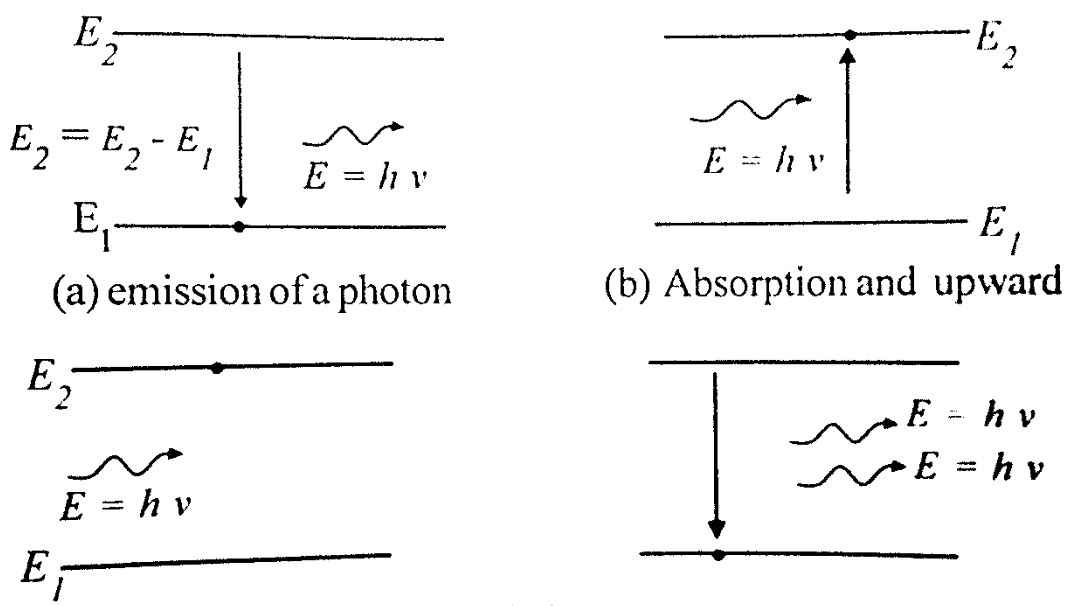
Safety Measures

1. Maximize distance between you and the source.
2. Minimize the time you spend near the source.
3. Use shielding whenever possible.
4. Use a film badge or other monitoring device to record the radiation dose you have received.

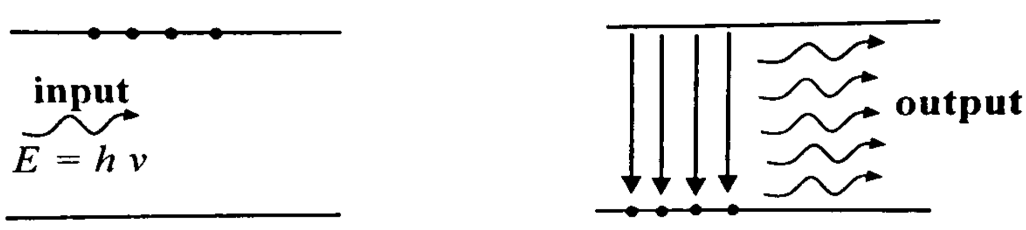
The Laser And Its Applications

It is a device that produces an intense, concentrated and highly parallel beam of coherent light.

It is a acronym of Light Amplification by Stimulated Emission of Radiation.



(c) Stimulated emission of radiation



(c) light amplification by stimulated emission of radiation (laser)

Fig: 6.4 The stimulated emission process involved in laser action.

Types of Laser

(1) Solid Laser
(2) Liquid Laser
(3) Gas Laser
(4) Semiconductor Laser

Laser Scalpels

Makes a very fine cut with a laser beam.

Eye Surgery

Laser beam can be used to mend a detached retina and to reshape the cornea for improving eye sight.

Skin Deep

- Carbon dioxide laser cuts, the heat seals the tiny blood vessels.
- Argon laser remove certain kinds of birth marks and tattoos without noticeable scar.
- To treat throat cancer

Boring Through Bone

Xenon laser vaporizes solid bone to bore through the skull.

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