PHYSICS FOR TTC

STUDENT'S BOOK

YEAR 3

OPTION: SME

FOREWORD

Dear Student- teacher,

Rwanda Education Board is honoured to present to you this Physics book for Year Three of TTC which serves as a guide to competence-based teaching and learning to ensure consistency and coherence in the learning of Physics subject. The Rwandan educational philosophy is to ensure that you achieve full potential at every level of education which will prepare you to be well integrated in society and exploit employment opportunities.

The government of Rwanda emphasizes the importance of aligning teaching and learning materials with the syllabus to facilitate your learning process. Many factors influence what you learn, how well you learn and the competences you acquire. Those factors include the instructional materials available among others. Special attention was paid to the activities that facilitate the learning process in which you can develop your ideas and make new discoveries during concrete activities carried out individually or with peers.

In competence-based curriculum, learning is considered as a process of active building and developing knowledge and meanings by the learner where concepts are mainly introduced by an activity, a situation or a scenario that helps the learner to construct knowledge, develop skills and acquire positive attitudes and values. For effective use of this textbook, your role is to:

- Work on given activities including laboratory experiments which lead to the development of skills;
- Share relevant information with other learners through presentations, discussions, group work and other active learning techniques such as role play, case studies, investigation and research in the library, from the internet or from your community;
- Participate and take responsibility for your own learning;
- Draw conclusions based on the findings from the learning activities.

I wish to sincerely extend my appreciation to the people who contributed towards the development of this book, particularly REB staff who organized the whole process from its inception. Special gratitude goes to teachers, illustrators and designers who diligently worked to successful completion of this book.

Dr. NDAYAMBAJE Irénée

Director General of Rwanda Education Board

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Joan MURUNGI,

Head of Curriculum, Teaching and Learning Resources Department

CONTENTS

UNIT 1

SOUND WAVES

Key Unit Competence:

Analyse the effects of sound waves in elastic medium

Introductory activity

What are the properties which explain mostly the behavior of sound?

Fig.1. 1: People listening to music

1. a) Most people like to listen to music, but hardly anyone likes to listen to noise. In your own view, how is musical sound different from noise?

   b) A guitarist as shown in the figure above plays guitar. The sound is made by the vibration of the guitar string and propagates as a wave through the air and reaches your ear.

i) Assuming you are near by the guitarist and your friend is behind you, who can hear more sound? Explain your reasoning

ii) If another person playing flute comes in and plays it. Can you distinguish sound from the flute from that of a guitar? How are the two sounds different?

2. a) Now, while they are playing their instruments you keep moving away and coming towards a point where they are playing the instruments. Explain the variations of sound heard by you.

   b) Do you think there would be any change in the sound if you(the observer) and the players (the source) remained in the same position?

3. With scientific explanations explain why you may not be able to communicate well in a room where music is being played at a high tone.

1.1 PRODUCTION OF STATIONARY SOUND WAVES

Activity 1.1

Look at the Fig.1.2 and then answer the following questions.

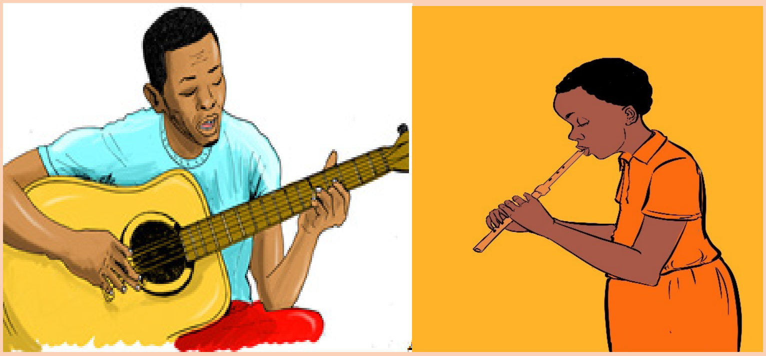


Fig.1. 2: Production of sound.

1. The two students in the figure above are producing sound. In each case, describe the method of production of sound.
2. Imagine that the student replaces the flute with a longer one, would the sound produced remain the same?Explain you answer.
3. Do you think a guitar with longer string produces the same sound as the one with a shorter string? Defend your answer using scientific explanations.

1.1.1 Sound in pipes

The source of any sound is vibrating object. Almost any object can vibrate and hence be a source of sound. For musical instruments, the source is set into vibration by striking, plucking, bowing, or blowing. Standing waves (also known as stationary waves are superposition of two waves moving in opposite directions, each having the same amplitude and frequency) are produced and the source vibrates at its natural resonant frequencies. The most widely used instruments that produce sound waves make use of vibrating strings, such as the violin, guitar, and piano or make use of vibrating columns of air, such as the flute, trumpet, and pipe organ. They are called **wind instruments.**

We can create a standing wave:

- In a tube, which is open on both ends. The open end of a tube is approximately a node in the pressure (or an antinode in the longitudinal displacement).
- In a tube, which is open on one end and closed on the other end. The closed end of a tube is an antinode in the pressure (or a node in the longitudinal displacement).

In both cases a pressure node is always a displacement antinode and vice versa.

A **node** is a point half way between the crest and the trough. The line that connects the nodes is the **nodal line.** The nodal line shows the original position of the matter carrying the wave.

Displacement node means that a very thin slice of the medium at the node does not move (zero displacement). If you have a standing wave in a half-open tube, there will be a displacement node (and a pressure antinode) at the closed end. This is due to the fact that the molecules cannot move back and forth at the closed end.In the open end you will, on the other hand, have a pressure node (and thus a displacement antinode). This is due to the fact that the pressure at the end of the tube is equal to that of the surrounding air.

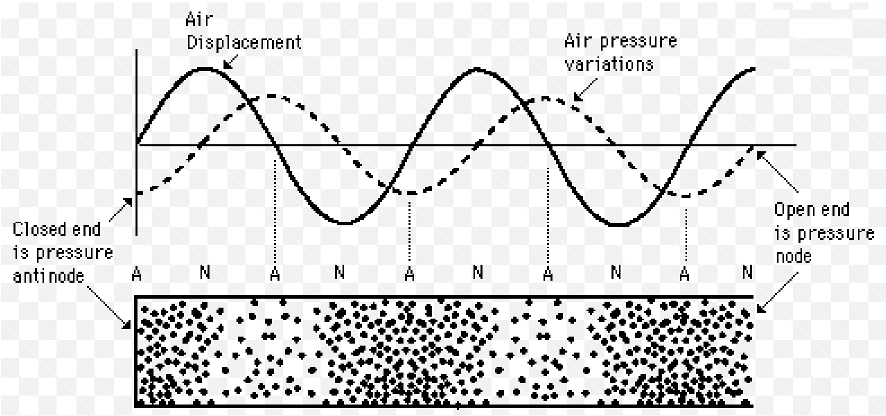


Fig.1.3 A pressure node is always a displa cement antinode and vice versa

Pressure node does not mean that the pressure is low; it simply means that the pressure is constant. Similarly, the pressure at the antinode is not "high"; it simply has the largest oscillations from low pressure to high pressure.

a. Tube of length L with two open ends

An open pipe is one which is open at both ends. The length of the pipe is the distance between consecutive antinodes. But the distance between consecutive antinode is $\frac{\lambda}{2}$ i.e. $L=\frac{\lambda}{2}$, where λ is a wavelength

The longest standing wave in a tube of length L with two open ends has displacement antinodes (pressure nodes) at both ends. It is called the **fundamental.**

$$L=\frac{\lambda}{2} \Leftrightarrow \lambda=2L \Rightarrow f_0=\frac{v}{2L}$$

Where f_0,and v are fundamental frequency and the speed of sound wave respectively.

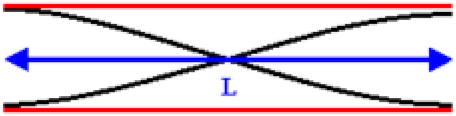


Fig.1. 4: Fundamental note (1st harmonic).

Notes with higher frequencies than fundamental can be obtained from the pipe by blowing harder. The stationary wave in the open pipe has always an antinode at each end.

The next longest standing wave in a tube of length *L* with two open ends is the **second harmonic (first overtone)**. It also has displacement antinodes at each end.

$$L=\lambda \Leftrightarrow f_1=\frac{v}{L}=2f_o$$

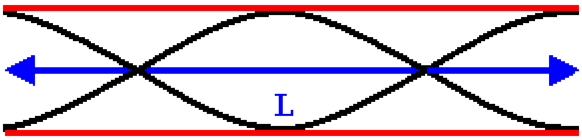


Fig.1. 5: First overtone (second harmonic).

The second overtone is obtained from Fig. 1.6 and is the third harmonic.

$$L=\frac{3\lambda}{2}\Leftrightarrow\lambda=\frac{2L}{3}\Rightarrow f_2=\frac{3v}{2L}=3f_o$$

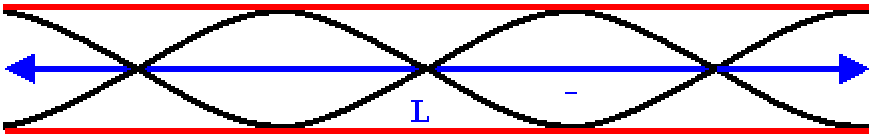


Fig.1. 6: Second overtone (third harmonic).

An integer number of half wavelength has to fit into the tube of length *L*:

$$L=\frac{n\lambda}{2}\Leftrightarrow\lambda=\frac{2L}{n}\Rightarrow f_{n-1}=\frac{nv}{2L}=nf_o$$

For a tube with two open ends, all frequencies $f_{n-1}=nf_0$ with *n* equal to an integer are **natural frequencies.**The frequency *f* of fundamental note emitted by a vibrating string of length *L*, mass per unit length *m* and under tension *T* is given by

$$f=\frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

Where μ is linear mass density.

Example 1.1

The fundamental frequency of a pipe that is open at both ends is 594 Hz. (a) How long is this pipe? (b) Find the wavelength of standing wave in the tube. Assume the temperature is $20\ ^0C$

Answer

a. Length of the pipe: $L=\frac{v}{2f_0}=\frac{343}{2\times 594}=0.29\ m$

b. The wavelength: $\lambda=2L=0.58\ m$

b. Tube of length *L* with one open end and one closed end.

The longest wavelength of standing wave in a tube of length *L* with one open end and one closed end has a displacement antinode at the open end and a displacement node at the closed end. This is the **fundamental.**

$$L=\frac{\lambda}{4}\Leftrightarrow\lambda=4L\Rightarrow f_0=\frac{v}{4L}$$

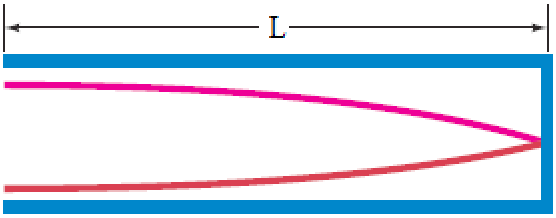


Fig.1. 7: Fundamental note (1st harmonic).

The next longest standing wave in a tube of length in a tube of length *L* with one open end and one closed end is the **third harmonic (second overtone)**. It also has a displacement antinode at one end and a node at the other.

$$L = \frac{3\lambda}{4} \Leftrightarrow \lambda = \frac{4L}{3} \Rightarrow f_1 = \frac{3v}{4L} = 3f_0$$

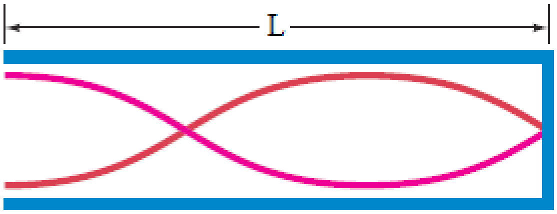


Fig.1. 8: First overtone (third harmonic)

The next longest standing wave in a tube of length *L* with one open end and one closed end is the **second overtone (fifth harmonic).**

$$L = \frac{5\lambda}{4} \Leftrightarrow \lambda = \frac{4L}{5} \Rightarrow f_2 = \frac{5v}{4L} = 5f_0$$

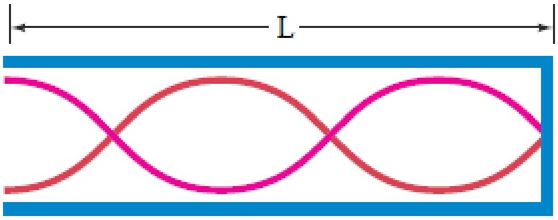


Fig.1. 9: Second overtone (fifth harmonic)

An odd-integer number of quarter wavelength has to fit into the tube of length L.

$$L = \frac{(2n+1)\lambda}{4} \Leftrightarrow \lambda = \frac{4L}{2n+1} \Rightarrow f_n = \frac{(2n+1)v}{4L} = (2n+1)f_o$$

For a tube with one open end and one closed end, frequencies

$f_n = \frac{(2n+1)v}{4L} = (2n+1)f_o$, with *n* equal to an odd integer are **natural frequencies.** Only odd harmonics of the fundamental are natural frequencies.

Example 1.2

A section of drainage culvert 1.23 m in length and makes a howling noise when the wind blows.

a. Determine the frequencies of the first three harmonics of the culvert if it is open at both ends. Take v = 343 m/s as the speed of sound in air.

b. What are the three lowest natural frequencies of the culvert if it is blocked at one end?

c. For the culvert open at both ends, how many of the harmonics present fall within the normal human hearing range (20 Hz to 17 000 Hz)?

Answer

a. The frequency of the first harmonic of a pipe open at both ends is

$$f_1 = \frac{v}{2L} = \frac{343}{2\times1.23} = 139 Hz$$

Because both ends are open, all harmonics are present; thus,

$$f_2 = 2f_1 = 2\times139 = 278\ Hz \text{ and } f_3 = 3f_1 = 3\times139 = 417\ Hz$$

b. The fundamental frequency of a pipe closed at one end is

$$f_1 = \frac{v}{4L} = \frac{343}{4\times1.23} = 69.7\ Hz$$

In this case, only odd harmonics are present; hence, the next two harmonics have frequencies

$$f_3 = 3f_1 = 3\times69.7 = 209\ Hz \text{ and } f_5 = 5f_1 = 5\times69.7 = 349\ Hz$$

c. Because all harmonics are present, we can express the frequency of the highest harmonic heard as $f_n = nf_1$ where n is the number of harmonics that we can hear.

For $f_n = nf_1 = 17000\ Hz$, we find that the number of harmonics present in the audible range is

$$n = \frac{17000}{139} = 122$$

Only the first few harmonics are of sufficient amplitude to be heard.

1.1.2 Vibrating strings

The string is a tightly stretched wire or length of gut. When it is struck, bowed or plucked, progressive transverse waves travel to both ends, which are fixed, where they are reflected to meet the incident waves. A stationary wave pattern is formed for waves whose wavelengths fit into the length of the string, i.e. resonance occurs.

If you shake one end of a cord (slinky) and the other end is kept fixed, a continuous wave will travel down to the fixed end and be reflected back, inverted. The frequencies at which standing waves are produced are the natural frequencies or resonant frequencies of the cord. A progressive sound wave (i.e. a longitudinal wave) is produced in the surrounding air with frequency equal to that of the stationary transverse wave on the string.

Now let consider a cord stretched between two supports that is plucked like a guitar or violin string. Waves of a great variety of frequencies will travel in both directions along the string, will be reflected at the ends, and will be travel back in the opposite direction. The ends of the string, since they are fixed, will be nodes.

Consider a string of length L fixed at both ends, as shown in Fig.1.10. Standing waves are set up in the string by a continuous superposition of wave incident on and reflected from the ends.

Note that there is a boundary condition for the waves on the string. The ends of the string, because they are fixed, must necessarily have zero displacement and are, therefore, **nodes** by definition.

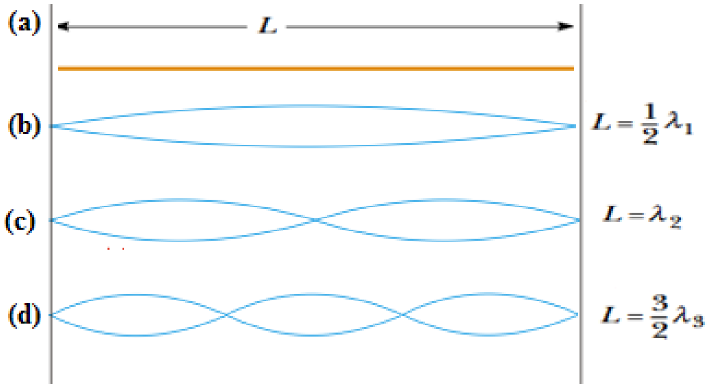


Fig.1. 10 (a) A string of length L fixed at both ends. The normal modes of vibration form a harmonic series: (b) the fundamental note; (c) First overtone; (d) the second overtone (Halliday, Resneck, & Walker, 2007).

Example 1.3

A piano string is 1.10 m long and has mass of 9 g.

a. How much tension must the string be under, if it is to vibrate at a fundamental frequency of 131 Hz?

b. What are the frequencies of the first four harmonics?

Answer

a. The wavelength of the fundamental frequency is $\lambda = 2L = 2.20\ m$

The velocity is then $v = \lambda f_0 = (2.2)(131) = 288.2\ m/s$

Then from $v = \sqrt{\dfrac{T}{\mu}} \Leftrightarrow v^2 = \dfrac{TL}{m} \Leftrightarrow T = \dfrac{v^2 m}{L}$

$$= \frac{(288.2)^2 (0.009)}{1.10} = 679.6\ N$$

b. The frequencies of second, third, and fourth harmonics are three, and four times the fundamental frequency: 262 Hz, 393 Hz, and 524 Hz.

Resonance of sound

We have seen that a system such as a taut string is capable of oscillating in one or more normal modes of oscillation. If a periodic force is applied to such a system, the amplitude of the resulting motion is greater than normal when the frequency of the applied force is equal to or nearly equal to one of the natural frequencies of the system. This phenomenon is known as ***resonance.*** Although a block–spring system or a simple pendulum has only one natural frequency, standing-wave systems can have a whole set of natural frequencies.

Because oscillating systems exhibit large amplitude when driven at any of its natural frequencies, these frequencies are often referred to as resonance frequencies. Fig.1.11shows the response of an oscillating system to various driving frequencies, where one of the resonance frequencies of the system is denoted by f_0

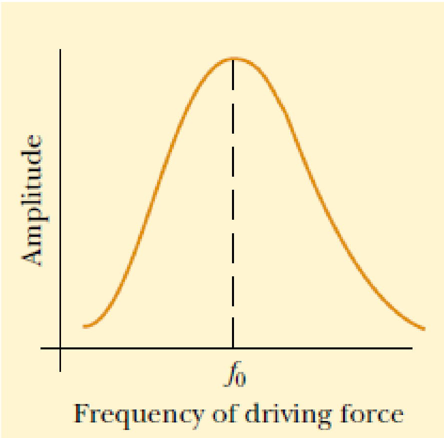


Fig.1. 11: Graph of the amplitude versus driving frequency for oscillating system. The amplitude is a maximum at the resonance frequency. Note that the curve is not symmetric (Halliday, Resneck, & Walker, 2007)

A more spectacular example is a singer breaking a wine glass with her amplified voice. A good-quality wine glass has normal-mode frequencies that you can hear by tapping it.

If the singer emits a loud note with a frequency corresponding exactly to one of these normal-mode frequencies, large-amplitude oscillations can build up and break the glass (Fig. 1.12)

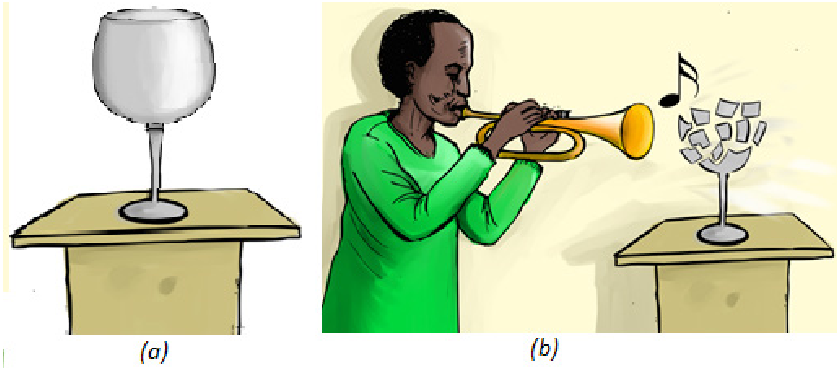


Fig.1. 12 : Some singers can shatter a wine glass by maintaining a certain frequency of their voice for seconds, (a) Standing-wave pattern in a vibrating wine glass. (b) A wine glass shattered by the amplified sound of a human voice

Beats and its phenomena

Beats occur when two sounds-say, two tuning forks- have nearly, but not exactly, the same frequencies interfere with each other. A crest may meet a trough at one instant in time resulting in destructive interference. However, at later time the crest may meet a crest at the same point resulting in constructive interference. To see how beats arise, consider two sound waves of equalamplitudes and slightly different frequencies as shown on the figure below.

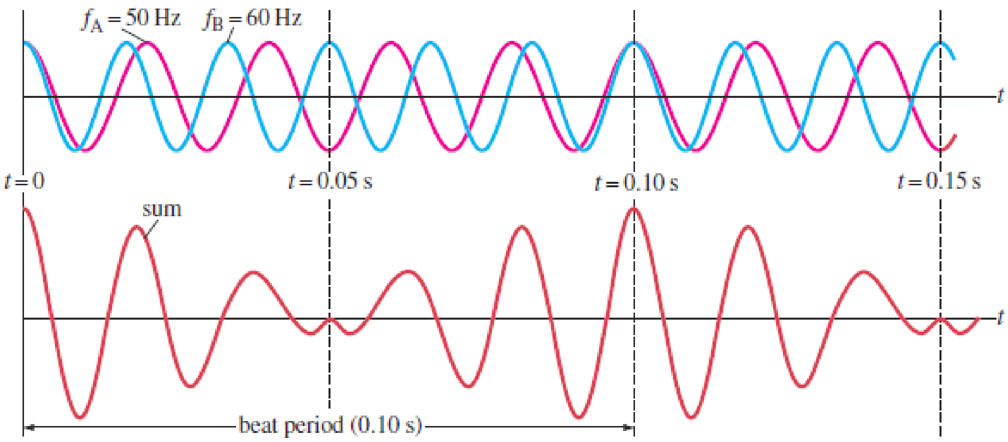


Fig.1. 13: Beats occur as a result of the superposition of two sound waves of slightly different frequencies (Cutnell & Johnson, 2006).

In 1.00 s, the first source makes 50 vibrations whereas the second makes 60. We now examine the waves at one point in space equidistant from the two sources. The waveforms for each wave as a function of time, at a fixed position, are shown on the top graph of Fig. 1.13; the red line represents the 50 Hz wave, and the blue line represents the 60 Hz wave. The lower graph in Fig. 1.13 shows the sum of the two waves as a function of time. At the time the two waves are in phase they interfere constructively and at other time the two waves are completely out of phase and interfere destructively. Thus, the resultant amplitude is large every 0.10 s and drops periodically in between. This rising and falling of the intensity is what is heard as beats. In this case the beats are 0.10 s apart. The **beat frequency** is equal to the difference in frequencies of the two interfering waves.

Consider two sound waves of equal amplitude traveling through a medium with slightly different frequencies f_1 and $f_2$atchosen point $x = 0$:

Wave functions are written as:

$y_1 = A\cos 2\pi f_1 t$ and $y_2 = A\cos 2\pi f_2 t$

Using the superposition principle, we find that the resultant wave function of these two waves at the point is:

$$y = y_1 + y_2 = A\left(\cos 2\pi f_1 t + \cos 2\pi f_2 t\right)$$

The trigonometric identity $\cos a + \cos b = 2\cos\frac{a-b}{2}\cos\frac{a+b}{2}$ allows us to write the expression for y as

$$y = y_1 + y_2 = 2A\cos 2\pi\left(\frac{f_1 - f_2}{2}\right)t\cos 2\pi\left(\frac{f_1 + f_2}{2}\right)t$$

We see that the resultant sound for a listener standing at any given point has an effective frequency equal to the average frequency $\frac{f_1 + f_2}{2}$ and amplitude given by the expression:

$$A_{\max} = 2A\cos 2\pi\left(\frac{f_1 - f_2}{2}\right)t$$

The frequency of the beats is equal to the difference in the frequencies of the two sound waves:

$$beat\ frequency = frequency\ of\ loud\ sound\ heared = f_1 - f_2$$

The interference pattern varies in such a way that a listener hears an alternation between loudness and softness. The variation from soft to loud and back to soft is called a **Beat.** The phenomena of beats can be used to measure the unknown frequency of a note.

Example 1.4

Two identical piano strings of length 0.750 m are each tuned exactly to 440 Hz. The tension in one of the strings is then increased by 1.0%. If they are now struck, what is the beat frequency between the fundamentals of the two strings?

Answer:

If the tension in one string is 1.0% larger than the other, then

$T_2 = T_1 + 0.01T_1 = 1.01T_1$ and we know that

Let us find the ratio of frequencies:

$$\frac{f_2}{f_1} = \frac{\frac{v_2}{2L}}{\frac{v_1}{2L}} = \frac{v_2}{v_1} = \frac{\sqrt{\frac{T_2}{\mu}}}{\sqrt{\frac{T_1}{\mu}}} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{1.01T_1}{T_1}} = 1.005$$

Thus, the frequency of the tightened string is $f_2 = 1.005 f_1 = 1.005 \times 440 = 442 Hz$

and the beat frequency is $f_{beat} = 442 - 440 = 2\ Hz$

Application activity 1.1

1. Is the wavelength of the fundamental standing wave in a tube open at both ends greater than, equal to, or less than the wavelength of the fundamental standing wave in a tube with one open end and one closed end? Explain your answer.

2. You blow across the opening of a bottle to produce a sound. What must be the approximate height of the bottle for the fundamental note to be a middle C (with the wavelength of 1.29 m).

3. Two loudspeakers are separated by 2.5 m. A person stands at 3.0 m from one and at 3.5 m from the other one. Assume a sound velocity of 343 m/s.

   a. What is the minimum frequency to present destructive interference at this point?

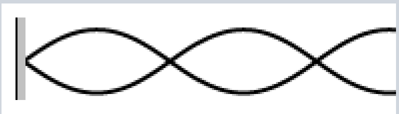
   b. Calculate the other two frequencies that also produce destructive interference.

4. How would you create a longitudinal wave in a stretched spring? Would it be possible to create a transverse wave in that spring?

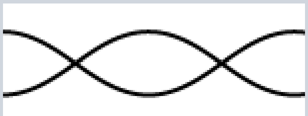
5. In mechanics, massless strings are often assumed. Why is this not a good assumption when discussing waves on strings?

6. Draw the second harmonic (The second lowest tone it can make.) of a one end fixed, one end open pipe. Calculate the frequency of this mode if thepipe is 53.2 cm long, and the speed of sound in the pipe is 317 m/s.

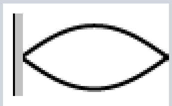
7. Calculate the wavelengths below. The length given is the length of the waveform in the picture bellow:



L = 45 cm

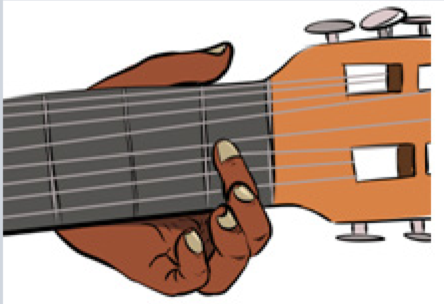


L = 2.67 m



L = 68 cm

8. A guitar string is 64 cm long and has a fundamental Mi frequency of 330 Hz. When pressing in the first fret (nearest to the tuning keys) see figure bellow the string is shortened in such a way that it plays a Fa note having a frequency of 350 Hz. Calculate the distance between this first fret and the nut necessary to get this effect.



9. Why is a pulse on a string considered to be transverse?
10. A guitar string has a total length of 90 cm and a mass of 3.6 g. From the bridge to the nut there is a distance of 60 cm and the string has a tension of 520 N. Calculate the fundamental frequency and the first two overtones

1.2 CHARACTERISTICS AND PROPERTIES OF SOUND WAVES

Activity 1.2

Read the scenario below and answer the questions that follow.

On an interview for Physics placement in a certain school in Rwanda, Claudette a S.6 leaver who had applied for the job was asked about **sound waves** during the interview.

She was asked to state the properties of sound waves. Confidently, she responded that the properties are **reflection**, **refraction**, **diffraction** and **interference.** This was enough to make Claudette pass the first level of the interview.

However, in the second step, she was required to discuss different media in which sound waves can propagate. Claudette started discussing these different media. What surprised the interviewer was Claudette's ability to relate sound waves to other kinds of waves stating that these waves behave the same way when they pass from one medium to another.

Looking at Claudette's face, the interviewer asked her to discuss the **laws governing reflection and refraction of sound waves.** With a smile, she started by saying that since sound waves have the same properties as for light; these laws therefore do not change.

As she was attempting to state them, the interviewer stopped her and congratulated her upon her confidence and bravery she showed in the room. She was directly told that she was successful and she was given the job. Claudette is now working as assistant S2 Physics Tutor and doubles as a Physics laboratory attendant.

Questions

a. Explain the meaning of underlined terms used in the text above?

b. Do you think, it was 100% correct for Claudette to relate sound waves to light waves? Explain?

c. There is where she was asked to discuss the different media in which sound waves can propagate. Discuss these different media and talk about speed of sound waves in the stated media.

d. In one of the paragraphs, Claudette said that the laws governing reflection and refraction of sound waves were similar to those of light. Can you explain these laws (Use diagrams where possible)

e. Assuming that you were an interviewer and the interview was out of 80. What mark would you award to Claudette? Why?

1.2.1 Properties of sound waves

Most of us start our lives by producing sound waves! We spend much of our life surrounded by objects which produce sound waves. Most machines in use vibrate and produce sound so the only sure way to silence them would be to put them in vacuum where there would be no surrounding medium for the vibrating surfaces of the machine to push against, hence no sound waves. Some physiologists are concerned with how speech is produced, how speech impairment might be corrected, how hearing loss can be alleviated.

Sound is associated with our sense of hearing and, therefore, with the physiology of our ears that intercept the sound and the psychology of our brain which interprets the sensations that reach our ears. Sound waves are longitudinal mechanical waves that can travel through solids, liquids, or gases.

As the sound wave propagates, many interactions can occur, including reflection, refraction, diffraction and interference. When a sound wave hits a surface, a part of the energy gets scattered while a part of it is absorbed.

a. Reflection of sound wave

➢ Fixed end

First consider an elastic rope stretched from end to end. One end will be securely attached to a pole on a lab bench while the other end will be held in the hand in order to introduce **pulses** (single disturbance, on vibration) into the medium as shown in Fig.1.14. Because the right end of the rope is attached to a pole (which is attached to a lab bench), the last particle of the rope will be unable to move when a disturbance reaches it. This end of the rope is referred to as a **fixed end**.

Fig.1. 14 An elastic securely tied to a pole can be used to study the behavior of waves at a fixed end

If a pulse is introduced at the left end of the rope, it will travel through the rope towards the right end of the medium. This pulse is called the **incident pulse** since it is incident towards (i.e., approaching) the boundary with the pole.

When the incident pulse reaches the boundary, two things occur:

- A portion of the energy carried by the pulse is reflected and returns towards the left end of the rope. The disturbance that returns to the left after bouncing off the pole is known as the reflected pulse.
- A portion of the energy carried by the pulse is transmitted to the pole, causing the pole to vibrate.

When one observes the reflected pulse off the fixed end, there are several notable observations. First the reflected pulse is **inverted**. That is, if an upward displaced pulse is incident towards a fixed end boundary, it will reflect and return as a downward displaced pulse.

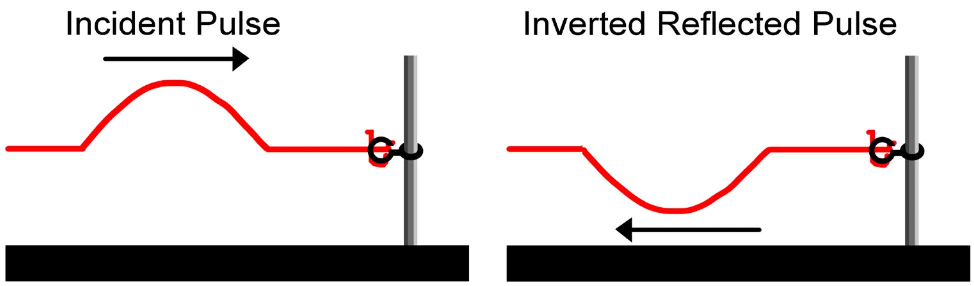


Fig.1. 15 Fixed end reflection

Similarly, if a downward displaced pulse is incident towards a fixed end boundary, it will reflect and return as an upward displaced pulse.

The inversion of the reflected pulse can be explained by returning to our conceptions of the nature of a mechanical wave. When a crest reaches the end of a medium ("medium A"), the last particle of the medium A receives an upward displacement. This particle is attached to the first particle of the other medium ("medium B") on the other side of the boundary. As the last particle of medium A pulls upwards on the first particle of medium B, the first particle of medium B pulls downwards on the last particle of medium A.

In general, ***Reflection leaves wavelength, speed, amplitude and frequency unchanged***

- **Free End Reflection**

Suppose a rope is attached to a ring that is loosely fit around the pole as in Fig.1.16. Because the right end of the rope is no longer secured to the pole, the last particle of the rope will be able to move when a disturbance reaches it. This end of the rope is referred to as a **free end**.

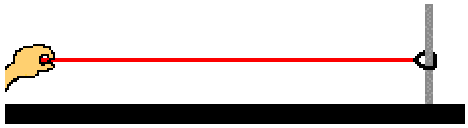


Fig.1. 16 If the end of elastic rope not fastened to the pole then it will be free to move up and down. This provides for the study of wave behavior at free end

When an upward displaced pulse is incident upon a free end, it returns as an upward displaced pulse after reflection. And when a downward displaced pulse is incident upon a free end, it returns as a downward displaced pulse after reflection as in Fig.1.17. Inversion is not observed in free end reflection.

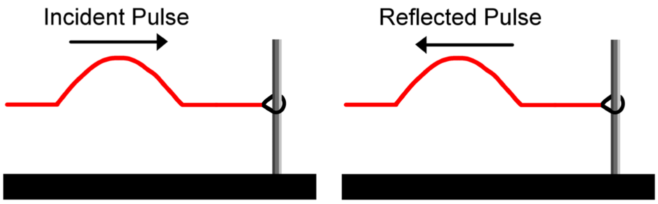


Fig.1. 17 Free end reflection

The reflection of sound waves can end up with any of the two phenomena either an **echo** or **reverberation**:

- Echo occurs when a reflected sound wave reaches the ear 0.1 s after we hear the original sound. If the time elapsed between the arrivals of the two sound waves is more than 0.1 s, then the sensation of the first sound will get died out. An echo sounder or fathometer is a device used on a ship for the purpose of measuring the depth of the sea.

In a small room the sound is also heard more than once, but the time differences are so small that the sound just seems to loom. This is known as **reverberation**.

b. Refraction and Snell's law and waves

Refraction of waves is the change in direction of waves as they pass from one medium to another. The bending of waves is accompanied by the change in speed and wavelength of the wave. So, if there is any change in media, the wave speed changes. Sound waves travel with less velocity in cool air than they do in the warmer air.

When a wave travels from deep water to shallow water in such a way that it meets the boundary between the two depths straight on, no change in direction occurs. On the other hand, if a wave meets the boundary at an angle, the direction of travel does change. This phenomenon is called **refraction** (Fig.1.18)

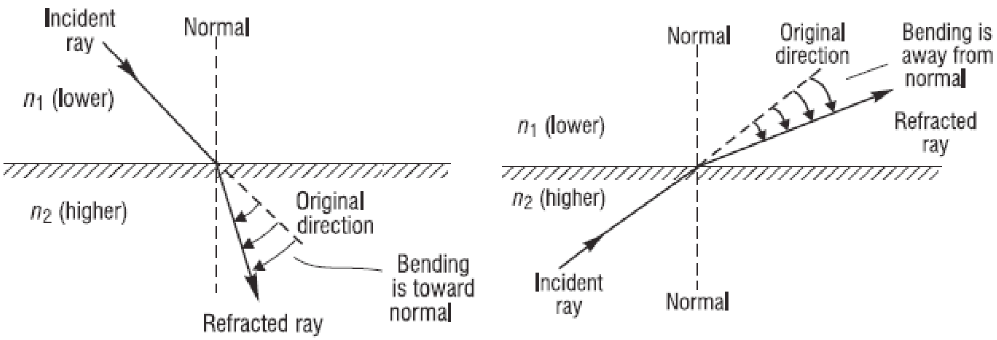


Fig.1. 18 Refraction of light at the interface between two media of different refractive indices, with

$n_2 > n_1$

Since the velocity is lower in the second medium ($v_2 < v_1$), the angle of refraction θ_2 is less than the angle of incidence θ_1; that is, the ray in the higher-index medium is closer to the normal.

Snell's law (also known as **Snell–Descartes law** or the **law of refraction**) is a **formula** used to describe the relationship between the **angles of incidence** and **refraction**, when referring to light or other **waves** passing through a boundary between two different **isotropic media,** such as water, glass, or air.

Snell's law states that the ratio of the **sines** of the angles of incidence and refraction is equivalent to the ratio of **phase velocities** in the two media, or equivalent to the reciprocal of the ratio of the indices of refraction:

$$n = \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Where

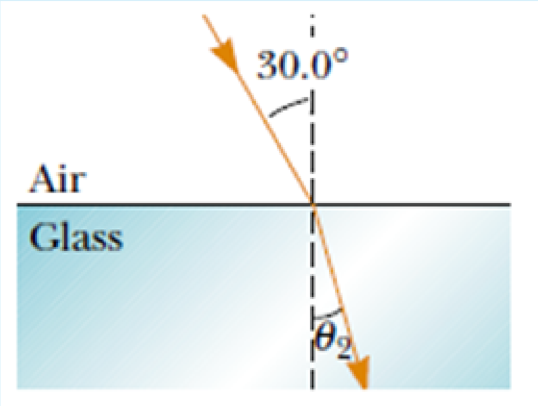
- with each θ as the angle measured from the normal of the boundary, v
- v as the velocity of light in the respective medium (SI units are meters per second, or m/s), λ
- λ as the wavelength of light in the respective medium

Comparisons between the characteristics of the transmitted pulse and the reflected pulse lead to the following observations.

- The transmitted pulse (in the less dense medium) is traveling faster than the reflected pulse (in the denser medium).
- The transmitted pulse (in the less dense medium) has a larger wavelength than the reflected pulse (in the denser medium).
- The speed and the wavelength of the reflected pulse are the same as the speed and the wavelength of the incident pulse.

Example 1.5: Determine the angle of refraction

Incident on a smooth, flat slab of crown glass (n = 1.52) at an angle of 30.0° to the normal, as sketched in Figure at below. Find the angle of refraction and its change in direction.



Answer

We rearrange Snell's law of refraction to obtain

$$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2} \Leftrightarrow \sin\theta_2 = \frac{\sin 30.0}{1.52} = 0.329 \Rightarrow \theta_2 = 19.2^0$$

Because this is less than the incident angle of 30°, the refracted ray is bent toward the normal, as expected. **Its change in direction is called the *angle of deviation* and is given by**

$$\delta = \theta_1 - \theta_2 = 30.0 - 19.2 = 10.8^0$$

c. Diffraction

Diffraction is the name given to the phenomenon in which a wave spreads out as it passes through a small aperture or around an obstacle. Diffraction patterns are formed when the diffracted waves interfere with one another to produce light and dark bands on a screen or piece of film. Diffraction patterns are most intense when the size of the aperture or obstacle is comparable to the size of the wavelength of the wave. Similar effects are observed when light waves travel through a medium with a varying refractive index. Diffraction is due to the wave nature of light

When light passes through an opening it is observed to spread out. This is known as diffraction and becomes more pronounced with narrower openings.

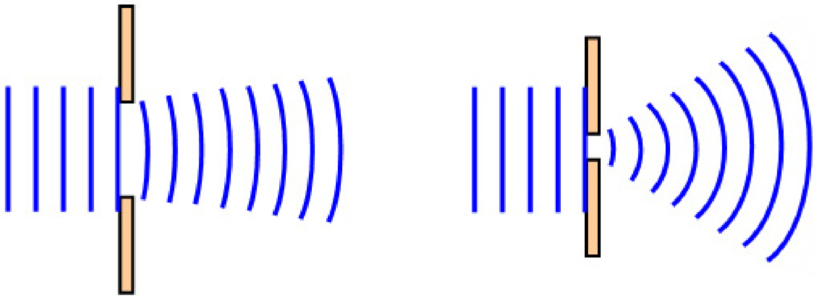


Fig.1. 19 Diffraction of light through wide and narrow openings

Diffraction occurs with all waves, including sound waves, water waves, and electromagnetic waves such as visible light, x-rays and radio waves. Since diffraction occurs for waves, but not for particles, it can serve as one means for distinguishing the nature of light.

d. Interference and principle of Superposition

Interference occurs when two or more waves traveling through the same medium overlap and combine together. Interference of incident and reflected waves is essential to the production of resonant standing waves.

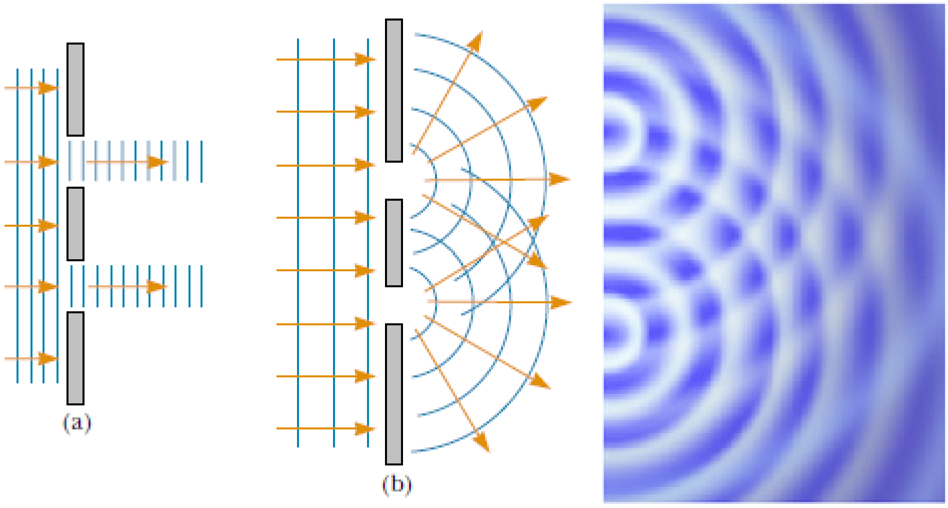


Fig.1. 20 (a) If light waves did not spread out after passing through the slits, no interference would occur. (b) The light waves from the two slits overlap as they spread out, filling what we expect to be shadowed regions with light and producing interference fringes.

We can have constructive and destructive interference:

- If a person stands equidistant from two speakers which are playing the same sound in phase, i.e. which are moving in and out together, then the two waves arrive in phase after traveling the same distance. Crest meets crest and trough meets trough at the location of the person. The amplitudes of the two waves add and the sound is loudest here.
- If the two speakers play the same sound but are out of phase, i.e. one is moving out while the other is moving in, and then the sound has a low volume at the location of the person equidistant from the two speakers. This can easily be demonstrated by switching the wires on one of the speakers. (This is why you need to pay attention to the color of the wires when setting up your stereo). Dead spots in an auditorium are sometimes produced by destructive interference.

In general, **the term "interference" refers to what happens when two or more waves pass through the same region at the same time.**

➢ The principle of superposition

Combining the displacements of the separate pulses at each point to obtain the actual displacement is an example of the **principle of superposition: "***When two waves overlap, the actual displacement of any point on the string at any time is obtained by adding the displacement the point would have if only the first wave were present and the displacement it would have if only the second wave were present".*

In other words, the wave function $y(t,x)$ that describes the resulting motion in this situation is obtained by *adding* the two wave functions for the two separate waves:

$$y(t,x) = y_1(t,x) + y_2(t,x)$$

Where $y_1(t,x) = A\sin(\omega t - kx + \phi_1)$ and $y_2(t,x) = A\sin(\omega t - kx + \phi_1)$

These waves overlap and interfere.

The resultant wave as these waves overlap and interfere can write as

$$y(t.x) = y_1(t,x) + y_2(t,x) = 2A\cos\frac{\phi_2 - \phi_1}{2}\sin(\omega t - kx + \frac{(\phi_2 + \phi_1)}{2})$$

As we saw with transverse waves, when two waves meet, they create a third wave that is a combination of the other two waves. This third wave is actually the sum of the two waves at the points where they meet. The two original waves are still there and will continue along their paths after passing through each other. After passing the third wave no longer exists.

Its amplitude is the magnitude $A_r = 2A\cos\frac{\varphi_2 - \varphi_1}{2}$

1.2.2 Characteristics of sound waves

Usually, the characteristics used to describe waves are period, frequency, wavelength, and amplitude.

a. Frequency ranges

Any periodic motion has a frequency, which is the number of complete cycles in a second and a period which is the time used to complete one cycle. While the frequency is measured in Hertz (***Hz***), the period is measured in seconds (**s**). For a wave, the frequency is the number of wave cycles that pass a point in a second. A wave's frequency equals the frequency of the vibrating source producing the wave.

Sound waves are classified into three categories that cover different frequency ranges:

- Audible sound

Audible sound lies within the range of sensitivity of the human ear. They can be generated in a variety of ways, such as musical instruments, human voices, or loudspeakers. It is almost impossible to hear sounds outside the range of **20 Hz** to **20 kHz**. These are the limits of audibility for human beings but the range decreases with age.

Hearing is the perception of sound. The hearing mechanism involves some interesting physics. The sound wave that impinges upon our ear is a pressure wave. The ear is a **transducer** that converts sound waves into electrical nerve impulses in a manner much more sophisticated than, but analogous to, a microphone.

- Infrasonic waves

Infrasonic waves have frequencies below the audible range. They are sound waves with frequencies that are below 20 Hz limit.

Some animals such as elephants can use infrasonic waves to communicate effectively with each other, even when they are separated by many kilometers. Their large ears enable them to detect these low frequency sound waves which have relatively long wavelengths.

Young bat-eared fox and Rhinoceros (Fig.1.21) also use infrasonic as low as 5 Hz to call one another. They have ears adapted for the detection of very weak sounds.

Fig.1. 21 Some animals, such as this young bat-eared fox, have ears adapted for the detection of very weak sounds.The use of infrasonic frequencies is likely an adaptation for rhinoceroses to keep in touch with each other where they inhabit dense vegetation and probably for females to advertise to males when females are receptive to breeding

A number of animals are sensitive to infrasonic frequencies. It is believed by many zoologists that this sensitivity in animals such as elephants may be helpful in providing them with early warning of earthquakes and weather disturbances. It has been suggested that the sensitivity of birds to infrasound aids their navigation and even affects their migration.

- Ultrasonic waves

Ultrasonic waves have frequencies above the audible range. They are sound waves whose frequencies are higher than 20 KHz. You may have used a "silent" whistle to retrieve your dog. The ultrasonic sound emitted by that device is easily heard by dogs, although humans cannot detect it at all. Ultrasonic waves are also used in medical imaging.

Some marine mammals, such as dolphin, whales, and porpoises use sound waves to locate distant objects. In this process, called **echolocation**, a dolphin produces a rapid train of short sound pulses that travel through the water, bounce off distant objects, and reflect back to the dolphin. From these echoes, dolphins can determine the size, shape, speed, and distance of their potential prey. Experiments have shown that at distance of 114 m, a blindfolded dolphin can locate a stainless-steel sphere with a diameter of 7.5 cm and can distinguish between a sheet of aluminum and a sheet of copper. The Ultrasonic waves emitted by a dolphin enable it to see through bodies of other animals and people (Fig.1.22).

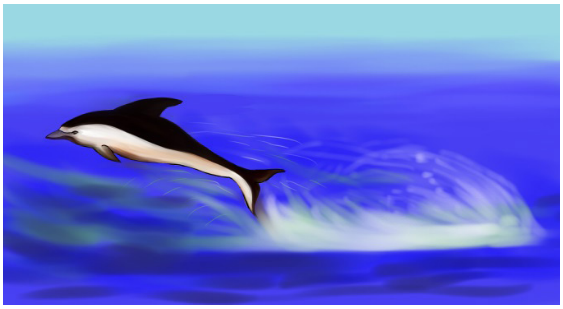


Fig.1. 22. The Ultrasonic waves emitted by a dolphin enable it to see through bodies of other animals and people.

Skin muscles and fat are almost transparent to dolphins, so they see only a thin outline of the body but the bones, teeth and gas-filled cavities are clearly apparent. Physical evidence of cancers, tumors, heat attacks, and even emotional shake can all be seen by dolphin. What is more interesting, the dolphin can reproduce the sonic signals that paint the mental image of its surroundings, and thus the dolphin probably communicates its experience to other dolphins. It needs no words or symbol for fish, for example, but communicates an image of the real thing.

Dogs, cats and mice can hear ultrasound frequencies up to 450 000 Hz. Some animals not only hear ultrasound but also use ultrasonic to see in dark. Bats also use echo to navigate through air.Bats use ultrasonic with frequencies up to 100 000 Hz to move around and hunt (Fig.1.23).

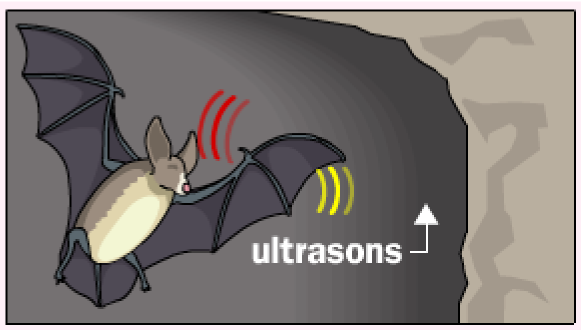


Fig.1. 23: Bats use ultrasonic with frequencies up to 100 000 Hz to move around and hunt.

The waves reflect off objects and return the bat's ears. The time it takes for the sound waves to return tells the bat how far it is from obstacles or prey. The bat uses the reflected sound waves to build up a picture of what lies ahead.

The process of imaging using **Sonar** (**S**ound **N**avigation and **R**anging) is the same as the echo-locating sonar of a submarine or a bat. The observer sends out a brief pulse of ultrasound and waits for an echo. The pulse travels out, reflects off the target and returns. The ultrasound machine uses pulses because the same device acts as both transmitter and receiver.

Ultrasound has been used in a variety of clinical settings, including obstetrics and gynecology, cardiology and cancer detection. The main advantage of ultrasound is that certain structures can be observed without using radiation. Ultrasound can also be done much faster than X-rays or other radiographic techniques.

Ultrasonic waves can be used to produce images of objects inside the body thus Physicians use ultrasonic to observe fetuses. Ultrasound has frequencies too high for you to hear. Echoes from ultrasound waves can show what is inside the body. Echo is a reflection of sound off the surface of an object.

Fig.1. 24 This ultrasound image is an example of using high-frequency sound waves to see within the human body.

In medicine, ultrasonic is used as a diagnostic tool, to destroy diseased tissue, and to repair damaged tissue.Ultrasound examination of the heart is known as **echocardiography.**

Many animals hear a much wider range of frequencies than human beings do. For example, dog whistles vibrate at a higher frequency than the human ear can detect, while evidence suggests that dolphins and whales communicate at frequencies beyond human hearing (ultrasound) see Fig.1.25 below.(Cutnell & Johnson, 2006).

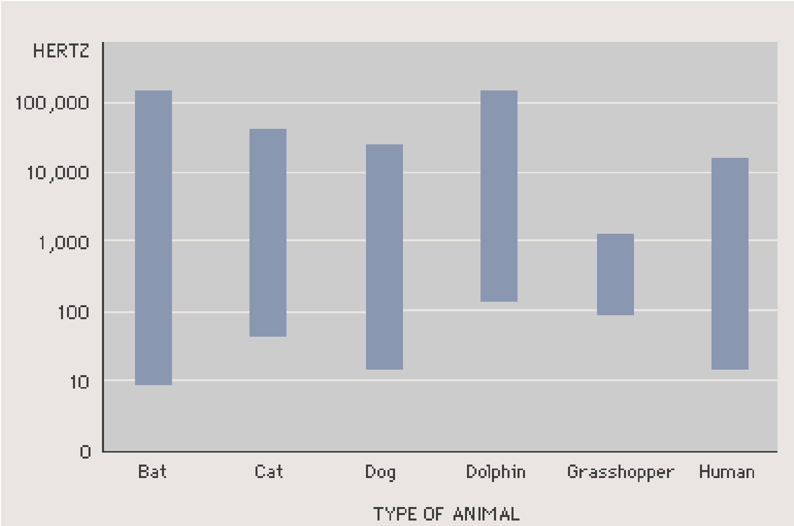


Fig.1. 25 Range of frequencies heard by various animals and human (Randall & Knight., Physics for scientists and engineers: Stategic approach., 2008)

b. Wavelength

Wavelength is the distance covered by a wave in a period. It is represented by the separation between a point on one wave and a similar point on the next cycle of the wave. For a transverse wave, wavelength is measured between adjacent crests or between adjacent troughs. For a longitudinal wave such as sound wave, wavelength is the distance between adjacent compressions or rarefaction.

c. Speed of sound

For a periodic wave, the shape of the string at any instant is a repeating pattern. The length of one complete wave pattern is the distance from one crest to the next or from one trough to the next or from any point to the corresponding point on the next repetition of the wave shape. We call this distance the **wavelength** of the wave, denoted by the Greek letter lambda (λ).

The wave pattern travels with constant speed and advances a distance of one wavelength in a time interval of one period T. So, the wave speed is given by

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

where f is the frequency of the wave.

Sound travels faster in liquids and solids than in gases, since the particles in liquids and solids are closer together and can respond more quickly to the motion of their neighbors. As examples, the speed of sound is 331 m/s in air, 1500 m/s in water and 5000 m/s in iron (though these mediums the seed of sound can change depending on temperature and pressure). Sound does not travel in vacuum.

Example 1.6: Wavelength of a musical sound

Sound waves can propagate in air. The speed of the sound depends on temperature of the air; at $20\ ^0C$ it is $344\ m/s$. What is the wavelength of a sound wave in air if the frequency is 262 Hz (the approximate frequency of middle C on a piano)?

Answer

Using equation of wave: $\lambda = \frac{v}{f} = \frac{344}{262} = 1.31\,m$

Factors which affect the velocity of sound in air

- The speed of sound waves in a medium depends on the compressibility and density of the medium. If the medium is a liquid or a gas and has a bulk modulus B and density ρ, the speed of sound waves in that medium is given by:

$$v = \sqrt{\frac{B}{\rho}}$$

It is interesting to compare this expression with the equation of the speed of transverse waves on a string $v = \sqrt{\frac{T}{\mu}}$. In both cases, the wave speed depends **on an elastic property of the medium** (bulk modulus β or tension in the string *T*) and **on an inertial property of the medium** (the density ρ or linear mass density μ).

For longitudinal sound waves in a solid rod of material, for example, the speed of sound depends on Young's modulus *Y* and the density of the solid ρ :

$$v = \sqrt{\frac{Y}{\rho}}$$

- Changes of pressure have no effect on the velocity of sound in air. Sir Isaac Newton showed that:

$$v = \sqrt{\frac{P}{\rho}}$$

In accordance with Boyle's law, if the pressure of a fixed mass of air is doubled, the volume will be halved. Hence the density will be doubled. Thus, at constant temperature, the ratio $\frac{P}{\rho}$ will always remain constant no matter how the pressure may change.

- The speed of sound increases with temperature

If the air temperature increases at constant pressure the air will expand according to Charles' law, and therefore become less dense.

The ratio $\frac{P}{\rho}$ will therefore increase, and hence the speed of sound increases with temperature.

For sound traveling through air, the relationship between wave speed and medium temperature is

$v = v_o\sqrt{\frac{T}{T_o}}$, where $v_0 = 331\ m/s$ is the speed of sound in air (at 0 degree Celsius and normal pressure) .

The **speed of sound** in air at standard temperature and pressure (25 °C, 760 mm of mercury) is 343 m/s. It is determined by how often the air molecules collide. The speed of sound increases by about 6 m/s if the temperature increases by 10 °C (Glencoe, 2005).

Example 1.7

Find the speed of sound in water, which has a bulk modulus of $B = 2.1\times10^9\ N/m^2$ at a temperature of 0 °C and a density of $\rho = 1.00\times10^3\ kg/m^3$.

Answer

Using equation ofthe speed of sound waves in liquid, we find that:

$$v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.1\times10^9}{1.00\times10^3}} = 1.4\ km/s$$

In general, sound waves travel more slowly in liquids than in solids because liquids are more compressible than solids.

d. Amplitude

The amplitude of a wave is the maximum displacement of the medium from its rest position. The amplitude of a transverse wave is the distance from the rest position to a crest or a trough. The more energy a wave has, the greater is its amplitude.

Application activity 1.2

1. The correct statement about sound waves is that:

   A. They are transverse waves

   B. They can be polarized

   C. They require material medium to propagate

2. Sound travels in

   A. Air   C. Water

   B. Iron   D. All of these

3. Two men talk on the moon. Assuming that the thin layer of gases on the moon is negligible, which of the following is the right answer:

   A. They hear each other with lower frequency

   B. They hear each other with higher frequency

   C. They can hear each other at such frequency

   D. They cannot hear each other at all

4. Do you expect an echo to return to you more quickly on a hot day or a cold day?Explain your answer.

   A. Hot day.

   B. Cold day.

   C. Same on both days.

5. A sound wave is different than a light wave in that a sound wave is:

   A. Produced by an oscillating object and a light wave is not.

   B. Not capable of traveling through a vacuum.

   C. Not capable of diffracting and a light wave is.

   D. Capable of existing with a variety of frequencies and a light wave has a single frequency.

6. A spider of mass 0.30 g waits in its web of negligible mass see Fig. below. A slight movement causes the web to vibrate with a frequency of about 15 Hz.

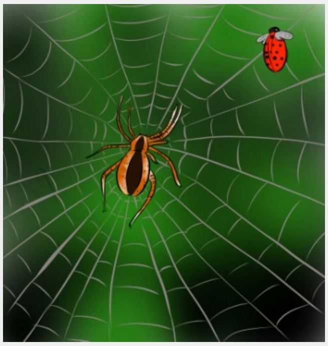


Fig.1. 26 A spider of mass waits in its web

a. Estimate the value of the spring stiffness constant *k* for the web assuming simple harmonic motion.

b. At what frequency would you expect the web to vibrate if an insect of mass 0.10 g were trapped in addition to the spider?

7. Dolphins use sound waves to locate food. Experiments have shown that a dolphin can detect a 7.5 cm target 110 m away, even in murky water. For a bit of "dinner" at that distance, how much time passes between the moment the dolphin emits a sound pulse and the moment the dolphin hears its reflection and thereby detects the distant target?

8. By what factor would you have to multiply the tension in a stretched string in order to double the wave speed? Explain your answer.

9. (a) The range of audible frequencies is from about 20 Hz to 20 000 Hz. What is the range of the wavelengths of audible sound in air?

   (b) The range of visible light extends from 400 nm to 700 nm. What is the range of visible frequencies of light?

   (c) Surgeons can remove brain tumors by using a cavitron ultrasonic surgical aspirator, which produces sound waves of frequency 23 kHz. What is the wavelength of these waves in air?

   (d) Sound having frequencies above the range of human hearing (about 20 000 Hz) is called *ultrasound.* Waves above this frequency can be used to penetrate the body and to produce images by reflecting from surfaces. In a typical ultrasound scan, the waves travel through body tissue with a speed of 1500 m/s. For a good, detailed image, the wavelength should be no more than 1.0 mm. What frequency sound is required for a good scan?

1.3 CHARACTERISTICS OF MUSICAL NOTES

Activity 1.3

The physical characteristics of a sound wave are directly related to the perception of that sound by a listener.

1. What is the difference between the sound of whistle and that of drum?
2. Mutoni is playing the same notes on different musical instruments, can you predict which musical instruments is played without seeing them? Explain your answers.

A **musical note** is produced by vibrations that are regular and repeating, i.e. by periodic motion. Non-periodic motion results in **noise** which is not pleasant to the ear. Many behaviors of musical note can be explained using a few characteristics: **intensity and loudness, frequency and pitch, and quality or timber**

1.3.1. Pitch and frequency

The sound of a whistle is different from the sound of a drum. The whistle makes a high sound. The drum makes a low sound. The highness or lowness of a sound is called its **pitch**. The higher the frequency, the higher is the pitch. The frequency of an audible sound wave determines how high or low we perceive the sound to be, which is known as pitch.

Frequency refers to how often something happens or in our case, the number of periodic, compression-rarefaction cycles that occur each second as a sound wave moves through a medium and is measured in Hertz (Hz) or cycles/second. The term **pitch** is used to describe our perception of frequencies within the range of human hearing.

If a note of frequency 300 Hz and note of 600 Hz, are sounded by a siren, the pitch of the higher note is recognized to be an upper octave of the lower note. The musical interval between two notes is an **upper octave** if the ratio of their frequencies is 2:1. It can be shown that the musical interval between two notes depends on the ratio of their frequencies, and not on the actual frequencies.

Whether a sound is high-pitched or low-pitched depends on how fast something vibrates. Fast vibrations make high-pitched sounds. Slow vibrations make low-pitched sounds.

Do not confuse the term **pitch** with **frequency**. Frequency is the physical measurement of the number of oscillations per second. Pitch is a psychological reaction to sound that enables a person to place the sound on a scale from high to low, or from treble to bass. Thus, frequency is the stimulus and pitch is the response. Although pitch is related mostly to frequency, they are not the same. A phrase such as “the pitch of the sound” is incorrect because pitch is not a physical property of the sound. The octave is a measure of musical frequency.

1.3.2 Intensity, amplitude and ear response

A police siren makes a loud sound. Whispering makes a soft sound. Whether a sound is loud or soft depends on the force or power of the sound wave. Powerful sound waves travel farther than weak sound waves. To talk to a friend across the street you have to shout and send out powerful sound waves. Your friend would never hear you if you whispered.

A unit called **the decibel** measures the power of sound waves. The sound waves of a whisper are about 10 decibels. Loud music can have a level of 120 decibels or more. Sounds above 140 decibels can actually make your ears hurt. The energy carried by a sound wave is proportional to the square of its amplitude. The energy passing in a unit area per unit time is called the **intensity** of the wave.

The intensity of spherical sound wave at a place *p* is defined as the energy per second per m², or power per m² flowing normally through an area at *X*. This can be written as:

$I = \dfrac{E/t}{A} = \dfrac{P}{4\pi r^2}$, where r is the distance from the source for a spherical wave. So, the unit of intensity is W/m^2

Example 1.8

If the intensity of an earth-quake P wave at 100 km from the source is $I = 1.0\times10^6\ W/m^2$, what is the intensity at 400 km from the source?

Answer: $I = \dfrac{P}{4\pi r^2}$

Power: $P = 4I_1\pi r_1^2 = 4I_2\pi r_2^2 \Leftrightarrow I_2 = I_1\dfrac{r_1^2}{r_2^2} = 6.2\times10^4\ W/m^2$

Sound intensity level

To the human ear the change in loudness when the power of a sound increases from 0.1 W to 1.0 W is the same as when 1W to 10 W. The ear responds to the ratio of the power and not to their difference.

We measure sound level intensity in terms of “decibels”. The unit *bel* is named after the inventor of the telephone, Alexander Graham Bell (1847–1922).

The decibel is a “relative unit” which is actually dimensionless, comparing a given sound to a standard intensity which represents the smallest audible sound:

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

where $I_0 = 10^{-12}\ W/m^2$ at 1000 Hz is the reference intensity and is the sound level at the location.

The intensity of 0dB represents the softest audible sound (threshold of human hearing), while 80 dB (i.e., moderately loud music) represents an intensity which is one hundred million times greater.

Example 1.9

Two identical machines are positioned the same distance from a worker. The intensity of sound delivered by each machine at the location of the worker is $2.0\times10^{-7}\ W/m^2$. Find the sound level heard by the worker

a. when one machine is operating

b. when both machines are operating.

Answer

a. The sound level at the location of the worker with one machine operating is

$$\beta_1 = 10\log\frac{2.0\times10^{-7}}{1.00\times10^{-12}} = 53\ dB$$

b. When both machines are operating, the intensity is doubled to $4.0\times10^{-7}\ W/m^2$

; therefore, the sound level now is $\beta_2 = 10\log\frac{4.0\times10^{-7}}{1.00\times10^{-12}} = 56\ dB$

From these results, we see that when the intensity is doubled, the sound level increases by only 3 dB.

The physical characteristics of a sound wave are directly related to the perception of that sound by a listener. For a given frequency the greater the pressure amplitude of a sinusoidal sound wave, the greater the perceived loudness.

The **loudness** or softness of sound depends on the intensity of the sound wave reaching the person concerned. Loudness is a subjective quantity unlike intensity. Sound that is not wanted or unpleasant to the ear is called **noise**. High intensity can damage hearing. The higher the intensity, the louder is the sound. Our ears, however, do not respond linearly to the intensity. A wave that carries twice the energy does not sound twice as loud.

Anatomy of human ear

The human ear is a remarkably sensitive detector of sound. Mechanical detectors of sound can barely match the ear in detecting low intensity sounds. The ear has a function of transforming the vibrational energy of waves into electrical signals that are carried to the brain by ways of nerves as does a microphone.

The ear consists of three main parts: the outer ear, the middle ear and the inner ear.

In the outer ear, sounds waves from the outside travel down the ear canal to the eardrum which vibrates in response to the colliding waves.The inner ear consists of three small bones known as the hammer, anvil and stirrup which transfer the vibrations of the eardrum to the inner ear at the oval window.

The function of the inner ear is to transduce vibration into nervous impulses. While doing so, it also produces a frequency (or pitch) and intensity (or loudness) analysis of the sound. Nerve fibres can fire at a rate of just under 200 times per second. Sound level information is conveyed to the brain by the rate of nerve firing, for example, by a group of nerves each firing at a rate at less than 200 pulses per second. They can also fire in locked phase with acoustic signals up to about 5 kHz. At frequencies below 5 kHz, groups of nerve fibres firing in lock phase with an acoustic signal convey information about frequency to the brain. Above about 5 kHz frequency information conveyed to the brain is based upon the place of stimulation on the basilar membrane. As an aside, music translated up into the frequency range above 5 kHz does not sound musical. (Hallowell, Davis; Richard,S., 1970)

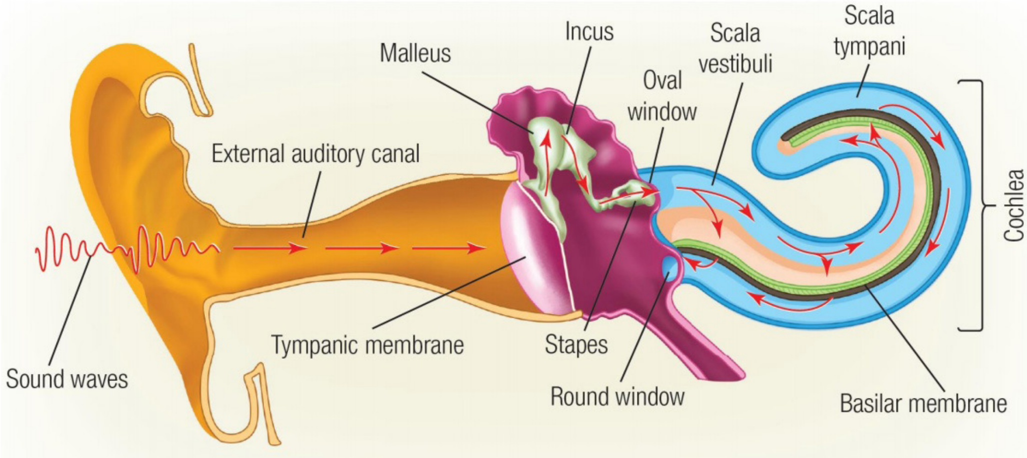


Fig.1. 27: Flow of acoustic energy: Outer ear, Middle ear, Inner ear

This delicate system of levers, coupled with the relatively large area of the eardrum compared to the area of the oval window, results in pressure being amplified by a factor of about 40. The inner ear consists of the semicircular canals, which are important for controlling balance, and the liquid filled cochlea where the vibrational energy of sound waves is transformed into electrical energy and sent to the brain.

Logarithmic response of the ear versus intensity

The ear is not equally sensitive to all frequencies. To hear the same loudness for sounds of different frequencies requires different intensities. Studies done over large numbers of people have produced the curves shown on Fig.1.28.

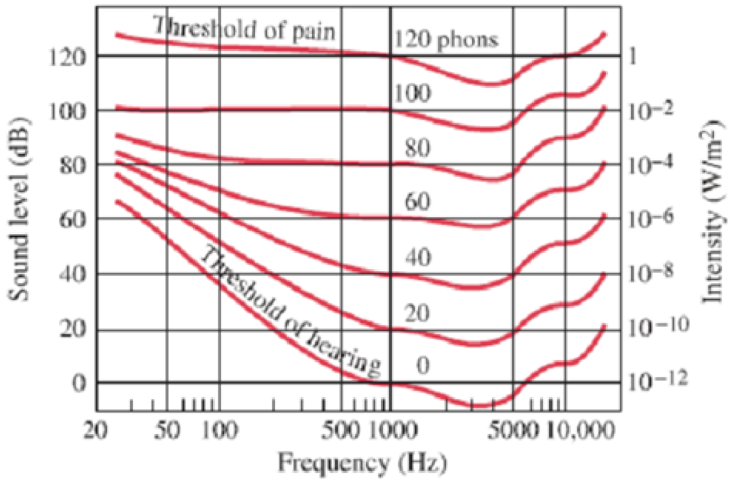


Fig.1. 28 Loudness in phons

On this graph, each curve represents sounds that seemed to be equally loud. The number labelling each curve represents the loudness level which is numerically equal to the sound level in dB at 1000 Hz. The units are called phons.

Example: The curve labelled 40 represents sounds that are heard by an average person to have the same loudness as 1000 Hz sound with a sound level of 40 dB. From this 40 phon curve, we see that a 100 Hz tone must be at a level of about 62 dB to be perceived as loud as a 1000 Hz tone of only 40 dB.

Two aspects of any sound are immediately evident to human listener: loudness and the pitch. Each refers to a sensation in the consciousness of the listener. But to each of these subjective sensations there corresponds a physically measurable quantity.

Loudness refers to the **intensity** in the sound wave. Intensity is related to the energy transported by a wave per unit time across a unit area perpendicular to the energy flow. Intensity is proportional to the square of the wave amplitude.

A unit called a **phon** is used to express loudness numerically. Phons differ from decibels because the phon is a unit of loudness perception, whereas the decibel is a unit of physical intensity. Fig.1.28 shows the relationship of loudness to intensity (or intensity level) and frequency for persons with normal hearing. The curved lines are equal-loudness curves. Each curve is labelled with its loudness in phons. Any sound along a given curve is perceived as equally loud by the average person. The curves were determined by having large numbers of people compare the loudness of sounds at different frequencies and sound intensity levels. At a frequency of 1000 Hz, phons are taken to be numerically equal to decibels.

Because of this relationship between the subjective sensation of loudness and the physically measurable quantity intensity, sound intensity levels are usually specified on a logarithmic scale. The unit of this scale is a **bel,** after the inventor Alexander Graham Bell.

1.3.3 Quality or timbre

If the same note is sounded on the violin and then on the piano, an untrained listener can tell which instrument is being used, without seeing it. We would never mistake a piano for flute. We say that the quality or timbre of note is different in each case. The manner in which an instrument is played strongly influences the sound quality.

Two tones produced by different instruments might have the same fundamental frequency (and thus the same pitch) but sound different because of different harmonic content. The difference in sound is called *tone color, quality,* or **timbre.** A violin has a different timbre than a piano.

Application activity 1.3

1. Complete each of the following sentences by choosing the correct term from the following words: loudness, pitch, sound quality, echoes, intensity and noise

   a. The ------------ of a sound wave depends on its amplitude

   b. Reflected sound waves are called ---------------------------

   c. Two different instruments playing the same note sound different because of ------------------

2. Plane sound wave of frequency 100 *Hz* fall normally on a smooth wall. At what distances from the wall will the air particles have:

   a. Maximum amplitude of vibration

   b. Minimum amplitude of vibration?

   Give reasons for your answer. The speed of sound in air may be taken as 340 m/s

3. A boy whistles a sound with the power of $0.5\times10^{-4}\ W$. What will be his sound intensity at a distance of 5 m?
4. Calculate the intensity level equivalent to an intensity 1nW/m^2
5. If the statement is true, write true. If it is false, change the underlined word or words to make the statement true.

a. Intensity is mass per unit volume.

b. Loudness is how the ear perceives frequency

c. Music is a set of notes that are pleasing

6. The sound level of sound whose intensity is $I=1.0\times10^{-10}\ W/m^2$ what will be the sound intensity level?

1.4 THE DOPPLER EFFECT AND ITS APPLICATIONS

Activity 1.4

1. People use sound for other things other than talking and making music. In your own words, give more examples and explanations to support this statement.
2. Imagine you are standing beside a road and a police car with its siren turned on, drives by you. What do you notice about the heard sound?
3. In the second case, the same police car turned and comes towards you. Comment on the heard sound
4. Compare and contrast the sounds heard in case 2 and 3.

1.4.1 Doppler Effect

Doppler's effect is the apparent variation in frequency of a wave due to the relative motion of the source of the wave and the observer.

The effect takes its name from the Austrian Mathematician Christian Johann Doppler (1803-1853), who first stated the physical principle in 1842. Doppler's principle explains why, if a source of sound of a constant pitch is moving toward an observer, the sound seems higher in pitch, whereas if the source is moving away it seems lower. This change in pitch can be heard by an observer listening to the whistle of an express train from a station platform or another train.

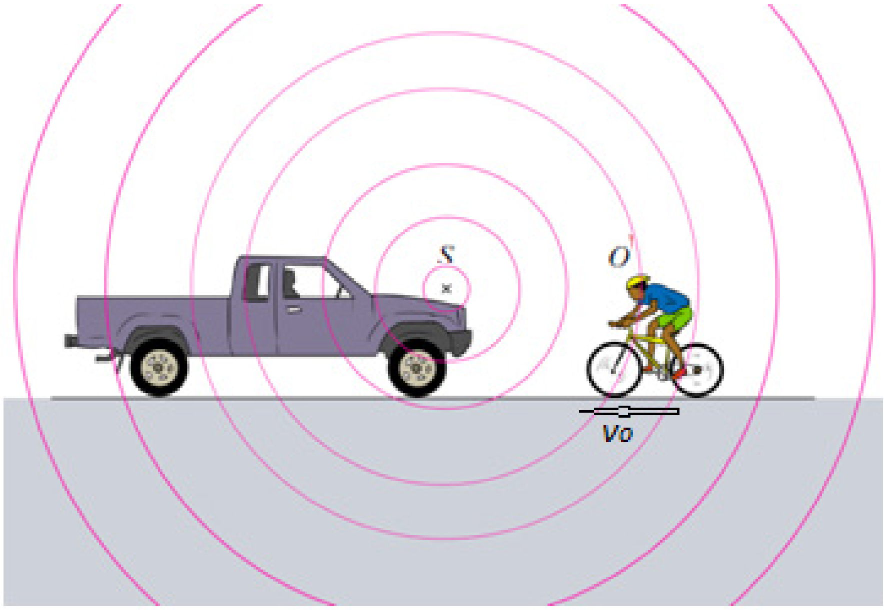


Fig.1. 29: An observer O (the cyclist) moves toward a stationary point source S, the horn of a parked truck. The observer hears a frequency f' that is greater than the source frequency.

a. When the observer is stationary but the source is approaching it at a speed v_s.

The wavelength is shortened by an amount v_sT, where T is the period of the wave. This is simply due to the motion of the source. Since the "received" wavelength (λ_r) is related to the "source" wavelength (λ_s) by: $\lambda_r = \lambda_s - v_sT = \lambda_s \dfrac{v - v_s}{v}$

Knowing the velocity of the moving source of wave (v_s), you can use the equation of the speed of a sound $v = \lambda f$ to convert the wavelength equations to solve for frequency.The received frequency is related to the source frequency by:

$$f_r = f_s \frac{v}{v - v_s}$$

Hence the frequency you hear is higher than the frequency emitted by the approaching source.

Example 1.10

If a source emits a sound of frequency 400 Hz when is at rest, then when the source moves toward a fixed observer with a speed of 30 m/s, what frequency does the observer hears knowing that the speed of a sound in air at room temperature is 343m/s?

Answer

The observer hears a frequency of $f_r = f_s \frac{v}{v - v_s} = 400 \frac{343}{343 - 30} = 438\ Hz$

As the source passes you and recedes, the "speed of approach" v_s becomes negative, and the frequency you hear becomes lower than the frequency emitted by the now receding source.

The frequency of the wave will be: $f_r = f_s \frac{v}{v + v_s}$

In this case if a source vibrating at 400 Hz is moving away from a fixed observer at 30 m/s, the later will hear a frequency of about $f_r = f_s \frac{v}{v - v_s} = 400 \frac{343}{343 + 30} = 434\ Hz$

b. When the source is stationary but observeris approaching it at a speed v_o.

The Doppler's effect also occurs when the source is at rest and the observer is in motion. If the observer is travelling toward the source the pitch is higher; and if the observer is travelling away from the source, the pitch is lower.

With a fixed source and moving observer, the distance between wave crests, the wavelength λ, is not changed. But the velocity of the crests with respect to the observer is changed. If the observer is moving toward the source, the speed of the wave relative to the observer is $v' = v + v_0$

Hence, the new frequency is $f_r = f_s \frac{v + v_0}{v}$

If the observer is moving away from the source, the relative velocity is $v' = v - v_o$ and

$$f_r = f_s \frac{v - v_o}{v}$$

Example 1.11

The siren of a police car at rest emits at a predominant frequency of 1600 Hz. What frequency will be heard if you were moving with speed of 25 m/s?

a. Toward it?

b. Away from it?

Answer

a. We use equation $f_r = f_s \dfrac{v+v_0}{v} = 1600\left(\dfrac{343+25}{343}\right) = 1716.6\ Hz$

b. We use equation: $f_r = f_s \dfrac{v-v_0}{v} = 1600\left(\dfrac{343-25}{343}\right) = 1483\ Hz$

c. If both the source and listener are moving

If both the source and receiver are moving and v_s and v_o are the speeds with which they are approaching each other (respectively), the Doppler shift is

$$f_r = f_s \frac{v+v_0}{v-v_s}$$

Here v is the speed of sound in air; v_o is the speed of the listener (substituted as positive if he moves towards the source, as negative if he moves away from the source), and v_s is the speed of the source (reckoned as positive if it moves towards the listener, as negative if it moves away from the listener.

Example 1.12

A car, sounding a horn producing a note of 500 Hz, approaches and passes a stationary observer O at a steady speed of 20 m/s. Calculate the change in pitch of the note heard by O (speed of sound is 340 m/s)

Answer:

Towards O, apparent frequency to O: $f' = f_s \dfrac{v}{v-v_s} = 500\dfrac{340}{340-20} = 531\ Hz$

AwayfromO,theapparentfrequencytoO: $f_r = f_s \dfrac{v}{v+v_s} = 500\dfrac{340}{340+20} = 472\ Hz$

Change in pitch: $\dfrac{f'}{f_r} = \dfrac{531\,Hz}{472\,Hz} = 1.125$

For convenience, we can write Doppler's effect equation as a single equation that covers all cases of both source and observer in motion:

$$f_r = f_o \frac{v \pm v_o}{v \mp v_s}$$

The upper signs apply if source and/or observer move toward each other. The lower signs apply if they are moving apart. The word *toward* is associated with an *increase* in observed frequency. The words *away from* are associated with a *decrease* in observed frequency.

Although the Doppler's effect is most typically experienced with sound waves, it is a phenomenon that is common to all waves. For example, the relative motion of source and observer produces a frequency shift in light waves. The Doppler's effect is used in police radar systems to measure the speeds of motor vehicles. Likewise, astronomers use the effect to determine the speeds of stars, galaxies, and other celestial objects relative to the Earth.

Example1.13

As an ambulance travels east down a highway at a speed of 33.5 m/s, its siren emits sound at a frequency of 400 Hz. What frequency is heard by a person in a car traveling west at 24.6 m/s

a. as the car approaches the ambulance and
b. as the car moves away from the ambulance?
c. Suppose the car is parked on the side of the highway as the ambulance speeds by. What frequency does the person in the car hear as the ambulance (i) approaches and (ii) recedes?

Answer

a. As the ambulance and car approach each other, the person in the car hears the frequency

$$f_r = f_o \frac{v+v_o}{v-v_s} = 400\frac{343+24.6}{343-33.5} = 475\ Hz$$

b. As the vehicles recede from each other, the person hears the frequency

$$f_r = f_o \frac{v-v_o}{v+v_s} = 400\frac{343-24.6}{343+33.5} = 338\ Hz$$

The *change* in frequency detected by the person in the car is 475 - 338 = 137 Hz, which is more than 30% of the true frequency.

c. i) $f' = f_s \dfrac{v}{v-v_s} = 400\dfrac{343}{343-33.5} = 443.29\ Hz$

ii) $f' = f_s \dfrac{v}{v+v_s} = 400\dfrac{343}{343+33.5} = 364.40\ Hz$

The motion of the source of sound affects its pitch.

1.4.2 Uses of Doppler Effect

Astronomy

Doppler Effect is used to measure the speed at which stars and galaxies are approaching or receding from us, in a mechanism named red shift or blue shift. Redshift happens when light seen coming from an object that is moving away is proportionally increased in wavelength, or shifted to the red end of the spectrum. Vice versa occurs with blue shift. Since blue light has a higher frequency than red light, the spectral lines of an approaching astronomical light source exhibit a blue shift and those of a receding astronomical light source exhibits a redshift.

Medical imaging

In medicine, the Doppler Effect can be used to measure the direction and speed of blood flow in arteries and veins. This is used in echocardiograms and medical ultrasonography and is an effective tool in diagnosis of vascular problems.

Radar

The Doppler Effect is used to measure the velocity detected objects where a radar beam is fired at a moving target. For example, the police use radar to detect a speeding vehicle. Radio waves are fired using a radar gun at the moving vehicle. The velocity is calculated using the difference between the emitted frequency and the reflected frequency. In a similar way, Doppler radar is used by weather stations to calculate factors like wind speed and intensity

Application activity 1.4

1. Choose the best answer: Bats can fly in the dark without hitting anything because

A. They are flying mammals

B. Their night vision is going

C. They are guided by ultrasonic waves produced by them

D. Of no scientific reason

2. Discuss application of sound waves in medicine and navigation
3. Explain how sonar is used to measure the depth of a sea
4. a. What is meant by Doppler Effect?

   b. A police car sound a siren of 1000 Hz as it approaches a stationary observer at a speed of 33.5 m/s. What is the apparent frequency of the siren as heard by the observer if the speed of sound in air is 340 m/s.

   c. Discuss applications of the Doppler Effect.

Skills Lab 1

In this activity, you will design any musical instrument of your choice.

Procedures:

- Think of the instrument you wish to design. You may have two alternatives.
- Check whether the materials can be locally available in your area
- When you have all the required materials, start making it. You can find a model instrument for reference.
- After you have designed your instrument, try to experiment (play it) to check whether it is functioning. In case it is not functioning, try to design it until it works
- When you are done, try to present it to the whole class in presence of your tutor.

Note: You can ask a place at your school where you can keep your instrument for future use by either other students or tutors.

End of unit 1 assessment

For question 1 to 6, choose the letter of the best answer

1. Which of the following affects the frequency of wave?

   A. Reflection
   C. Diffraction
   B. Doppler Effect
   D. All of the above

2. Consider the following statements:
   I) Recording of sound on tapes was first invented by Valdemar Poulsen.
   II) Audio tapes have magnetic property.
   III) The tapes may also be made of PVC (Polyvinyl-chloride)

2. Considering the above statements in question 2 choose the letter of the best answer:

   A. I, II, and III all are correct.
   C. I and II are correct, III is wrong
   B. I, II, and III all are wrong
   D. I and II are wrong, III is correct

3. Nodes are

   A. Positions of maximum displacement
   B. Positions of no displacement
   C. A position between no displacement and maximum displacement
   D. None of these

4. Sound waves are:

   A. Transverse waves characterized by the displacement of air molecules.
   B. Longitudinal waves characterized by the displacement of air molecules.
   C. Longitudinal waves characterized by pressure differences.
   D. Both (B) and (C).
   E. (*A*), (*B*), and (*C*).

5. In which of the following is the wavelength of the lowest vibration mode the same as the length of the string or tube?

   A. A string.
   D. An open tube.
   B. A tube closed at one end.
   E. None of the above.
   C. All of the above.

6. When a sound wave passes from air into water, what properties of the wave will change?

A. Frequency. D. Wavelength.

B. Wave speed. E. Both frequency and wavelength.

C. Both wave speed and wavelength.

7. Does the phenomenon of wave interference apply only to sinusoidal waves? Explain.

8. As oppositely moving pulses of the same shape (one upward, one downward) on a string pass through each other, there is one instant at which the string shows no displacement from the equilibrium position at any point. Has the energy carried by the pulses disappeared at this instant of time? If not, where is it?

9. Can two pulses traveling in opposite directions on the same string reflect from each other? Explain.

10. When two waves interfere, can the amplitude of the resultant wave be greater than the amplitude of any of the two original waves? Under which conditions?

11. When two waves interfere constructively or destructively, is there any gain or loss in energy? Explain.

12. Explain why your voice seems to sound better than usual when you sing in the shower.

13. An airplane mechanic notices that the sound from a twin-engine aircraft rapidly varies in loudness when both engines are running. What could be causing this variation from loud to soft?

14. Explain how a musical instrument such as a piano may be tuned by using the phenomenon of beats.

15. Fill in the gap

A. As a sound wave or water ripple travels out from its source, its -------------- decreases.

B. The vibrating air in a/an ---------------------------- has displacement antinodes at both ends.

C. For a /an ...., the fundamental corresponds to a wavelength four times the length of the tube.

D. The .... refers to the change in pitch of a sound due to the motion either of the source or of the observer. If source and observerare approaching each other, the perceived pitch is .... If they are moving apart, the perceived pitch is ....

16. A bat, moving at 5.00 m/s, is chasing a flying insect. If the bat emits a 40.0 kHz chirp and receives back an echo at 40.4 kHz, at what speed is the insect moving toward or away from the bat? (Take the speed of sound in air to be v = 340 m/s.)
17. If you hear the horn of the car whose frequency is 216 *Hz* at a frequency of 225 *Hz*, what is their velocity? Is it away from you or toward you? The speed of sound is 343 m/s
18. You run at 12.5 m/s toward a stationary speaker that is emitting a frequency of 518 *Hz*. What frequency do you hear? The speed of sound is 343 m/s
19. If you are moving and you hear the frequency of the speaker at 557 *Hz*, what is your velocity? Is it away from or toward the speaker? The speed of sound is 343 m/s

20. Read the following text and answer the question

Researchers have known for decades that whales sing complicated songs. Their songs can last for 30 min and a whale may repeat the song for two or more hours. Songs can be heard at a distances of hundreds of kilometers. There is evidence that whales use variations in the songs to tell other whales about the location of food and predators. Only the male whales sing, which has led some researchers to think that songs are also used to attract a male.

The whale songs may be threatened by noise pollution. In the past 50 years, ocean noise has increased due to human activities. Goods are transported across the ocean in larger ships than ever before. Large ships use bigger engines. They produce low-frequency noise by stirring up air bubbles with their propellers. Unfortunately, whales also use low-frequency sound in their songs, perhaps because these sounds carry further than high-frequency sounds in the ocean. Propeller noise from large ships is loud enough to interfere with whale songs at a distance of 20 km.

Question: Are regulations needed to protect whales from noise?

In your own words, describe the major issue that needs to be resolved about ocean noise pollution. List three arguments for those who think regulations should require large ships to reduce noise pollution. List three arguments for those who think regulations are not necessary.

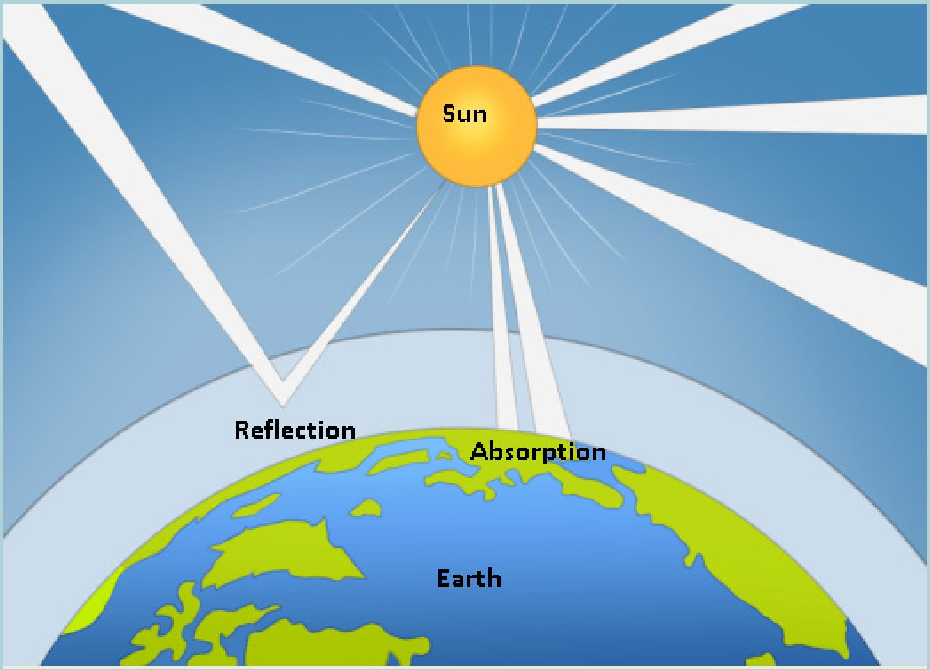
UNIT 2

CLIMATE CHANGE AND GREENHOUSE EFFECT

Key Unit Competence:

Evaluate the environmental survey conducted on climate change and greenhouse effect.

Introductory activity



Most of the solar radiation that is incident onto the Earth is absorbed and the rest is reflected into the atmosphere. Our Earth acts almost as a black body, thereby radiating back to the space part of the energy it has absorbed from the sun. The earth and its atmosphere are a part of the solar system. Life on the Earth cannot exist without the energy from the sun.

a. Basing on Physics concepts, how do humans and plants get energy from the sun? Account for the use of this energy.
b. Do humans and plants maintain the energy absorbed forever? Explain your reasoning using physics concepts.
c. State and explain the scientific term used to describe a body that can absorb or emit radiations that fall on them.
d. Basing on your ideas in question (c) above what could be the effect on that body if:

i) It maintains the energy for a long time

ii) Reflects energy after a given time.

iii) Do you think that these reflected and absorbed radiations have effect on the Climate? Why? Discuss your answers with your friends and even present it to your Physics tutor

e. Some radiations may be prevented from leaving the atmosphere and remain concentrated in the atmosphere. What do you think are effects of these gases as they remain in the atmosphere?
f. In your own view what changes have been brought by this concentration of radiations and how has man tried to control some of the changes.

2.1 CLIMATE CHANGE

Activity 2.1

The sun is the major source of energy (in form of radiation) on the earth. Some of these radiations are absorbed by different aerosols in the space and part of it reaches the earth. Our earth has special features that leads to absorption of these radiations and these processes are continuous.

a. What do you think are the effects of these radiations on the earth and its atmosphere after absorption and reflection?
b. From your own understanding, what would happen if there is imbalance between the absorbed and radiated energy in the earth's atmosphere.
c. Can that incidence be controlled? How?
d. With practical examples, discuss how these changes in climate have been noticed in our country Rwanda
e. In your own words, what are the scientific measures that can be done to avoid that kind of situation?

2.1.1 Climate change and related facts

Climate is usually defined as the "**average weather**," or more rigorously, as the **statistical description in terms of the mean and variability of relevant quantities over a period of time** ranging from months to thousands of years. The classical period is 3 decades, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Weather is measured in terms of the following parameters: wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate can be described as the sum of weather. While the weather is quite variable, the trend over a longer period, the climate, is more stable.

However, climate change can be observed over a longer period of time. Climate change refers to any significant change in the climate parameters such as temperature, precipitation, or wind patterns, among others, that occur over several decades or longer Natural and human systems have adapted to the prevailing amount of sunshine, wind, and rain. While these systems can adapt to small changes in climate, adaptation is more difficult or even impossible if the change in climate is too rapid or too large. This is the driving concern over anthropogenic, or human induced, climate change. If climate changes are too rapid, then many natural systems will not be able to adapt and will be damaged and societies will need to incur the costs of adapting to a changed climate (REMA)

There has been variation in the atmospheric conditions in a given time. This has affected the seasons leading to a less output of our produce especially from agriculture, fishing and other activities.

These changes are sometimes for a short time but also may take a long time. Some of these changes result from our practices like farming, industrialization, urbanization, mining and other infrastructure developments. Care should be taken so as these changes in the atmospheric conditions can be avoided.

Some of important terms we need to know

- Climate feedback: This refers to a process that acts to amplify or reduce direct warming or cooling effects.
- Climate lag: This is the delay that can occur in a change of some aspect of climate due to the influence of a factor that is slow acting.
- Climate model: This is a quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice. Models can range from relatively simple to quite comprehensive

This explains a delay that occurs in climate change as a result of some factors that changes only very slowly. For example, the effects of releasing more carbon dioxide into the atmosphere occur gradually over time because the ocean takes a long time to warm up in response to these emissions.

2.1.2 Causes of climate change.

Physics behind climate change and causes

The climate of the earth is controlled by its absorption and the subsequent emission of that energy.

The Earth's surface temperature is determined by the balance between the absorption and emission of Sun's radiation.

The major cause of climate change is the concentration of greenhouse gases, especially water vapor and carbon dioxide. These gases trap thermal radiation from the earth's surface and this effect keeps the surface warmer than it would be.

a. Human causes

Human activities are major factors that lead to natural greenhouse effect. Most of activities done by human lead to high concentration of greenhouse gases. From research it has been found that the concentration of carbon dioxide has risen by about 30% in this period as compared to pre-industrial period. This gives a projection that the concentration of these greenhouse gases is still increasing day and night as people continue using fossil fuels.

Such activities include bush burning, burning of fossil fuels, deforestation and agriculture. All these activities have a strong impact on the climate of a given area as they may lead to either warming or cooling the land.

On another hand, industries have also led to the change in climatic conditions as they emit carbon gases into the atmosphere. From what is happening currently, the climatic conditions are worsening if the world becomes more industrialized. Peoples are trying to limit this by making machines that emit less carbon gases (REMA).

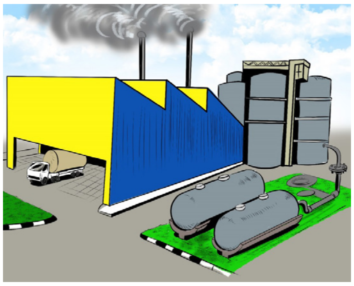


Fig.2. 1An operating industry giving out gases. These gases affect the atmosphere that leads to climate change.

b. Natural causes

- Volcanicity: When volcanoes erupt, they throw out large volumes of Sulphur dioxide (SO_2), water vapor, dust, and ash into the atmosphere. Although the volcanic activity may last only a few days, the large volumes of gases and ash can influence climatic patterns for years. Millions of tons of Sulphur dioxide gas can reach the upper levels of the atmosphere (called the stratosphere) from a major eruption.
- Ocean currents: Oceans plays a major role in the change of climate. Oceans cover about 71% of the Earth and absorb about twice as much of the sun's radiation as the atmosphere or the land surface. Ocean currents move vast amounts of heat across the planet - roughly the same amount as the atmosphere does. But the oceans are surrounded by land masses, so heat transport through the water is through channels.

Application activity 2.1

1. Explain the meaning of the following terms.
   a) Weather
   b) Climate
   c) Climatic change
   d) Humidity
   e) Temperature
2. What do you think are the factors that lead climatic change in your area? Make a general conclusion using a case study of Rwanda.
3. Using Physics Concepts, discuss why different areas found in the same region may have different climatic conditions.

2.2 SOLAR AND BLACK BODY RADIATIONS.

Activity 2.2

The earth receives almost all its energy from the Sun's radiation. The heat or energy from the sun prevents the earth from becoming cold and lifeless planet. Our earth is made in a way that it absorbs some of radiations from the sun and reflects some.

a. From your scientific understanding, what is the mode of transfer of energy from the sun to the earth?

b. Do you think all radiations that is emitted from the sun reaches the earth? Explain your reasoning.

c. Explain factors you think affect the intensity of radiations from the sun received by the earth.

d. From the introductory statement, it's clear that the earth absorbs some of the radiations from the sun. Discuss the factors you think makes the earth absorb radiations.

e. From knowledge you acquired in unit 2 in year two, what is the scientific name of the body that reflects absorbs radiations that falls on it.

2.2.1 Intensity of the sun's radiation and albedo

Sun produces heat of very high intensity that is spread and then received by all surrounding objects. These objects include all the planets and other objects around it.

The intensity of the sun (at the top of the earth's atmosphere) is **approximately 1400 W/m²** also known as the solar constant. The amount received on the earth surface is slightly below 1400 w/m². The main reasons for variation in intensity include:

- The shape of the earth: The earth has a spherical shape and therefore the sunlight is more spread out near the poles because it is hitting the earth at an angle, as opposed to hitting the earth straight-on at the equator. There are also fewer atmospheres at the equator, allowing more sunlight to reach the earth. Therefore, the intensity varies depending on the geographical latitude of the earth's location.
- The earth's rotation: all areas are not consistently exposed to sunlight. Areas that are experiencing 'night time' are not receiving a lot of the sun's power; therefore, the time of the day or night will affect the solar constant.
- The angle of the surface to the horizontal at that particular location: When the Sun is directly overhead, its rays strike Earth perpendicular to the ground and so deliver the maximum amount of energy. When the Sun is lower in the sky, a sunbeam strikes the ground at an angle and so its energy is "spread out" over a larger area

The solar constant represents the mean amount of incoming solar electromagnetic radiation per unit area on the earth's surface. This constant takes into account all types of solar radiation, including UV and infrared. The accuracy of the solar constant is questionable due to the following generalizations: This radiation is assumed to be incident on a plane perpendicular to the earth's surface. It is assumed that the earth is at its mean distance from the sun.

- Our seasons also determine how much Sun's radiation strikes a square meter of ground in a given place on the planet's surface at a given time of the year. The sun's radiation is maximum in the summer and it is minimum in winter.

Scientists use a quantity called "**albedo**" to describe the degree to which a surface reflects light that strikes it. It can be calculated by the ratio of reflected radiation from the surface to the incident radiation upon it.

$$albedo = \frac{total\ \ scattered\ \ power}{total\ \ incident\ \ power}.$$

The albedo has no units since it is a ratio of the similar quantities.

Being a dimensionless fraction, it can also be expressed as a percentage and is measured on a scale from 0 (0%) for no reflective power to 1 (100%) for perfect reflectors. The earth's albedo is about 0.3, meaning, on average, 30% of the radiation incident on the earth is directly reflected or scattered back into space. An object that has no reflective power and completely absorbs radiation is also known as ***a black body***

The table below gives you some values of estimated albedo for various surfaces expressed as percentages:

Surface	Albedo (%)	Surface	Albedo%	Surface	Albedo (%)
Fresh snow or ice	60-90	Tropical forests	13	Fresh snow	80-95
Old, melting snow	40-70	Woodland	14	Water bodies	10-60
Clouds	40-90	Sandy desert	37	Grass	25-30
Desert sand	30-50	Sea ice	25-60	Crops, grasslands	10-25
Soil	5-30	Grassland	20	Forests	10-20
Tundra	15-35	Snowy vegetation	20-80	Light roof	35-50

Grasslands	18-25	Stony desert	24	Dark roof	8-18
Forest		Snowy Ice	80	Brick, stone	20-40
Water		Water	8-10	Concrete, dry	17-27

Table 2. 1 Albedo for various surfaces

2.2.2 Factors affecting earth's albedo

Among other factors, the following are some of the factors that affect the albedo of the earth:

- Clouds. The atmosphere is usually covered with clouds that usually pass over the earth's surface. This leads to reduction or increase in the temperature of the earth's surface. This is because these clouds may absorb or reflects back sun's light to the free space. However, this depends on the distance from which the clouds are from earth's surface. When sun's radiation is reflected, the earth's surface is cooled and when it is absorbed the earth is warmed.
- Oceans While observing from the space, you will find out that water bodies appear differently from land surfaces. They appear darker and therefore absorb more sun's radiations than land. However, some of the radiations heating the water surface (ocean) may be carried away by the currents while others may form water vapor.
- Thick vegetation covers or forested areas. Places covered with vegetation absorb a lot of sun's radiation. This is because the vegetation cover provides a dark surface which absorbs more radiations than the bare land.
- Surface albedo. Different surfaces appear differently. Light coloured surfaces absorb different amounts of radiations than dark coloured surfaces. Snow covered areas are highly reflective. They thus absorb less amounts of energy (Sun's radiation). The snow cover reduces the heating effect of the earth's surface. However, if temperatures reduce, the snow cover reduces leading to the absorption of radiation by the exposed ground surface.

2.2.3 Black body radiation

An object that absorbs all radiation falling on it and therefore emitting radiation in whole spectrum of wavelengths is called a ***blackbody***. At equilibrium temperature, a blackbody has a characteristic frequency spectrum that depends only on its temperature.

A perfect blackbody is one that absorbs all incoming light and does not reflect any. At room temperature, such object would appear to be perfectly black (hence the term *blackbody*). However, if heated to a high temperature, a blackbody will begin to glow with *thermal radiation*.

Blackbody radiation is radiant energy emitted by an ideal black surface (blackbody) whose spectral power distribution is only governed by its own temperature. Blackbody radiation is radiant energy emitted by an ideal black surface (blackbody) whose spectral power distribution is only governed by its own temperature Black body radiation is the radiant energy emitted by a black body surface whose spectral power distribution is governed by its own temperature.

LAWS OF BLACK BODY RADIATION

a. Stefan-Boltzmann law

The law states that, *"the power per unit area radiated by a surface of a black body is directly proportional to the forth power of its temperature".*

$$P = e\sigma A T^4$$

Where: P is *Power radiated in watts*

- e is *emissivity*
- A is *surface area in* m^2
- $\sigma = 5.67 \times 10^{-8}\ W.m^{-2}.K^{-4}$ *Stefan-Boltzmann constant*
- T is *Temperature in Kelvin*

Using this formula, we can calculate the amount of power radiated by an object. A black body which emit in whole spectrum of wavelength would have an emissivity of 1.

Since the earth is not a perfect black body, it has a certain emissivity value.

Example 2.1

The earth is considered to be a perfect black body at temperature 25^{0}C.Assuming the earth to be a perfect sphere with radius 6380 km. Calculate the total power radiated from the sun. Take $\sigma = 5.67 \times 10^{-8}\ W.m^{-2}.K^{-4}$

Answer:

Power radiated from a black body is given by:

$P = e\sigma A T^4$ and $e = 1$ for a perfect black body

$P = 1 \times 5.67 \times 10^{-8} \times 298 = 1.7 \times 10^{-5}\ W$

The emissivity is defined as *the power radiated by a surface divided by the power radiated from a perfect black body of the same surface area and temperature*.

In simpler terms, it is the relative ability of a surface to emit energy by radiation. A true blackbody would have an emissivity of 1 while highly polished silver could have an emissivity of around 0.02. *The emissivity is a dimensionless quantity.*

b. Wien's displacement law

It states that ***"the maximum wavelength of the emitted energy from a blackbody is inversely proportional to its absolute temperature"*.**

This law was formulated by the German physicist Wilhelm Wien in 1893 who related the temperature of a black body and its wavelength of maximum emission following the equation.

$$\lambda_{\max} T = b$$

Where b is Wien's constant approximately equal to $2.9 \times 10^{-3}\,m\,K$, T is the absolute temperature in Kelvin and $\lambda_{\max}$ wavelength of maximum emission.

Example 2.2

Calculate the peak wavelength of emitted radiation from a black body at 1500 K. Take b is Wien's constant be $2.9 \times 10^{-3}\,m\,K$

Solution

From $\lambda_{\max} T = b$

$$\lambda_{\max} = \frac{b}{T} = \frac{2.9 \times 10^{-3}}{1500} = 1.9 \times 10^{-6}\,m$$

It is thus found out that as the temperature of blackbody increases, the total amount of light emitted per second increases, and the wavelength of the spectrum's peak shifts to bluer colors.

Remember: It is not good to put on black clothes on a sunny day. This is because these dark clothes will absorb more radiations from the sun which may be harmful to our health.

BLACK BODY RADIATION CURVES

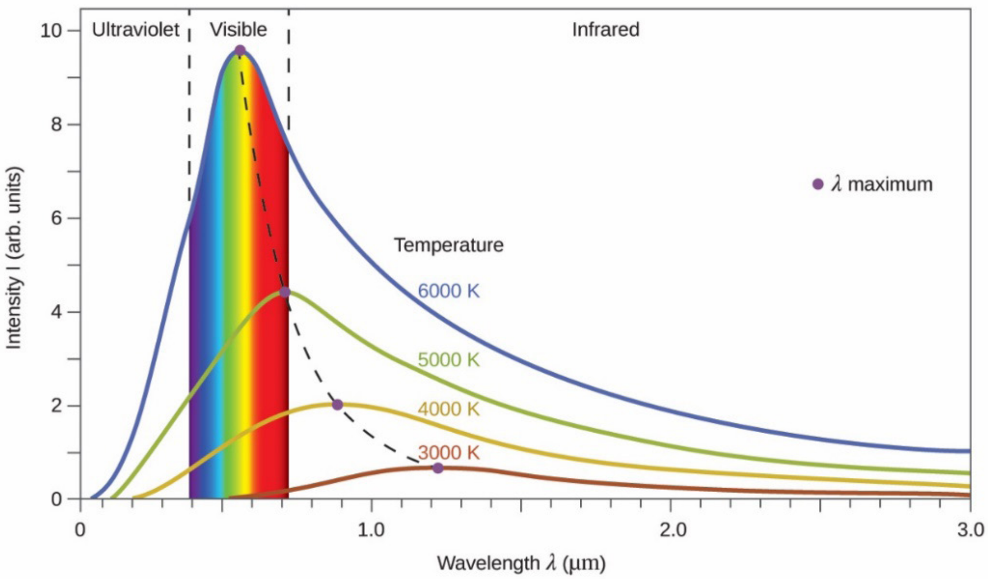


Fig.2. 2 Black body radiation curves showing peak wavelengths at various temperatures (https://opentextbc.ca/chemistry/chapter/6-1-electromagnetic-energy/)

This Fig.2.2 shows how the black body radiation curves change at various temperatures. The graph indicates that as the temperature increases, the peak wavelength emitted by the black body decreases. It therefore begins to move from the infra-red towards the visible part of the spectrum. Again, none of the graphs touch the x-axis so they emit at every wavelength. This means that some visible radiation is emitted even at these lower temperatures and at any temperature above absolute zero, a black body will emit some visible light.

Features/Characteristics of the Graph

- As temperature increases, the total energy emitted increases, because the total area under the curve increases.
- It also shows that the relationship is not linear as the area does not increase in even steps. The rate of increase of area and therefore energy increases as temperature increases.

Application activity 2.2

1. a. With clear explanations, explain the approximate spectral composition of the Sun's radiation before it interacts with Earth's atmosphere?

   b. Is the amount of solar energy that reaches the top of Earth's atmosphere constant? Explain giving valid examples and evidence.

   c. Are all wavelengths of Sun's radiation transmitted equally through Earth's atmosphere? Explain your reasoning.

2. a. What effect does absorption have on the amount of solar radiation that reaches Earth's surface?

   b. List down other processes (besides absorption) that affect radiation reaching the earth's surface?

   c. What can be percentage of incoming solar radiation that is affected by absorption and scattering (or reflection)?

3. a. Jane Says that clouds have a high albedo while Pierre says land vegetation has a low albedo? Using Scientific explanations, discuss what they base on to make their deductions.

   b. What do you think are major factors that influence the insolation at a particular location on a particular day? How do they affect it?

   c. What latitudinal regions experience least variation in day-to-day solar radiation? Which one experiences the greatest? Why?

4. a) Explain the meaning of a blackbody.

   b) Interpret Stefan-Boltzmann law and Wein's displacement law.

   c) The sun behaves as an approximate blackbody radiator with peak energy radiation occurring at a wavelength of $5.2\text{x}10^{-7}$m. Show that the sun has a surface temperature of about 6000 K(Wien's constant b is approximately equal to $2.9 \times 10^{-3} m\ K$)

5. A student teacher in year III is constructing a spread sheet to calculate the radius R of some stars. To obtain the radius, the surface temperature T of the star must be first calculated. She is given values for the star's Luminosity L and the wavelength at which peak energy emission occurs. Part of the spreadsheet is shown, A is the surface area of the star.(Wien's constant is approximately equal to $2.9 \times 10^{-3} m\ K$ and Stefan's constant $\sigma = 5.67 \times 10^{-8}\ W.m^{-2}.K^{-4}$).

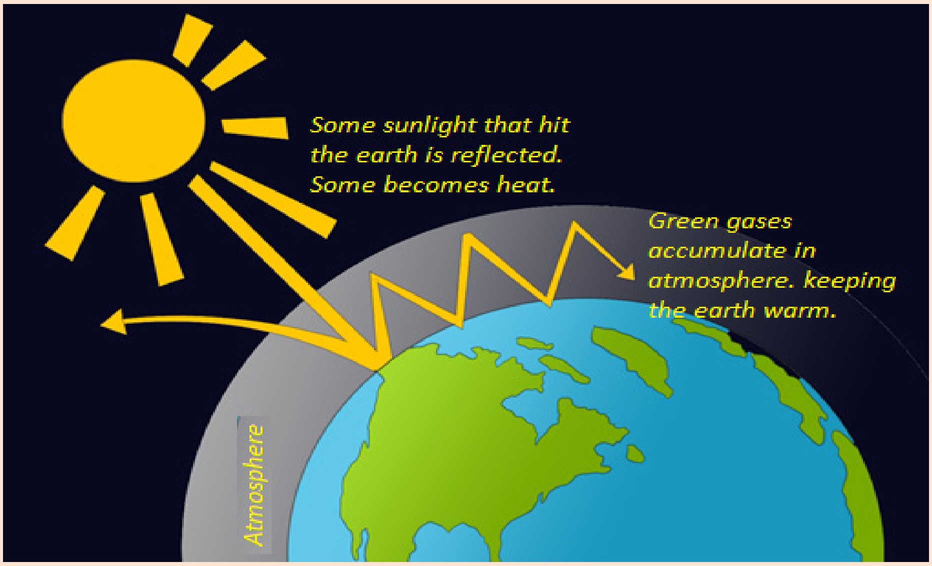
	A	B	C	D	E
1	λ_{max} / 10^{-7} m	T / 10^3 K	L / 10^{27} W	A / 10^{19} m^2	R / 10^9 m
2	6.85	4.23	0.039		0.41
3	5.74	5.05	0.384	1.04	0.91
4	3.56	8.14	3.385	1.36	1.04
5					

a. Write an equation to show how the value B2 is calculated.

b. Show that the value in D2 is about 0.2

2.3 GREENHOUSE EFFECTS AND ITS IMPACT ON CLIMATE CHANGE.

Activity 2.3



a) What do you know about greenhouse?

b) Different activities like industrialization and others give out gases after burning fossil fuels.

  i) What special name do you think is given to these gases?

  ii) If these gases accumulate in the atmosphere, what effect do they have on to the temperature of the earth and its atmosphere?

c) Suggest measures that can be done to limit high accumulation of these gases in the atmosphere.

Greenhouse effect is the process by which thermal radiation from the sun is prevented from leaving the atmosphere and then re-radiated in different directions.

The relationships between the atmospheric concentration of greenhouse gases and their radiative effects are well quantified. The **greenhouse effect** has the root from greenhouses that becomes warmer when heated by sun's radiation. The mode of operation of a greenhouse is that a part of the sunlight radiations incident on the ground surface of the greenhouse are absorbed and warms the surface inside the greenhouse. Both the reflected radiations and the heat emitted by the ground surface in the greenhouse are trapped and re-absorbed inside the structure. Thus, the temperature rises inside the greenhouse compared to its surrounding environment.

Therefore, the greenhouse effect heats up the earth's surface because the green gases that are in the atmosphere prevent radiations from leaving the atmosphere. The absorption of these radiations contributes to the increase of the atmosphere's temperature.

A greenhouse is constructed by using any material that allows sunlight to pass through usually plastic or glass. This prevents reflected radiations from leaving the structure thereby leading to the increase in the temperature within. If a small puncture is made on to the greenhouse, the temperature within reduces.

Since some of these re-radiated radiations come back to the earth's surface, they lead to the increase in the temperature of the earth's surface leading to global warming.

(a)

(b)

Fig.2. 3(a) Greenhouses in one of the parts of Rwanda and (b) emission of greenhouse gases.

2.3.1 Greenhouse gases

Some gases in the earth's atmosphere act a bit like the glass in a greenhouse, trapping the sun's heat and stopping it from leaking back into space.

Many of these gases occur naturally, but human activity is increasing the concentrations of some of them in the atmosphere, in particular:

- Carbon dioxide (CO_2)
- Methane
- Nitrous oxide
- Fluorinated gases

CO_2 is the greenhouse gas most commonly produced by human activities and it is mainly **responsible for man-made global warming**. Its concentration in the atmosphere keeps on increasing with industrialization.

Other greenhouse gases are emitted in smaller quantities, but they trap heat far more effectively than CO_2, and in some cases are thousands of times stronger. **Methane** is responsible for 17% of man-made global warming, **nitrous oxide** for 6%.

Causes for rising emissions:

Burning coal, oil and gas that produce carbon dioxide and nitrous oxide.

Cutting down forests (deforestation). Trees help to regulate the climate by absorbing CO_2 from the atmosphere. So when they are cut down, that beneficial effect is lost and the carbon stored in the trees is released into the atmosphere, adding to the greenhouse effect.

Increasing livestock farming. Cows and sheep produce large amounts of methane when they digest their food.

Fertilizers containing nitrogen produce nitrous oxide emissions.

Fluorinated gases produce a very strong warming effect, up to 23 000 times greater than CO_2. Thankfully these are released in smaller quantities and are being phased down by European Union regulation.

2.3.2 Impact of greenhouse effect on climate change.

With the greenhouse effect, the earth is unable to emit the excess heat to space and this leads to increase in atmosphere's temperature and global warming. Scientists have recorded about 0.75°C increase in the planet's overall temperature during the course of the last 100 years. The increased greenhouse effect leads to other effects on our climate and has already caused: (REMA).

- Greater strength of extreme weather events like: heat waves, tropical cyclones, floods, and other major storms.
- Increasing number and size of forest fires.
- Rising sea levels (predicted to be as high as about 5.8 cm at the end of the next century).

- Melting of glaciers and polar ice.
- Increasing acidity in the ocean, resulting in bleaching of coral reefs and damage to oceanic wildlife.

Solutions to reduce the impact of greenhouse gases

- High efficiency during power production
- Replacing coal and oil with natural gas
- Combined heating and power systems (CHP)
- Renewable energy sources and nuclear power
- Carbon dioxide capture and storage
- Use of hybrid vehicles.

2.3.3 Global warming

Global warming is the persistent increase in temperature of the earth's surface (both land and water) as well as its atmosphere. Scientists have found out that the average temperature in the world has risen by about 0.75^0C in the last 100 years and about 75% of this rise is from 1975.

Previously the changes were due to natural factors but currently the changes are due to both natural and human activities. From research, Natural greenhouse maintains the temperature of the earth making it a better place for human kind and animal life. However ever since the evolution of industries, there has been significant change in the temperature. The causes are both natural and human activities and they are the ones that cause climate change.

Note: *If these greenhouse gases were completely not there, the Earth would be too cold for humans, plants and other creatures to live*.

Can you now see the importance of these greenhouse gases! Though they cause greenhouse effect, they are responsible for regulating the temperature of the earth.

Global warming is damaging the earth's climate as well as the physical environment. One of the most visible effects of global warming can be seen in the Arctic region where glaciers, permafrost and sea ice are melting rapidly. Global warming is harming the environment in several ways. Global warming has led to: Desertification, Increased melting of snow and ice, Sea level rise, stronger hurricanes and cyclones.

Application activity 2.3

1. Differentiate the term “greenhouse effect from global warming.
2. With clear explanations, explain why it is called the “greenhouse” effect?
3. From your own reasoning and understanding, why do you think Environmental experts have become worried about the greenhouse effect?
4. Below is a bar graph showing emitted Greenhouse gases worldwide from 1990 to 2005. Use it to answer the questions that follow

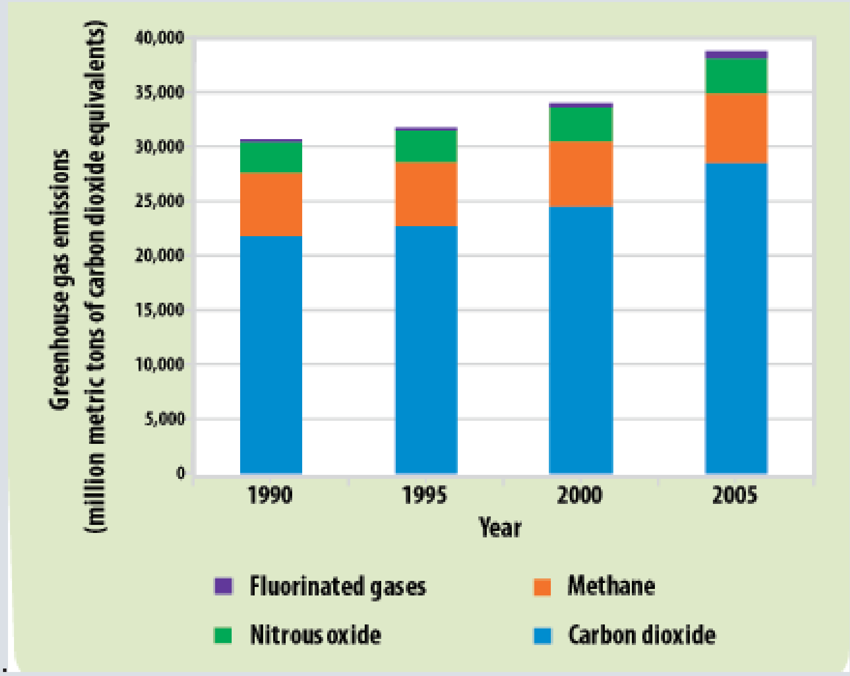


Fig.2.4 Emissions of greenhouse gases worldwide from 1990 to 2005 by Rwanda Environment Management authority (REMA)

a) From your analysis (using the graph) which kind of gas was emitted in excess for the specified period?

b) What could be the factors that led that gas to be emitted in large quantities?

c) What do you think one can do to limit such emissions?

d) From your own point of view, do you think it’s a good idea to stop completely emission of these gases? Explain your reasoning by giving valid examples

2.4 CLIMATE CHANGE MITIGATION

Activity 2.4

Read the text below and answer the questions that follow.

The government of Rwanda is trying to sensitize people not to cut down trees for charcoal, drying wetlands for farming activities and regulating people from approaching wetlands, forests (Both Natural and artificial) and Fighting all activities that may lead to climate change.

a. As a good citizen of Rwanda, do you support these plans of the government? Support your stand with clear justifications
b. If yes what have you done to implement some of these policies?
c. What are some of the New Technologies that the government is advocating for to stop these negative climate changes?

2.4.1 Climate change mitigation

Climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. (IPCC, 1996)

Climate change is one of the most complex issues we are facing today. It involves many dimensions science, economics, society, and moral and ethical questions and is a global problem, felt on local scales that will be around for decades and centuries to come. Carbon dioxide, the heat-trapping greenhouse gas that has driven recent global warming, lingers in the atmosphere for centuries, and the earth (especially the oceans) takes a while to respond to warming.

So even if we stopped emitting all greenhouse gases today, global warming and climate change will continue to affect future generations. In this way, humanity is "committed" to some level of climate change.

Because we are already committed to some level of climate change, responding to climate change involves a two-pronged approach:

1. Reducing emissions and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere **("mitigation")**;
2. Adapting to the climate change already in the pipeline **("adaptation").**

2.4.2 Mitigation and adaptation

Because of these changes in climatic conditions, man has devised all possible measures to see how he can live in harmony on this planet. This has made man to think harder so that these greenhouse gases can be minimized.

The process of preventing all these greenhouse gases is what is known as **mitigation.** This is very important as it is aimed at controlling the rise in temperatures of the earth while regulating earth's temperature.

The main goal of mitigation is to reduce human interference to nature thereby stabilizing the greenhouse gas levels in a given time to allow ecosystem to adapt naturally to the climate changes. Care should be taken while these adjustments are made not to affect food production and other economic developments.

Among other strategies, mitigation strategies include:

a) Retrofitting buildings: Retrofitting is the process of modifying something after it has been manufactured.

Retrofitting a building involves changing its systems or structure after its initial construction and occupation. This work can improve amenities for the building's occupants and improve the performance of the building. As technology develops, building retrofits can significantly reduce energy and water usage hence conserving energy sources.

Retrofitting has come to prominence in recent years as part of the drive to make buildings more thermal efficient and sustainable. This can help cut carbon emissions, make it cheaper and easier to run buildings, and can contribute to overcoming poor ventilation and damp problems.

b) Adopting **renewable energy** sources like solar, wind and small hydro-electric plants:

Human activities are overloading our atmosphere with carbon dioxide and other global warming emissions. These gases act like a blanket, trapping heat. The result is a web of significant and harmful impacts, from stronger, more frequent storms, to drought, sea level rise, and extinction.

In contrast, most renewable energy sources produce little to no global warming emissions. Even when including "life cycle" emissions of clean energy (ie, the emissions from each stage of a technology's lifemanufacturing, installation, operation, decommissioning), the global warming emissions associated with renewable energy are minimal.

c) Helping **cities develop more sustainable transport** such as **bus rapid transit, electric vehicles**. This helps in reducing carbon emissions.

d) Promoting more **sustainable uses of land and forests** and making people aware of the impacts of mis-using these natural gifts.

e) **Creating carbon sinks** like in big oceans in case there are no alternatives.

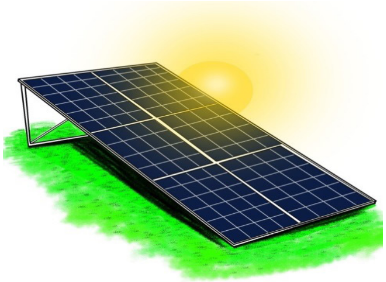


Fig.2. 5: Solar panels have been used to reduce some of the problems caused by other sources of energy

Application activity 2.4

1. Plan and write an essay about climatic change mitigation in Rwanda.
2. Make a research about climate change mitigation in your neighborhood (either for the school or for your home) and answer the following questions.
   a) What are some of the conditions you have experienced that used in order to prevent the greenhouse gases?
   b) How have you adapted to the changes in conditions you have mentioned in a) above.
   c) What are you doing to stop these climatic changes?

Skills Lab 2

Aim:* Constructing a greenhouse. *(Can be done over a long period of time)

In this activity you may need

- Polyethene paper (should be relatively white in color)
- Wood
- Nails
- Any fiber that can be used while tying
- Laboratory thermometer.
- Bean seeds

Procedures

a) Collect materials listed above.

b) Chose a place where to construct the greenhouse. It may either be near your school or near your home.

c) Fix and connect the materials together until you make a structure similar to the one indicated in the figure below.

d) Each day measure temperatures and keep noting down records.

e) What do you think are the causes of temperature variations in your records?

f) Sow seeds of beans in your greenhouse.

g) After seeds have germinated, keep observing changes in the development of the bean plant.

h) Make a comprehensive report about your Greenhouse. (Include temperature and vapor changes within the greenhouse).

i) Share it with your friends or your physics tutor.

End of unit 2 assessment

Re-write the questions (1) to (8) below in your notebook and circle the best alternative

1. The emissivity (ε) can be defined as the ratio of
   A. emissive power of real body to the emissive power of black body
   B. emissive power of black body to the emissive power of real body
   C. reflectivity of real body to emissive power of black body
   D. Reflectivity of black body to emissive power of real body.

2. Imagine two planets. Planet A is completely covered by an ocean and has and overall average albedo of 20%. Planet B is blanketed by clouds and has an overall average albedo of 70%. Which planet reflects more sunlight back into space?
   A. Planet A
   B. Planet B
   C. the two planets reflect the same amount of light
   D. more information is needed to answer this question

3. ________________ is a term used to a process that acts to amplify or reduce direct warming or cooling effects

   A. Climate change C. Climate feedback

   B. Weather D. Climate model

4. The filament of an electric bulb has length of 0.5 m and a diameter of 6×10^{-5} m. The power rating of the lamp is 60 W Assuming the radiation from the filament is equivalent to 80% that of a perfect black body radiator at the same temperature. The temperature of the filament is (Stefan Constant is $5.7 \times 10^{-8}\ Wm^{-2}K^{-4}$):

   A. 1933 K C. 64433333.3 K

   B. 796178.3 K D. 60 K

5. The long-term storage of carbon dioxide at the surface of the earth is termed as

   A. Black body radiation C. Solar radiation management

   B.Thermal expansion D. Sequestration

6. The balance between the amount of energy entering and exiting the Earth system is known as

A. Radiative balance C. Paleoclimatology

B. Black body Radiation D. Solar radiation

7. The following are examples of greenhouse gases except

A. Carbon dioxide C. Methane

B. Nitrous oxide D. Oxygen

8. The government of Rwanda is advising the people to conserve the nature. This is intended to limit the incidence of rise in the temperature. This conservation of nature

A. Reduces the amount of water vapor that leads to increase in temperature

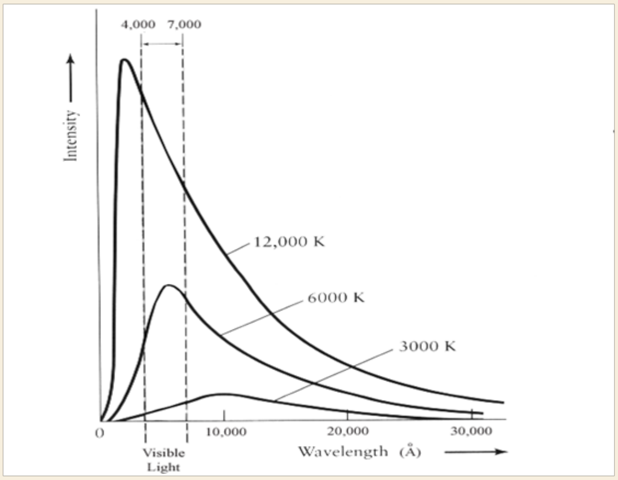
B. Reduces the amount of Carbon dioxide in the space

C. Increases the amount of plant species that is required to boost our tourism industry

D. Provides a green environment for human settlement

9. a) State Wien's displacement law and its practical implications

b) Use the graph indicated below to answer the questions that follow



i) What does the graph explain?

ii) Explain the spectrum that is found between temperatures of 4000 and 7000 K

iii) Why do you think the three curves have different shapes

10. Discuss any 4 main reasons that brings about variation of sun's Intensity

11. a) Calculate the albedo of a surface that receives 15000 Wm^{-2} and reflects 15 $KW.m^{-2}$.Comment on the surface of that body.

b) Discuss some of the scientific factors that affect planets Albedo

12. a) What do you understand by the following terms?

    i) Climate change as applied in physics

    ii) Greenhouse Effect

    b) With Clear explanations, discuss how Greenhouse effect can be avoided

13. Mutesi a year 3 student in the faculty of engineering in University of Rwanda, found out in her research that a strong metal at 1000K is red hot while at 2000K its white hot. Using the idea of black body, explain this observation.

14. Kamari defined black body as anybody that is black. Do you agree with his definition? If YES why? and if NOT why not? Also sketch curves to show the distribution of energy with wavelength in the radiation from a black body varies with temperature.

15. An electric bulb of length 0.6 m and diameter 5×10^{-5} m is connected to a power source of 50 W. Assuming that the radiation from the bulb is 70% that of a perfect black body radiator at the same temperature, Estimate the steady temperature of the bulb. (Stefan's constant = 5.7×10^{-8} W m ^{2} K^{-4}.)

16. Write short notes about greenhouse effect and explain all its effects.

17. What do you understand by the term greenhouse gases? How do these gases contribute to the global warming?

18. REMA is always advising people to plant more trees and stop cutting the existing ones. Using scientific examples, explain how this is aimed at controlling global warming

19. Explain climate change mitigation and explain why it's important.

20. Explain what happens to most radiation that is absorbed by the surface of earth?

21. Is there a difference between sensible and latent heat?

22. Write short notes on the following terms as applied in climate change

    i) Climate feedback

    ii) Climate lag

    iii) Climate model

23. Plan and write a good composition about causes of climate change and how it can be controlled. (Your essay should bear introduction, body and conclusion)

UNIT 3

APPLICATIONS OF OPTICAL FIBER IN COMMUNICATION SYSTEM

Key Unit Competence:

Evaluate the application of optical fiber transmission and other transmitting systems

Introductory activity

Investigating the use of optical fiber in RWANDA

Rwandan government has started connecting three million people to the World Wide Web as part of the "Internet for All" project. The project is a World Economic Forum initiative that aims to connect 25 million new Internet users in Kenya, Uganda, South Sudan and Rwanda at the beginning of 2019.

This goal will partly be achieved by addressing the challenges of affordability, digital skills gap, lack of local content and limited infrastructure, which are hindering growth in the use of Internet across the region

Fig.3. 1: The installation and use of optical fiber in Rwanda

By using the information provided above, answer to the following questions:

1. Observe the images A, B and C of the figure .3.1 and describe each one.
2. What do you think are the uses of the materials shown in the figure above?

3. By using scientific ideas, explain why one may opt to use the method(s) indicated in the figure above over another.
4. Can you highlight some of the disadvantages of the method of signal transmission shown in the figure above?

3.1. OPTICAL FIBRE

Activity 3.1

Investigating the types of optical fiber.

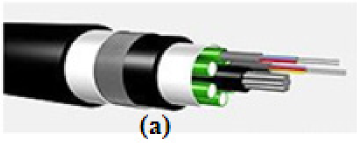
a) Use search on internet or in library, discuss different types of optical fiber.
b) Differentiate them according to their respective uses.

3.1.1 Concept of optical fiber

An optical fiber (fiber optics) is a medium for carrying information from one point to another in the form of light. It uses a flexible, transparent fiber made by drawing glass or plastic and has a diameter slightly thicker than that of a human hair. They are arranged in bundles called **optical cables** and can be used to transmit signals over long distances.

An *optical fiber* is a cylindrical dielectric waveguide (non conducting waveguide) made of low loss material that transmits light along its axis, by the process of total internal reflection. The *fiber* consists of a core surrounded by a cladding layer, both of which are made of dielectric materials.

The Fiber optic cable is made of high-quality extruded glass (si) or plastic, and it is flexible. The diameter of the fiber optic cable is in between 0.25 to 0.5 mm (slightly thicker than a human hair). Fiber optics continues to be used in more and more applications due to its inherent advantages over copper conductors.


(a)

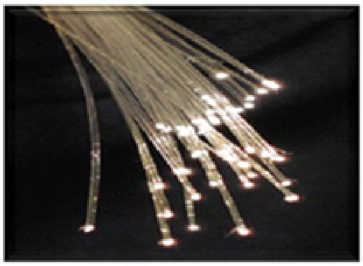

(b)

Fig.3. 2(a) An optical fiber cable and (b) a bundle of optical fibers

An optical fiber essentially consists of three layers *Core*,*Cladding* and *Buffer* coating. The rest of the layers are provided in order to increase the flexibility, strength and protection from external stresses.

- **Core:**

Core is a thin glass/silica at the center of the optical fiber through which light travels. A Glass material with high refractive index is used for this purpose. The core of a fiber cable is a cylinder of plastic that runs all along the fiber cable's length, and offers protection by cladding. The diameter of the core depends on the application used. Due to internal reflection, the light travelling within the core reflects from the core, the cladding boundary. The core cross section needs to be a circular one for most of the applications.

- **Cladding:**

Core is surrounded by a medium, with lesser *refractive index*. Ray of light incident on the core-cladding interface is reflected back into the core. Cladding ensures that no light signal escapes from the optical fiber. Cladding is an outer optical material that protects the core. The main function of the cladding is that it reflects the light back into the core. When light enters through the core (dense material) into the cladding (less dense material), it changes its angle, and then reflects back to the core.

- **Coating:**

The coating is the first non-optical layer around the cladding. The coating typically consists of one or more layers of polymer that protect the silica structure against physical or environmental damage.

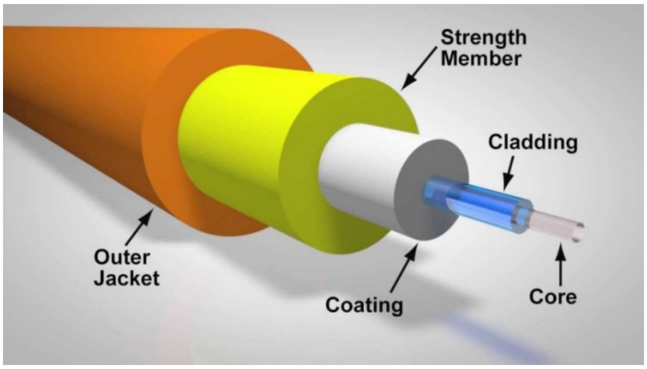


Fig.3. 3the structure of optical fiber

- **Buffer Coating (Strength member)**

The entire structure is protected by a *plastic coating*. It is composed of multiple layers and materials in order to protect from external shocks, moisture, surrounding materials etc. The main function of the buffer is to protect the fiber from damage and thousands of optical fibers arranged in hundreds of optical cables. These bundles are protected by the cable's outer covering that is called jacket.

- **Outer Jacket**

Fiber optic cable's jackets are available in different colors that can easily make us recognize the exact color of the cable we are dealing with. The color **yellow** clearly signifies a single mode cable, and **orange** color indicates multimode.

The light is guided down the core of the fiber by the optical cladding which has a lower refractive index. Remember that the refractive index is the ratio of the velocity of light in a vacuum to its velocity in a specified medium. Then light is trapped in the core through total internal reflection. The other outer parts that are the **strength member** and the **outer jacket,** serve as protectors.

Connecting two optical fibers is done by fusion splicing or mechanical splicing. It requires special skills and interconnection technology due to the microscopic precision required to align the fiber cores.

3.1.2 Types of optical fiber

The properties of data transmission via a fiber optic depend on the core. Hence, based on the differences in the structure of the core, there are three main types of optical fibers:

a. Single mode (monomode) fiber

To understand the behavior of electromagnetic waves in waveguides we use a theory known as mode theory. The mode theory (this is a bit of an oversimplification) essentially classifies electromagnetic waves on the basis of wavelengths into different **modes**. A mode is a stable propagation state (stable operating points or standing waves) in optical fibers.

Single-Mode Fibers: is a single stand of glass fiber with a diameter of $8.3\ \mu m$ to $10\ \mu m$ that has one mode of transmission.Single mode fibers are used to transmit one signal per fiber; these fibers are used in telephone and television sets. Single mode fibers have small cores.

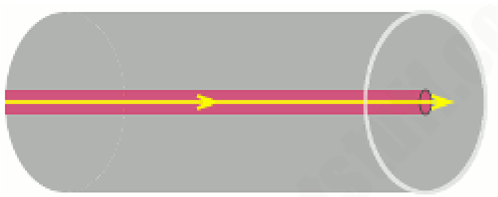


Fig.3. 4 Single mode optical fiber

As the name suggests, this type of optical fiber transmits only one mode of the light. To put it another way, it can carry only one wavelength of light across its length. This wavelength is usually 1310 nm or 1550 nm. Major reasons for this situation are as follows:

- The single mode optical fibers are much better than multimode optical fibers as they have more bandwidth and experience fewer losses of the fiber transmission. So the speed is unmatched.
- Interestingly, single mode fibers came into existence after multimode fibers. They are more recent than the multimode cables.
- These cables can carry only one mode, physically, by having a tiny core. That is to say that the diameter of the core is essentially of the same order as the wavelength of the light passing through it.
- Only lasers are used as a light source. To point out, the light used in single mode fibers are not in the visible spectrum.
- Since the light travels in a straight direction, there are fewer losses, and it can be used in applications requiring longer distance connections.
- An obvious disadvantage of single mode fiber is that they are hard to couple.
- They have a superior transmission quality over other fiber types because of the absence of modal noise.

3.1.3 Multimode optical fiber

Multimode fibers are used to transmit many signals per fiber; these signals are used in computer and local area networks that have larger cores.

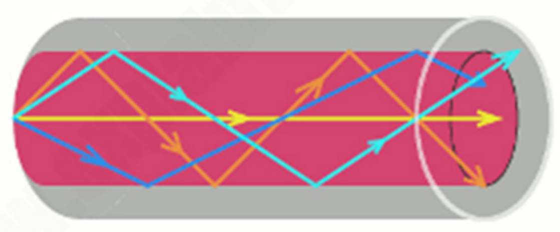


Fig.3. 5 Multimode optical fiber

- As the name implies, these types of optical fibers allow multiple modes of light to travel along their axis.
- To explain physically, they can do this by having a thicker core diameter.
- The wavelengths of light waves in multimode fibers are in the visible spectrum ranging from 850 to 1300 nm.
- The reflection of the waves inside the multimode fiber occurs at different angles for every mode. Consequently, based on these angles the number of reflections can vary.
- We can have a mode where the light passes without striking the core at all.
- We can have a slightly higher mode which will travel with appropriate internal reflections.

- Since the basis of optical fiber communication is a total internal reflection, all modes with incident angles that do not cause total internal reflection get absorbed by the cladding. As a result, losses are created.
- We can have higher order modes, waves that are highly transverse to the axis of the waveguide can reflect many times. In fact, due to increased reflections at unusual angles, higher order modes can get completely lost inside the cable.
- Lower order modes are moderately transverse or even completely straight and hence fare better comparatively.
- There are two types of multimode optical fibers: stepped index and graded index.

a. Stepped index

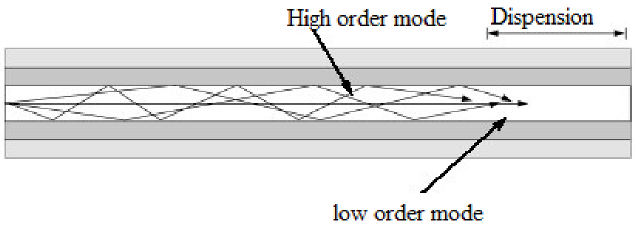


Fig.3. 6 Stepped index multimode

In step-index multimode type, the core has the relatively large diameter of 50 µm and the refractive index of the core is uniform throughout and undergoes an abrupt change (or step) at the cladding boundary.

The wide core allows the infrared to travel by several paths or modes. Paths that cross the core more often are longer, and signals in those modes are take longer to travel along the fiber. Arrival times at the receiver are therefore different for radiation of the same pulse, 30 ns km^{-1}, being a typical difference. The pulse is said to suffer **dispersion,** it means that it is spread out.

b. Graded-index multimode fiber

The core refractive index is made to vary as a function of the radial distance from the center of the fiber.

If you look at the figure of stepped and graded index multimode fibers shown above, you will notice that the waves in stepped index fiber arrive at the same point at different times. This is because multiple modes have different velocities. As a result, outputs are out of sync, and this reduces bandwidth. This is called intermodal dispersion/distortion. However, this issue can be mitigated by using graded index fibers. Since the refractive index changes radially the higher order modes are bent towards the lower order modes and as a result, they are synchronized in time.

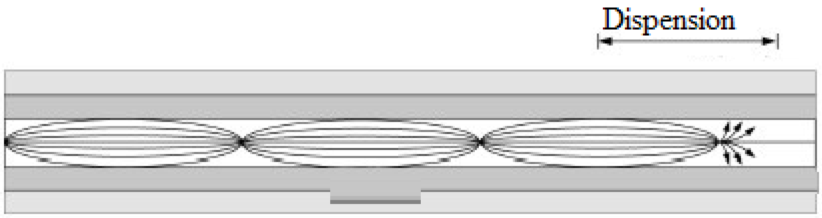


Fig.3. 7 Graded-index multimode

In the **graded index multimode type,** the refractive index of the glass varies continuously from a higher value at the center of the fiber to a low value at the outside, so making the boundary between core and the cladding indistinct. Radiation following a longer path, travel faster on average, since the speed of light is inversely proportional to the refractive index. The arrival times for different modes are the about the same (to within 1ns km^{-1}) and all arrive more or less together at the receiving end. Dispersion is thereby much reduced.

3.1.4 Micro structured optical fibers

These are the new types of optical fiber cables. In ordinary optical fibers mentioned above, light travels due to total internal reflection and refractive indices of the core and cladding. In micro structured optical fibers, the physical structure of the waveguide is used at a nano-scale level to manipulate light.

Different types of micro structured optical fibers are constructed with a non-cylindrical core and/or cladding layer, usually with an elliptical or rectangular cross-section.

These include:

- Polarization-maintaining fiber is a unique type of fiber that is commonly used in fiber optic sensors due to its ability to maintain the polarization of the light inserted into it.
- Photonic-crystal fiber is made with a regular pattern of index variation. It is often in the form of cylindrical holes that run along the length of the fiber. Such fiber uses diffraction effects instead of or in addition to total internal reflection, to confine light to the fiber›s core.
- Air-clad or double clad fibers
- Fresnel fibers

Application activity 3.1

1. Fiber optics is best known for its application in long-distance telecommunications.

   A. True
   B. False

2. Choose the basic types of optical fiber:

A. Single-mode	E. Multi-mode
B. X-mode	F. A and C
C. Microwave-mode	G. B and D
D. Graded-index mode	H. A and E

3. Single-mode fiber has the advantage of greater bandwidth capability. It has the disadvantage of:

   A. Being harder to bend
   B. Smaller mechanical tolerances in connectors and splices
   C. Being difficult to couple light into
   D. B and C
   E. None of the above

4. Describe with the aid of simple ray diagrams:

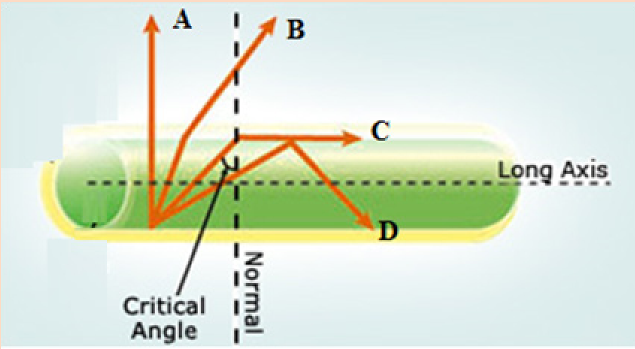
   A. The multimode step index fiber;
   B. The single-mode step index fiber.
   C. Compare the advantages and disadvantages of these two types of fiber for use as an optical channel.

5. Match the words of column A to their meaning of column B

Column A	Column B
1. Multimode fiber	A. The core is only 5µm in diameter, and the only one straight path for transmission.
2. Photonic-crystal fiber	B. Is commonly used in fiber optic sensors due to its ability to maintain the polarization of the light
3. Graded index multimode type	C. Light travels through the fiber following different light paths called “modes
4. Mono mode fiber	D. The refractive index of the glass varies continuously from a higher value at the Centre of the fiber to a low value at the outside,
5. Polarization-maintaining fiber	E. Such fiber uses diffraction effects instead of or in addition to total internal reflection, to confine light to the fiber’s core.

3.2 PRINCIPLE OF OPERATION OF OPTICAL FIBRES

Activity 3.2



Given the illustration above, one can see different rays inside the optical fiber. As the angle of incidence in the core increases, the angle of refraction increases more until it becomes right angle.

Discuss:

1. Name the rays A, B, C and D
2. As observed from the diagram, comment on the cause of different directions of these rays.
3. Explain the scientific name of the angle for ray C to be in the direction indicated in the figure.
4. Explain the scientific phenomenon represented by ray D.
5. Explain any fields where the phenomenon stated in 4) above is applied.

3.2.1 Refractive index of light

When light fall at the interface (boundary) of two media, it is partially reflected and partially refracted. As it passes from one medium to another it changes its direction.

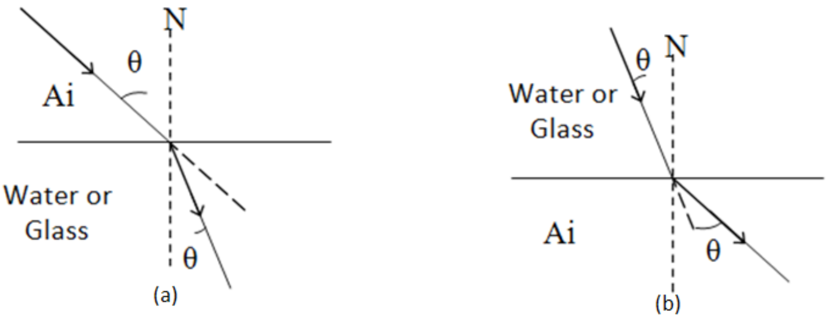


Fig.3. 8: Refraction of light from air to water and water to air for comparison.

The change in its direction is associated with the change in velocity. The ratio of the speed of light in the vacuum c (or air) and that of light in a certain medium v is called the absolute refractive index n.

$$n = \frac{c}{v}$$

3.2.2 Total internal reflection

When light passes from one a medium of higher index of refraction into a medium of lower refractive index the light bends away from the normal as indicated on Fig.3.9. A weak internally reflected ray is also formed and its intensity increases as the incident angle increases.

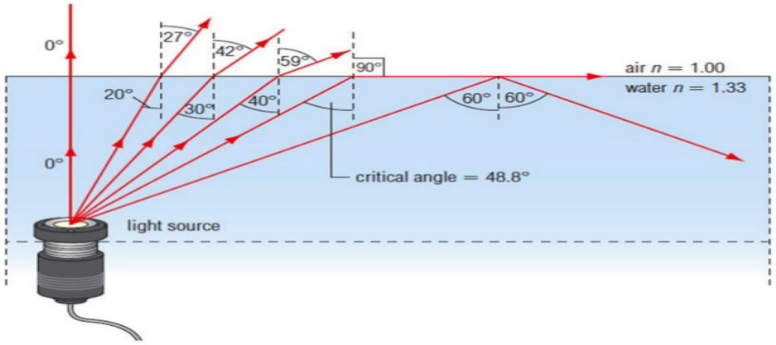


Fig.3. 9: Illustration of total internal reflection

Increasing the angle of incidence increases the angle of refraction and at a particular incidence, the angle of refraction reaches the 90°. This particular incident angle is called the **critical angle** θ_c. As the incident angle exceeds the critical angle, the incident beam reflects on the interface between the 2 media and return in the first medium. This effect is called **total internal reflection**.

For any two media, using Snell's law the critical angle is calculated using the expression

$$\sin\theta_c = \frac{n_2}{n_1}$$

Where n_1 and n_2 are respectively the refractive indices of the first and second media

Example 3.1

Calculate the critical angle of ray at a glass-air boundary if the index of glass is $n_g = 1.50$.

Answer

By definition of critical angle: $\sin\theta_C = \frac{n_a}{n_g} = \frac{1}{3/2} \Leftrightarrow \theta_C = 42^0$

One of the applications of total internal reflection is optical fiber. An optical fiber is basically made of 2 types of glass put together in a concentric arrangement so the middle is hollow. The inner circle of glass also called the **Core** consists of a glass of higher refractive index than the outside layer as indicated on Fig.3.10.

The outer layer of glass, which is also known as the optical **cladding**, does not carry light but is essential to maintain the critical angle of the inner glass.

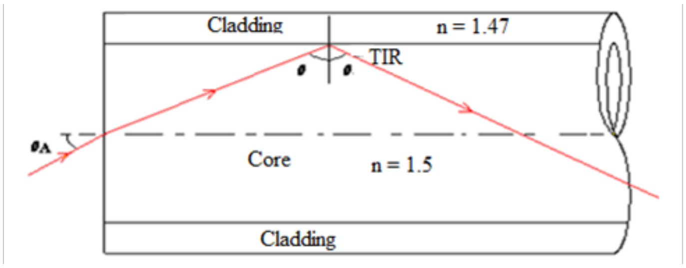


Fig.3. 10: Total internal reflection in optical fiber as the angle of incidence is greater than the critical angle.

The underlying main physics concept behind the functioning of an optical fiber is a phenomenon known as **total internal reflection.** Any light entering the fiber will meet the cladding at an angle greater than the critical angle. If light meets the inner surface of the cladding or the core - cladding interface at greater than or equal to critical angle then total internal reflection (TIR) occurs. So, all the energy in the ray of light is reflected back into the core and none escapes into the cladding. The ray then crosses to the other side of the core and, because the fiber is more or less straight, the ray will meet the cladding on the other side at an angle which again causes the total internal reflection. The ray is then reflected back across the core again and again until it reaches the end of the optical fiber.

A single optical fiber utilizes total internal reflection to transmit light, allowing bends along its path. Minimal light loss during transmission allows optical fibers to transmit light or data quickly over long distances. When bundled, fiberoptics can transmit large quantities of data for telecommunication applications.

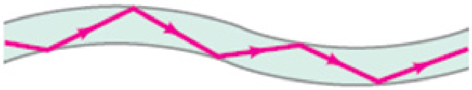


Fig.3. 11 Optical fibers

Optical fibers use multiple total internal reflections to transmit light. They allow signals to travel for long distances without repeaters, which are needed to compensate for reductions in signal strength. Fiber-optic repeaters are currently about 100 km apart, compared to about 1.5 km for electrical systems.

Various consequences of Snell's Law include the fact that for light rays traveling from a material with a high index of refraction to a material with a low index of refraction, it is possible for the interaction with the interface to result in zero transmission. This phenomenon is called **total internal reflection**. As light signals travel down a fiber optic cable, it undergoes total internal reflection allowing for essentially no light lost over the length of the cable.

Maximum angle of incidence

An optical fiber consists of an inner material (the fiber) with refractive index n_f and an outer material of lower refractive index n_c, known as cladding, as in Fig.3.12 below. The purpose of the cladding is to improve the transmission efficiency of the optical fiber. If cladding is not used then the signal is attenuated dramatically.

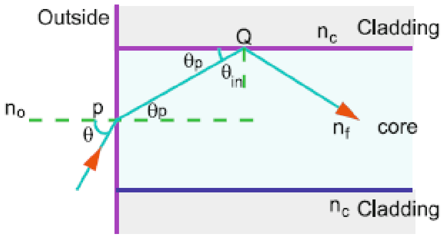


Fig.3. 12 Travelling of light in optical fiber

Let a ray be incident at an angle θ, Fig.3.12, the angle of refraction at P being θ_p
Let C be the critical angle at Q, interface of core and cladding:

Refraction from air to core: $n_0 \sin\theta = n_1 \sin\theta_p \Leftrightarrow \sin\theta_p = \dfrac{\sin\theta}{n_1}$ (1)

Refraction from core to cladding: $n_1 \sin c = n_2 \sin 90 \Leftrightarrow \sin c = \dfrac{n_2}{n_1}$ (2)

Also $\theta_p = 90 - c$ so $\sin\theta_p = \cos c$ (3)

From (1) and (2) and using trigonometrically relation: $\cos^2 c + \sin^2 c = \left(\dfrac{n_2}{n_1}\right)^2 + \left(\dfrac{\sin\theta}{n_1}\right)^2$

Simplifying $\sin\theta = \pm\sqrt{n_1^2 - n_2^2}$

This the **maximum angle of incidence** in air for which all the light is total reflected at the core-cladding.

This shows that there is a maximum angle of acceptance cone outside of which entering rays will not be totally reflected within the fiber. For the largest acceptance cone, it is desirable to choose the index of refraction of the cladding to be as small as possible. This is achieved if there is no cladding at all. However, this leads to other problems associated with the loss of intensity.

The transmission is reduced due to multiple reflections and the absorption of the fiber core material due to impurities.

Example 3.2

A step-index fiber 0.01 cm in diameter has a core index of 1.53 and a cladding index of 1.39. See Fig.3.13. Such clad fibers are used frequently in applications involving communication, sensing, and imaging. What is the maximum acceptance angle θ_m for a cone of light rays incident on the fiber face such that the refracted ray in the core of the fiber is incident on the cladding at the critical angle?

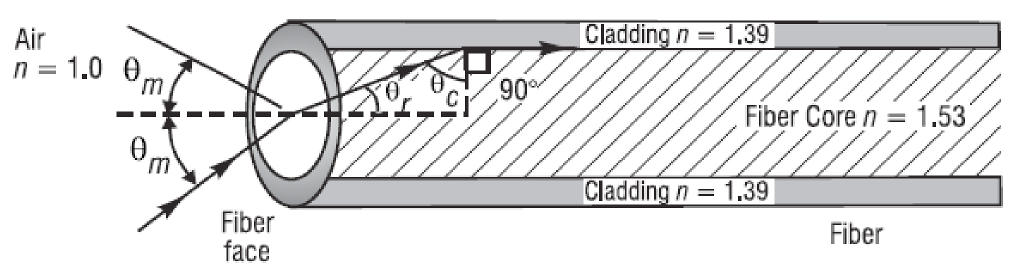


Fig.3. 13 Paths of light in optical fiber

Answer:

First find the critical angle θ_c in the core, at the core-cladding interface. Then, from geometry, identify θ_r and use Snell's law to find θ_m.

1. Refraction from the core to cladding interface: $\sin\theta_c = \frac{1.39}{1.53} \Rightarrow \theta_c = 65.3^0$

2. From right-triangle geometry, $\theta_r = 90 - 65.3 = 45.7^o$

3. From Snell's law, at the fiber face, $n_{air}\sin\theta_m = n_{core}\sin\theta_r \Leftrightarrow \frac{\sin\theta_m}{\sin r} = \frac{n_{core}}{n_{air}}$

Hence $\sin\theta_m = \frac{n_{core}}{n_{air}} = \frac{1.53}{1.00}\sin 45.7^0 \Rightarrow \theta_c = 39.7^0$

Thus, the maximum acceptance angle is 39.7° and the acceptance cone is twice that, $2\theta_m = 79.4^0$.

The acceptance cone indicates that any light ray incident on the fiber face within the acceptance angle will undergo total internal reflection at the core-cladding face and remain trapped in the fiber as it propagates along the fiber.

Application activity 3.2

1. Operation of optical fiber is based on:

   A. Total internal reflection

   B. Total internal refraction

   C. Snell's law

   D. Einstein's theory of reality

   E. None of the above

2. When a beam of light passes through an optical fiber

   A. Rays are continually reflected at the outside(cladding) of the fiber

   B. Some of the rays are refracted from the core to the cladding

   C. The bright beam coming out of the fiber is due to the high refractive index of the core

   C. The bright beam coming out of the fiber is due to the total internal reflection at the core-cladding interface

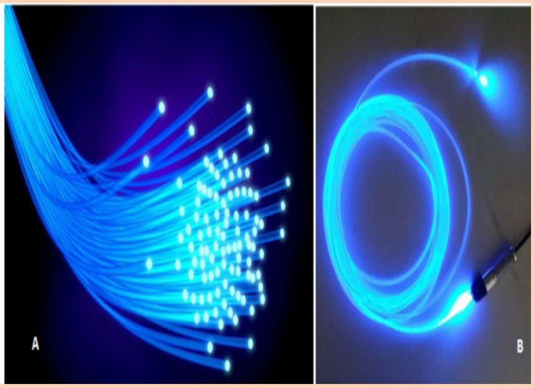
   E. All the rays of light entering the fiber are totally reflected even at very small angles of incidence

3. A laser is used for sending a signal along a mono mode fiber because
   A. The light produced is faster than from any other source of light
   B. The laser has a very narrow band of wavelengths
   C. The core has a low refractive index to laser light
   D. The signal is clearer if the cladding has a high refractive index
   E. The electrical signal can be transferred quickly using a laser
4. Given that the refractive indices of air and water are 1 and 1.33 respectively, find the critical angle.
5. A beam of light is propagating through diamond, n = 2.42 and strikes a diamond-air interface at an angle of incidence of 28°.
   a) Will part of the beam enter the air or will the beam be totally refracted at the interface?
   b) Repeat part (a) assuming that diamond is surrounded by water, n = 1.33
6. A beam of light passes from water into polyethylene (n = 1.5). If the $\theta_i = 57.5^0$, What is the angle of refraction?
7. (a) What is the critical angle when light is going from a diamond (n = 2.42) to air?

   (b) Using the answer to (a), what happens when:
   i) The angle of incidence is less than that angle?
   ii) The angle of incidence is more than that angle?

3.3. MECHANISM OF ATTENUATION AND LIGHT SCATTERING

Activity 3.3



The image above is a section of optical fiber. Imagining that it is transmitting signal over a long distance,

a) Do you think all the fed signal can reach the destination? Defend your reasoning.
b) If no, what do you think causes the loss in the signal transmission?
c) Suggest measures that should be done to minimize the energy loss during transmission.

3.3.1 Mechanism of attenuation

Attenuation in fiber optics, also known as **transmission loss**, is the reduction in intensity of the light beam (or signal) as it travels through the transmission medium. Over a set distance, fiber optic with a lower attenuation will allow more power to reach its receiver than a fiber with higher attenuation.

Attenuation can be caused by several factors both extrinsic and intrinsic:

- Intrinsic attenuation is due to something inherent to the fiber such as impurities in the glass during manufacturing. The interaction of such impurities with light results in the scattering of light or its absorption.
- Extrinsic attenuation can be caused by microbending and microbending. A bent imposed on an optical fiber produce a strain in that region of the fiber and affects its refractive index and the critical angle of the light ray in that area. Microbending that is a large-scale bent and microbending which is a small-scale bent and very localized are external causes that result in the reduction of optical power.

Attenuation coefficients in fiber optics usually are expressed decibels per kilometer (*dB/km*) through the medium due to the relatively high quality of transparency of modern optical transmission media. It is observed that the attenuation is a function of the wavelength of the light. The attenuation $\alpha_{tot}(\lambda)$ at wavelength λ of a fiber between two cross-sections, *1* and *2*, separated by distance *L*is defined, as

$$\alpha_{tot}(\lambda) = \frac{10}{L}\log\frac{P_1(\lambda)}{P_2(\lambda)}$$

where $P_1(\lambda)$ optical power at the cross-section *1*, and $P_2(\lambda)$ the optical power at the cross-section *2*.

Attenuation is an important limiting factor in the transmission of a digital signal across large distances. Thus, much research has gone into both limiting the attenuation and maximizing the amplification of the optical signal.

Example 3.3

When the mean optical power launched into an 8 km length of fiber is $120\ \mu W$, the mean optical power at the fiber output is $3\ \mu W$. Determine:

a. The overall signal attenuation or loss in decibels through the fiber assuming there are no connectors or splices;
b. The signal attenuation per kilometre for the fiber.
c. The overall signal attenuation for a 10 km optical link using the same fiber with splices at 1 km intervals, each giving an attenuation of 1 dB;
d. The numerical input/output power ratio in (c).

Answer:

a. The overall signal attenuation in decibels through the fiber is:

Signal attenuation $\alpha_{tot} = 10\log\frac{P_i(\lambda)}{P_0(\lambda)} = 10\log\frac{120\times10^{-6}}{3\times10^{-6}} = 16.0\ dB$

b. The signal attenuation per kilometre for the fiber may be simply obtained by dividing the result in (a) by the fiber length which corresponds to it where:

The signal attenuation per length L is $\alpha = \frac{10}{L}\log\frac{P_i(\lambda)}{P_0(\lambda)} = \frac{10}{8}\log\frac{120\times10^{-6}}{3\times10^{-6}} = 2.0\ dB/km$

c. As $\alpha = 2.0\ dB/km$ then the loss incurred along 10 km of the fiber is given by

$$\alpha_{tot} = 2.0\ dB/km \times 10\ km = 20\ dB$$

d. However, the link also has nine splices (at 1 km intervals) each with an attenuation of 1 dB. Therefore, the loss due to the splices is 9 dB. Hence, the overall signal attenuation for the link is: Signal attenuation $\alpha = 20 + 9 = 29\ dB$

To obtain a numerical value for the input/output power ratio, the relation

Signal attenuation $\alpha = 10 \log \frac{P_i}{P_0}$ can be equal to $\frac{P_I}{P_0} = 10^{\frac{\alpha}{10}}$

Hence $\frac{P_1}{P_0} = 10^{\frac{29}{10}} = 794.3$

3.3.2 Light scattering and absorption

In the light transmission of signals through optical fibers, attenuation occurs due to light scattering and absorption of specific wavelengths, in a manner similar to that responsible for the appearance of color.

a. Light scattering

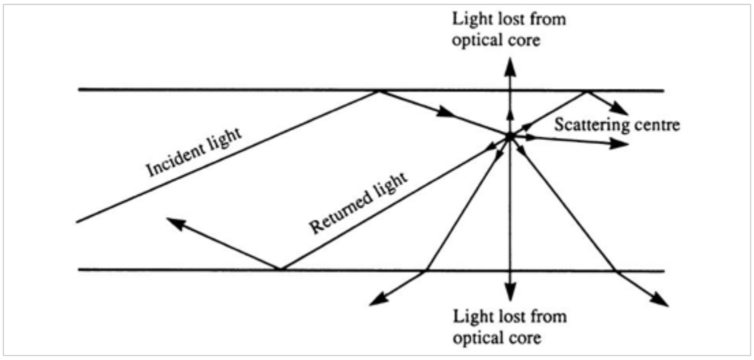


Fig.3. 14: Light scattering in optical fiber.

The propagation of light through the core of an optical fiber is based on total internal reflection of the light wave. Rough and irregular surfaces, even at the molecular level, can cause light rays to be reflected in random directions as it is illustrated on Fig.3.14. This is called diffuse reflection or scattering, and it is typically characterized by wide variety of reflection angles.

Light scattering depends on the wavelength of the light being scattered. Thus, limits to spatial scales of visibility arise, depending on the frequency of the incident light-wave and the physical dimension (or spatial scale) of the scattering center, which is typically in the form of some specific micro-structural feature. Since visible light has a wavelength of the order of one micrometer (one millionth of a meter) scattering centers will have dimensions on a similar spatial scale. Thus, attenuation results from the incoherent scattering of light at internal surfaces and interfaces.

b. Light absorption

Material absorption is a loss mechanism related to the material composition and fiber fabrication process. This results in the dissipation of some transmitted optical power as heat in the waveguide. Absorption is classified into two basic categories: Intrinsic and extrinsic absorptions. (John, 2009)

- Intrinsic absorption: is caused by basic fiber material properties. If an optical fiber is absolutely pure, with no imperfections or impurities, ten all absorption will be intrinsic. Intrinsic absorption in the ultraviolet region is caused bands. Intrinsic absorption occurs when a light particle (photon) interacts with an electron and excites it to a higher energy level.
- Extrinsic absorption is caused by impurities caused by impurities introduced into the fiber material. The metal impurities such as iron, nickel and chromium are introduced into the fiber during fabrication. Extrinsic absorption is caused by electronic transition of these metal ions from one energy level to another level.

3.3.3 Measures to avoid Attenuation

The transmission distance of a fiber-optic communication system has traditionally been limited by fiber attenuation and by fiber distortion.

- **Repeaters:** Repeaters convert the signal into an electrical signal, and then use a transmitter to send the signal again at a higher intensity than was received, thus counteracting the loss incurred in the previous segment. They mostly used to be installed about once every 20 km.
- **Regenerators:** Optical fibers link, in common with any line communication system, have a requirement for both jointing and termination of the transmission medium. When a communications link must span at a larger distance than existing fiber-optic technology is capable of, the signal must be regenerated at intermediate points in the link by optical communications repeaters called regenerators. An optical regenerator consists of optical fibers with special coating (doping). The doped portion is pumped with a laser. When the degraded signal comes into the doped coating, the energy from the laser allows the doped molecules to become lasers themselves. The doped molecules then emit a new strong light signal with the same characteristics as the incoming weak signal. Basically, the regenerator is a laser amplifier for the incoming signal.
- **Optical Amplifiers:** Another approach is to use an optical amplifier which amplifies the optical signal directly without having to convert the signal into the electrical domain. It is made by doping a length of fiber with the rare-earth mineral erbium and pumping it with light from a laser with a shorter wavelength than the communications signal (typically 980 nm). Amplifiers have largely replaced repeaters in new installations.

Application activity 3.3

1. For each of the statements below, indicate **true** if it is correct and **false** if it is wrong

A. One of the reasons fiber optics hasn't been used in more areas has been the improvement in copper cable such as twisted pair.

B. With current long-distance fiber optic systems using wavelength-division multiplexing, the use of fiber amplifiers has become almost mandatory.

C. Fiber optics has extraordinary opportunities for future applications because of its immense bandwidth.

2. (a) What do we mean by attenuation in optical fibers?

   (b) State two ways in which energy is lost in optical fibers.

   (c) If a fiber loses 5% of its signal strength per kilometer, how much of its strength would be left after 20 km?

3.4 OPTICAL FIBRE COMMUNICATION

Activity 3.4

With the basic information you know about the functioning process of optical fiber, answer to the following questions:

1. Where does the light that is transmitted into the optical fiber core medium come from?
2. What are the type compositions of the light signal propagating into optical fiber?
3. Discuss and explain the function principle of signal generators and signal receivers of light from optical fibers.

3.4.1 Basic Fiber Optic Communication System

Even without defining information formally, we intuitively understand that speech, audio, and video signals contain information. We use the term ***message signals***for such signals, since these are the messages we wish to convey over a communication system. In their original formboth during generation and consumptionthese message signals are ***analog****:* they are continuous time signals, with the signal values also lying in a continuum. When someone plays the violin, an analog acoustic signal is generated (often translated to an analog electrical signal using a microphone). Even when this music is recorded onto a digital storage medium such as a CD (using the digital communication), when we ultimately listen to the CD being played on an audio system, we hear an analog acoustic signal. The transmitted signals corresponding to physical communication media are also analog. For example, in both wireless and optical communication, we employ electromagnetic waves, which correspond to continuous time electric and magnetic fields taking values in a continuum.

In all of these instances, the key steps in the operation of a communication link are as follows:

a. insertion of information into a signal, termed the ***transmitted signal***, compatible with the physical medium of interest;

b. propagation of the signal through the physical medium (termed the ***channel)*** in space or time;

c. Extraction of information from the signal (termed the ***received signal)*** obtained after propagation through the medium.

For gigabits and beyond gigabits transmission of data, the fiber optic communication is the ideal choice. This type of communication is used to transmit voice, video, telemetry and data over long distances and local area networks or computer networks. A Fiber Optic Communication System uses light wave technology to transmit the data over a fiber by changing electronic signals into light.

Some exceptional characteristic features of this type of communication system like large bandwidth, smaller diameter, light weight, long distance signal transmission, low attenuation, transmission security, and so on make this communication a major building block in any telecommunication infrastructure. The subsequent information on fiber optic communication system highlights its characteristic features, basic elements and other details.

3.4.2 Block diagram of Fiber Optic Communication

Unlike copper wire based transmission where the transmission entirely depends on electrical signals passing through the cable, the fiber optics transmission involves transmission of signals in the form of light from one point to the other. Furthermore, a fiber optic communication network consists of **transmitting** and **receiving circuitry**, **a light source** and **detector devices** like the ones shown in the Fig.3.15.

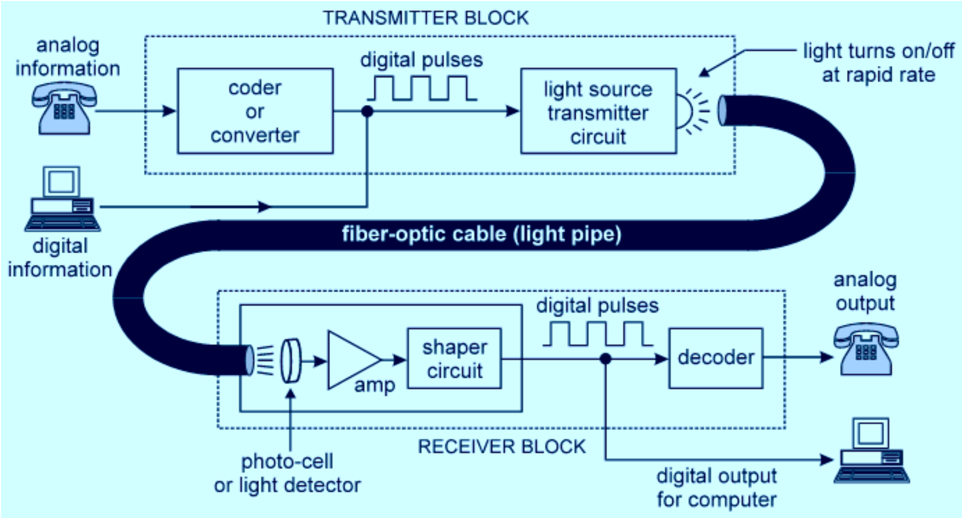


Fig.3. 15 Block diagram of Fiber optic communication

The basic components are light signal transmitter, the optical fiber, and the photo detecting receiver.

The additional elements such as fiber and cable splicers and connectors, regenerators, beam splitters, and optical amplifiers, switches, couplers, multiplexing devices, amplifiers and splices are employed to improve the performance of the communication system.

When the input data, in the form of electrical signals, is given to the **transmitter circuit** (Fig.3.15), it converts them into light signal with the help of a light source. This source is of LED whose amplitude, frequency and phases must remain stable and free from fluctuation in order to have efficient transmission. The light beam from the source is carried by a **fiber optic cable** to the destination circuitry wherein the information is transmitted back to the electrical signal by a receiver circuit.

Fiber optic communication system consists of transmitter, optical fiber, optical regenerator and finally a receiver as shown in the following figure.

- **Transmitter block**

Transmitter is the first stage of the optical fiber communication system. It consists of a light source which converts electric signals into light signals and a focusing lens is used to focus the light beam into the optical fiber. Both *Lasers* and **LEDs** can be used as a light source. Lasers have more power than LEDs, but its characteristics vary with changes in temperature.

- **Optical fiber**

Light signal from the transmitter is given into the optical fiber. Signal is propagated through it by multiple *internal reflections*.

- **Optical regenerator**

When light passes through the optical fiber, the signal may get distorted due to the presence of impurities in the core. Distance to which the light signal can propagate through the fiber depends on the purity of the glass and the wavelength of the transmitted light. Therefore, to improve the transmission distance, Optical regenerators must be used at regular intervals. One or more optical regenerators are used to boost the degraded light signals in the optical communication system. In certain systems, the feeble optical signals are converted back into electrical signals and the optical data is reconstructed as in the case of a transmitter. Optical regenerators are also called *laser amplifiers*. They are optical fibers with a special coating (doping). When degraded signal comes into the doped coating, the energy from the laser allows the doped molecules to become lasers themselves. Thus degraded light signal will get amplified and propagate further.

- **Optical receiver**

Optical receiver receives light signals which it converts back to electrical signals. Receiver uses a *photocell* or **photodiode** to detect the light and convert it to proportional electric signals, which is capable of measuring magnitude, frequency and phase of the optic field. This type of communication uses the wave lengths near to the infrared band that are just above the visible range.

Two types of photo detectors are mainly used for optical receiver in optical communication system: PN photo diode and avalanche photo diode. Depending on the application's wavelengths, the material composition of these devices varies. These materials include silicon, germanium, InGaAs, etc

Both LED and Laser can be used as light sources based on the application.

- **Compact Light Source**

Depending on the applications like local area networks and the long haul communication systems, the light source requirements vary. The requirements of the sources include power, speed, spectral line width, noise, ruggedness, cost, temperature, and so on. Two components are used as light sources: light emitting diodes (LED's) and laser diodes.

The **light emitting diodes** are used for short distances and low data rate applications due to their low bandwidth and power capabilities. Two such LEDs structures include Surface and Edge Emitting Systems. The surface emitting diodes are simple in design and are reliable, but due to its broader line width and modulation frequency limitation edge emitting diode are mostly used. Edge emitting diodes have high power and narrower line width capabilities.

For longer distances and high data rate transmission, **Laser Diodes** are preferred due to its high power, high speed and narrower spectral line width characteristics. But these are inherently non-linear and more sensitive to temperature variations.

Both these sources are modulated using either direct or external modulation techniques.

3.4.3 Uses of optical fibers

a. Telecommunications Industry

Optical fibers offer huge communication capacity. The latest generations of optical transmission systems are beginning to exploit a significant part of this huge capacity, to satisfy the rapidly growing demand for data communications and the Internet.

Some of them are as follows

- Used in telephone systems
- Used in sub-marine cable networks
- Used in data link for computer networks, CATV Systems
- Used in CCTV surveillance cameras
- Used for connecting fire, police, and other emergency services.

The main advantages of using optical fibers in the communications industry are:

- A much greater amount of information can be carried on an optical fiber compared to a copper cable.
- In all cables some of the energy is lost as the signal goes along the cable. The signal then needs to be boosted using regenerators. For copper cable systems these are required every 2 to 3km but with optical fiber systems they are only needed every 50 km.
- Unlike copper cables, optical fibers do not experience any electrical interference. Neither will they cause sparks so they can be used in explosive environments such as oil refineries or gas pumping stations.
- For equal capacity, optical fibers are cheaper and thinner than copper cables and that makes them easier to install and maintain.

b. Medicine Industry

The advent of practicable optical fibers has seen the development of much medical technology. Optical fibers have paved the way for a whole new field of surgery, called laproscopic surgery (or more commonly, keyhole surgery), which is usually used for operations in the stomach area such as appendectomies. Keyhole surgery usually makes use of two or three bundles of optical fibers. A “bundle” can contain thousands of individual fibers”. The surgeon makes a number of small incisions in the target area and the area can then be filled with air to provide more room.

One bundle of optical fibers can be used to illuminate the chosen area, and another bundle can be used to bring information back to the surgeon. Moreover, this can be coupled with laser surgery, by using an optical fiber to carry the laser beam to the relevant spot, which would then be able to be used to cut the tissue or affect it in some other way.

3.4.4 Block Diagrams of Telecommunication

The elements of basic communication system are as follows

- **Information or input signal:**

Information is any entity or form that resolves uncertainty or provides the answer to a question of some kind. It is thus related to data and knowledge, as data represents values attributed to parameters, and knowledge signifies understanding of real things or abstract concepts. The information can be in the form of sound signal like speech or music or it can be in the form of pictures, words, group of words, code, symbols, sound signal etc. However, out of these messages, only the desired message is selected and communicated**.** Therefore, we can say that the function of information source is to produce required message which has to be transmitted

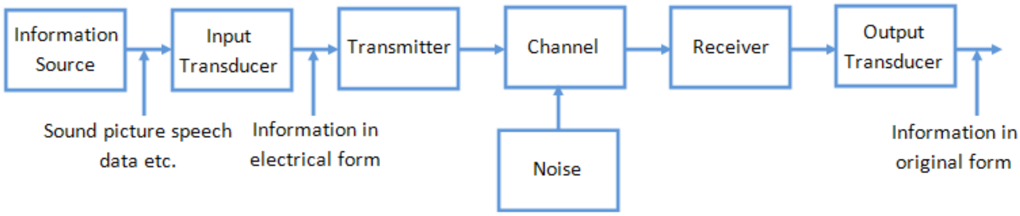


Fig.3. 16 Block-diagram of communication system with input and output transducers

A message is a term standing for information put in an appropriate form for transmission. Each message contains information. A message can be either **analog message (**a physical time variable quantity usually in smooth and continuous form) or **a digital message (**anordered sequence of symbols selected from finite set of elements) as shown in Fg.3.16.

A signal is a mathematical function representing the time variation of a physical variable characterizing a physical process and which, by using various models, can be mathematically represented. In telecommunication, the message is also known as a signal and the signal is transmitted in an electrical or voltage form i.e. Signal ≈ Message

- **Input Transducer.**

A transducer is a device which converts one form of energy into another form. The information in the form of sound, picture or data signals cannot the transmitted as it is. First it has to be converted into a suitable electrical signal. The input transducers commonly used in the communication systems are microphones, TV etc. For example, in case of radio-broadcasting, a microphone converts the information or massage which is in the form of sound waves into corresponding electrical signal.

- **Transmitter:**

The function of the transmitter block is to convert the electrical equivalent of the information to a suitable form. It increases the power level of the signal. The power level should be increased in order to cover a large range. The transmitter consists of the electronics circuits such as:

- **Mixer**
- **The oscillators** are the sources of carrier signals which are used to modulate and help the original signal to reach the destination
- **Amplifiers:** The signal normally, must be raised at a level that will permit it to reach its destination. This operation is accomplished by **amplifiers**
- **antenna**

- **Communication channel or medium:**

The communication channel is the medium used for the transmission of electronic signals from one place to another. The communication medium can be conducting wires, cables, optical fibres or free space. Depending upon the type of the communication medium, two types of the communication system will exist: Wire communication or line communication and Wireless communication or radio communication

The term channel means the medium through which the message travels from the transmitter to the receiver. In other words, we can say that the function of the channel is to provide a physical connection between the transmitter and the receiver.

There are two types of channels, namely point-to-point channels and broadcast channels.

Examples of point-to-point channels are wire lines, microwave links and optical fibres.

- **Wire-lines** operate by guided electromagnetic waves and they are used for local telephone transmission.
- In case of **microwave links**, the transmitted signal is radiated as an electromagnetic wave in free space. Microwave links are used in long distance telephone transmission.
- An **optical fibre** is a low-loss, well-controlled, guided optical medium. Optical fibres are used in optical communications.

Although these three channels operate differently, they all provide a physical medium for the transmission of signals from one point to another point. Therefore, for these channels, the term point-to-point is used.

On the other hand, the broadcast channel provides a capability where several receiving stations can be reached simultaneously from a single transmitter. An example of a broadcast channel is a satellite in geostationary orbit, which covers about one third of the earth's surface.

During the process of transmission and reception the signal gets distorted due to noise introduced in the system. Noise is an unwanted electrical signal which gets added to the transmitted signal when it is travelling towards receiver. Due to noise, the quality of the transmitted information will degrade. One added the noise cannot be separated out from the information. Hence noise is a big problem in the communication systems.

- **Receiver**

The reception is exactly the opposite process of transmission. The received signal is amplified and demodulated and converted in a suitable form. The receiver consists of the electronic circuits like mixer, oscillator, detector,amplifier and antenna.The main function of the receiver is to reproduce the message signal in electrical form from the distorted received signal. This reproduction of the original signal is accomplished by a process known as the **demodulation** or **detection.** Demodulation is the reverse process of modulation carried out in transmitter.

- **Output Transducer**

Destination is the final stage which is used to convert an electrical message signal into its original form. Output Transducer consists of the electrical signal at the output of the receiver back to the original form i.e. sound or TV pictures. The typical examples of the output transducers are loud speakers, picture tubes etc.For example, in radio broadcasting, the destination is a loudspeaker which works as a transducer i.e. converts the electrical signal in the form of original sound signal.

- **Types of Antenna**

Antennas are essential components of all equipment which are used in radio. They are used in broadcasting systems, broadcast television systems, two-way radio systems, communications receiver's systems, radar systems, cell phones systems, and satellite communications systems, garage door openers systems, wireless microphones systems, Bluetooth enabled devices systems, wireless computer networks systems, baby monitors systems, and Radio Frequency Identification (RFID) tags systems on merchandise etc.

An antenna or aerial is an electrical device connected (often through a transmission line) to the receiver or transmitter which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an oscillating radio frequency electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, which is fed to a receiver to be amplified.

In radio wave communication system, antennas are used at both transmitter and receiver end. At the transmitter end, output from the transmitter is fed into the antenna which launches the radio waves into space. At the receiver end, antenna picks up as much of the transmitter's power as possible. Size and construction of antenna depends on the *frequency* that it deals with. An antenna consists of an arrangement of *metallic conductors*. High frequency electric current fed to these cause free electrons to vibrate at very high frequency resulting in the electromagnetic radiation. There are a very large variety of antennas used in telecommunication. Here we can discuss at least four types of antenna among others.

- **Wire antennas**

The wire antennas are dipole, monopole, loop antenna, helix and are usually used in personal applications, automobiles, buildings, ships, aircrafts and super crafts.

Fig.3. 17 Wire antenna

- **Aperture antennas**

These are horn antennas and waveguide opening and they are usually used in aircrafts and space crafts because they are flush-mounted.

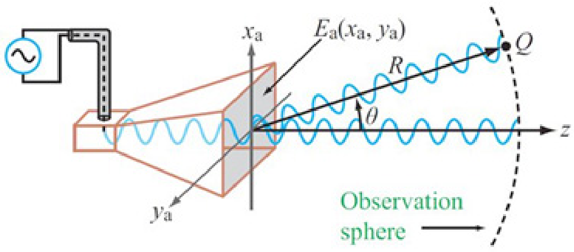


Fig.3. 18 A horn antenna with aperture field distribution

- **Reflector antennas**

These are parabolic reflectors and corner reflectors and they are high gain antennas usually used in radio astronomy, microwave communication and satellite tracking.

Fig.3. 19 Reflector antenna

- **Array antennas**

These are also called Yagi-Uda antennas or micro-strip patch arrays or aperture arrays, slotted waveguide arrays. They are suitable for very high gain applications with added advantage, such as, controllable radiation pattern.

Fig.3. 20 Array antenna

3.4.5 Advantages and desadvantages of optical fiber

- Advantages of optical fibers are:

- The power loss is very low and hence helpful in long-distance transmissions.
- Fiber optic cables are immune to electromagnetic interference.
- These are not affected by electrical noise.
- The capacity of these cables is much higher than copper wire cables.
- Since these cables are di-electric, no spark hazards are present.
- These cables are more corrosion resistant than copper cables, as they are bent easily and are flexible.
- The raw material for the manufacture of fiber optic cables is glass, which is cheaper than copper.
- Fiber optic cables last longer than copper cables.

- **Capacity:** Optical fibers carry signals with much less energy loss than copper cable and with a much higher bandwidth. This means that fibers can carry more channels of information over longer distances and with fewer repeaters required.
- **Size and weight:** Optical fiber cables are much lighter and thinner than copper cables with the same bandwidth. This means that much less space is required in underground cabling ducts. Also they are easier for installation engineers to handle.
- **Security:** Optical fibers are much more difficult to tap information from undetected; a great advantage for banks and security installations. They are immune to electromagnetic interference from radio signals, car ignition systems, lightning etc. They can be routed safely through explosive or flammable atmospheres, for example, in the petrochemical industries or munitions sites, without any risk of ignition.
- **Running costs:** The main consideration in choosing fiber when installing domestic cable TV networks is the electric bill. Although copper coaxial cable can handle the bandwidth requirement over the short distances of a housing scheme, a copper system consumes far more electrical power than fiber, simply to carry the signals.

▪ Disadvantages

Although there are many benefits to using optical fibers, there are also some disadvantages as discussed below:

- Though fiber optic cables last longer, the installation cost is high.
- The number of repeaters is to be increased with distance.
- They are fragile if not enclosed in a plastic sheath. Hence, more protection is needed than copper ones.
- **Price:** In spite of the fact that the raw material for making optical fibers, sand, is abundant and cheap, optical fibers are still more expensive per meter than copper. Having said this, one fiber can carry many more signals than a single copper cable and the large transmission distances mean that fewer expensive repeaters are required.
- **Special skills:** Optical fibers cannot be joined together (spliced) as an easily as copper cable and requires additional training of personnel and expensive precision splicing and measurement equipment.

Application activity 3.4

1. Circle the three basic components in a fiber optic communications system.

   A. Telescope
   B. Transmitter
   C. Receiver
   D. Surveillance satellites
   E. Maser fiber
   F. Optical fiber
   G. Alternator

2. Information (data) is transmitted over optical fiber by means of:

   A. Light
   B. Radio waves
   C. Cosmic rays
   C. Acoustic waves
   D. None of the above

3. The basic unit of digital modulation is:

   A. Zero
   B. One
   C. Two
   D. A and B
   E. None of the above

4. For each of the statements below, indicate true if it is correct and false if it is wrong

   A. Connectors and splices add light loss to a system or link.
   B. The replacement of copper wiring harnesses with fiber optic cabling will increase the weight of an aircraft.

5. 5. List two advantages and disadvantages of using optical fiber.

6. (a) Explain the optical transmitter and receiver in optical fiber transmission system.

   (b) Explain attenuation and state the measures to avoid it in optical fiber transmission system.

Skills Lab 3

In this activity you will demonstrate on how a signal can be transmitted using water.It's best to do it in a darkenedbathroom or kitchen at the sink or washbasin.

You'll need an old clear, plastic drinks bottle, the brightest flashlight (torch) you can find, some aluminium foil, and some sticky tape.

a. Take the plastic bottle and wrap aluminium foil tightly around the sides, leaving the top and bottom of the bottle uncovered. If you need to, hold the foil in place with sticky tape.

b. Fill the bottle with water.

c. Switch on the flashlight and press it against the base of the bottle so the light shines up inside the water. It works best if you press the flashlight tightly against the bottle. You need as much light to enter the bottle as possible, so use the brightest flashlight you can find.

d. Standing by the sink, tilt the bottle so the water starts to pour out. Keep the flashlight pressed tight against the bottle. If the room is darkened, you should see the spout of water lighting up ever so slightly. Notice how the water carries the light, with the light beam bending as it goes! If you can't see much light in the water spout, try a brighter flashlight.

End of unit 3 assessment

1. Which of the following is the most effective carrier of information?

   A. Cables　　　C . Microwaves

   B. Radio waves　　　D. Optical fibers

2. (a) An endoscope uses coherent and non-coherent fiber bundle

   i) State the use of the coherent bundle and describe its arrangement of fibers.

   ii) State the use of the non-coherent bundle and describe its arrangement of fibers.

   (b) Each fiber has a core surrounded by cladding. Calculate the critical angle at the core-cladding interface. Refractive index of core is 1.52 and Refractive index of cladding is 1.

3. (a) Fig.3.21 shows a ray of light travelling through an individual fiber consisting of cladding and a core. One part has a refractive index of 1.485 and the other has a refractive index of 1.511.

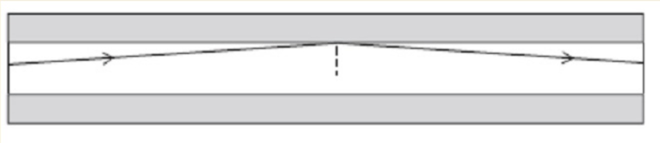


Fig.3. 21: Light transmission in optical fiber.

i) State which part of the fiber has the higher refractive index and explain why.

ii) Calculate the critical angle for this fiber.

(b) The figure below shows the cross-section through a clad optical fiber which has a core of refractive index 1.50.

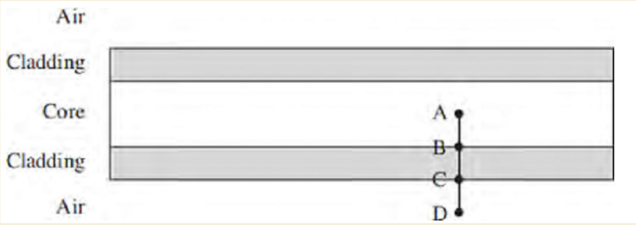


Fig.3. 22

Complete the graph below to show how the refractive index changes with the radial distance along the line ABCD in the figure above.

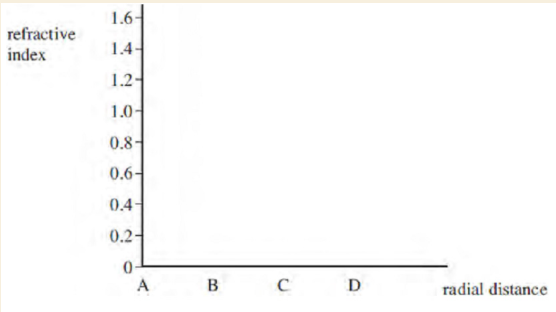


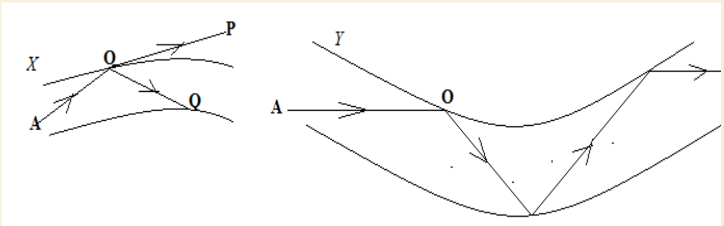
Fig.3. 23: Axes for the half-life decay curve

4. State and explain the measures to avoid the attenuation in optical fiber transmission system
5. Estimate the length of time it would take a fiber optic system to carry a signal from the UK to the USA under the Atlantic. (Take $c = 2\times10^{8}\ m/s$ in the cable. Estimate the length of the cable under the sea, $d_{USA-UK} = 50\,000\ km$)

a. Estimate the length of time it would take a microwave signal to travel from the UK to the USA a satellite Enk. (Geosynchronous satellites orbit at a height of about 86 000 km above the Earth's surface.

b. Which would give less delay in a telephone conversation?

6. Write in your own words the description of step index fiber and graded index fiber
7. One kind of optical fiber consists of two very thin rods one inside the other.



i) Explain why only a small amount of light is piped trough the fiber in X.

ii) Why does the light travel along the fiber in Y without losing its intensity.

iii) State how the inner and outer surfaces differ in their refractive indices.

iv) Why is a fiber coated with a layer of plastic?

v) State two applications of optical fibers.

8. Do fiber optics transmit radiations?

UNIT 4

NATURE OF PARTICLES AND THEIR INTERACTIONS

Key Unit Competence:

Classify the nature of particles and their interactions

Introductory activity

In the study of matter description and energy as well as their interactions; the fascinating thing of discovery is the structure of universe of unknown radius but still to know the origin of matter one need to know about small and smallest composites of matter.

a) Basing on the text above, what are the smallest particles in the universe you know as of now?
b) Are those particles mentioned in a) above, have the same mass? If no, what causes the difference in masses?
c) Basing on your submission in a) above do those particles interact? If not, why not? If yes, how do they interact?
d) Scientifically, how would you classify these particles?

4.1 FUNDAMENTAL PARTICLES

Activity 4.1

a) From your knowledge and understanding about atom in chemistry, can you define an atom?
b) State all the particles you think make up an atom
c) Can you suggest a scientific name that may be used to describe these particles?

The idea that the world is made of fundamental particles has a long history. In about 400 B.C. The Greek philosophers **Democritus** and **Leucippus** suggested that **matter is made of indivisible particles** that they called **atoms**, a word derived from **a** (not) and **tomos**(cut or divided). At that time atoms were thought to be indivisible constituents of matter. They were regarded as **elementaryparticle.** This idea lay dormant until about 1804, when the English scientist John **Dalton** (1766–1844), often called the father ofModern Chemistry, discovered that many chemical phenomena could be explained if atoms of each element are the basic, indivisible building blocks of matter.

Although Dalton had postulated that atoms were indivisible particles, experiments conducted around the beginning of the last century showed that atoms themselves consist of particles. These experiments showed that an atom consists of two kinds of particles: a **nucleus**, the atom's central core, which is positively charged and contains most of the atom's mass, and one or more **electrons**.

4.1.1 The Electron and the Proton

Some of the earliest evidence about atomic structure was supplied in the early 1800s by the English chemist **HumphryDavy** (1778–1829). He found that when he passed electric current through some substances, the substances decomposed. He therefore suggested that the elements of a chemical compound are held together by **electrical forces**. In 1832–1833, **MichaelFaraday** (1791–1867), Davy's student, determined the quantitative relationship between the amount of electricity used in electrolysis and the amount of chemical reaction that occurs. Studies of Faraday's work by **GeorgeStoney** (1826–1911) led him to suggest in 1874 that units of electric charge are associated with atoms. In 1891, he suggested that they be named **electrons.**

Rutherford'sexperiments in 1910–1911 revealed that atoms consist of mostly empty space with electrons surrounding a dense central **nucleus** made up of **protons** and **neutrons**.

4.1.2 The Neutron

In 1930 the German physicists Walther **Bothe** and Herbert **Becker** and Irene Joliot-Curie (1897–1956) observed that when beryllium, boron, or lithium was bombarded by alpha particles, the target material emitted a radiation that had much greater penetrating power than the original alpha particles.

Experiments done by the English physicist James **Chadwick (1891–1974)** in 1932 showed that the emitted particles were electrically neutral, with mass approximately equal to that of the proton. Chadwick christened these particles **neutrons**(symbol $^{1}_{0}n$).

Elementary particles are usually detected by **their electromagnetic effect**for instance, by the ionization that they cause when they pass through matter. (This is the principle of the **cloud chamber**). Because neutrons have no charge, they interact hardly at all with electrons and produce little ionization when they pass through matter and so are difficult to detect directly.

However, neutrons can be slowed down by scattering from nuclei, and they can penetrate a nucleus. Hence slow neutrons can be detected by means of a nuclear reaction in which a neutron is absorbed and an alpha particle is emitted. An example is ${}_0^1n + {}_5^{10}B \rightarrow {}_3^7C + {}_2^4He$

The ejected alpha particle is easy to detect because it is charged. Later experiments showed that neutrons, like protons and electrons, are spin $\frac{1}{2}$ particles.

4.1.3 The Photon

Einstein explained the photoelectric effect in 1905 by assuming that the energy of electromagnetic waves is quantized; that is, it comes in little bundles called ***photons*** with energy

$$E = hf$$

Atoms and nuclei can emit (create) and absorb (destroy) photons. Considered as particles, photons have zero charge and zero rest mass. In particle physics, a ***photon*** is denoted by the symbol γ (the Greek letter gamma). The photon is said to ***mediate***, or ***carry,*** the electromagnetic force.

4.1.4 The Neutrino

The Sun emits neutrinos copiously from the nuclear furnace at its core, and at night these messengers from the center of the Sun come up at us from below, Earth being almost totally transparent to them.

4.1.5 The Positron and other antiparticles

In 1928 P. A. M. **Dirac** predicted the existence of a positively charged electron, or ***positron(*** e^+ ***)***, which is the antiparticle of the electron.

Experiment and theory tell us that the masses of the positron and electron are identical, and that their charges are equal in magnitude but opposite in sign. We use the term ***antiparticle*** for a particle that is related to another particle as the positron is to the electron. The ***positron*** is said to be the ***antiparticle*** to the electron.

In 1955 the antiparticle to the proton, the ***antiproton (*** $\overline{p}$ ***)*** which carries a negative charge, was discovered at the University of California, Berkeley, by Emilio ***Segrè*** (1905–1989) and Owen ***Chamberlain*** (1920–2006). A bar, such as over the p, is used to indicate the antiparticle.

Each kind of particle has a corresponding antiparticle. But a few, like the photon, the π^0 and the Higgs, do not have distinct antiparticleswe say that they are their own antiparticles.

By the 1930s, it was accepted that all atoms can be considered to be made up of neutrons, protons, and electrons. The basic constituents of the universe were no longer considered to be atoms (as they had been for 2000 years) but rather the **proton**, **neutron**, and **electron**. Besides these three "elementary particles," several others were also known by the 1950s and 1960: the **positron** (a positive electron), the **neutrino**, and the γ particle (or **photon**), for a total of six elementary particles.

4.1.6 Mesons and Beginning of Elementary Particle Physics

Elementary particle physics might be said to have begun in 1935 when the Japanese physicist Hideki **Yukawa** (1907–1981) predicted the existence of a new particle that would mediate the **strong nuclear force**the force that holds nucleons together in the nucleus. Yukawa called this predicted particle **meson** (meaning medium mass).

In 1937, the **muons** (μ^-) were discovered in cosmic**.** The μ^- has charge equal to that of the electron, and its antiparticle the μ^+ has a positive charge with equal magnitude. The two particles have equal mass, about 207 times the electron mass ($207\ m_e = 106\ MeV/c^2$).

In 1947 a family of three particles, called π *mesons* or **pions,** were discovered in cosmic rays. The π come in three varieties, corresponding to the three charges state: π^-, π^+ and π^0 and their masses are about 270 times the electron mass ($264\ m_e = 135\ MeV/c^2$). The pions interact strongly with nuclei.

The **tau** particle was detected in a series of experiments between 1974 and 1977 and the discovery of the tau neutrino was announced in 2000.

The particles that transmit the weak force are referred to as the W^+, W^- and Z^0 and were detected in 1983.

Electrons contain no discernible structure; they cannot be reduced or separated into smaller components. It is therefore reasonable to call them "elementary" particles, a name that in the past was mistakenly given to particles such as the proton, which is in fact a complex particle that contains quarks. The term **subatomic particle** refers both to the true elementary particles, such as quarks and electrons, and to the larger particles that quarks form.

By the term **fundamental particle**, we mean a particle that is so simple, so basic; that it has no internal structure (is not made up of smaller subunits).

The science of the study of the particle is called **ParticlePhysics**, **ElementaryParticlePhysics** or sometimes **HighEnergyPhysics** (HEP).

Application activity 4.1

1. The positron is called the antiparticle of electron, because it

   A. Has opposite charge

   B. Has the same mass

   C. Collides with an electron

   D. Annihilates with an electron

2. Beta particles are

   A. Neutrons

   B. Protons

   C. Electrons

   D. Thermal neutrons

3. The proton, neutron, electron, and the photon are called

   A. secondary particles

   B. fundamental particles

   C. basic particles

   D. initial particles

4. Particles that are unaffected by strong nuclear force are

   A. protons

   B. leptons

   C. neutrons

   D. bosons

5. The first antiparticle found was the

   A. positron.

   B. hyperon.

   C. quark.

   D. baryon.

6. The exchange particle of the electromagnetic force is the

   A. Gluon.

   B. Muon.

   C. proton.

   D. photon.

4.2 CLASSIFICATION OF PARTICLES

Activity 4.2

a) Basing on what so-far you have studied, classify these elementary particles?

b) Explain what you have based on to classify them.

c) State the common characteristics/features for each group.

Today there are several hundreds of known particles. Naming them has strained the resources of the Greek alphabet, and most are known only by an assigned number in a periodically issued compilation. To make sense of this array of particles, we look for simple physical criteria by which we can place the particles in categories. The result is known as the **Standard Model** of particles. Although this model is continuously challenged by theorists, it remains our best scheme of understanding all the particles discovered to date.

To explore the Standard Model, we make the following three rough families of the known particles: the photon: fermion or boson, hadron or lepton, particle or antiparticle?

As more and more particles were discovered, it became clear that they were not all **elementaryparticles (fundamental or basic particles)**. The suggestion was made that the hadrons are made up of smaller, more elementary particles called **quarks**. They are three families of quarks and three corresponding antiquarks, and hadrons are constructed from combinations of these. Thus the quarks are elevated to the status of elementary particles for the elementary particles for the family of hadrons. The particles in the photon and lepton families are considered to be elementary, and such they are not composed of quarks.

The fundamental particles were classified into two categories according to their spin: Fermions and Bosons

4.2.1 Fermions

Particles with half-integer spin quantum numbers $S=\frac{1}{2}$ (like electrons) are called **fermions,** afterFermi, who (simultaneously with Paul Dirac) discovered the statistical laws that govern theirbehavior.

They are two families of fermions (of spin ½): leptons and quarks

a. Leptons

Leptons (from the Greek leptos meaning small or light) are a group of particles that participate in the weak nuclear force, they can exert gravitational, and they are charged particles hence exert electromagnetic force on other particles. All leptons have spin $\frac{1}{2}$ and thus are fermions.

Three pairs or families of leptons and their anti-particles exist as listed in the table 4.1.

Particle	symbol	Antiparticle	charge (e)	Mas (MeV/c^2)	spin	Lepton number
Electron	e^-	e^+	-1	0.511	½	1
Electron neutrino	ν_e	$\overline{\nu}_e$	0	< 0.007	½	1
Muon	μ^-	μ^+	-1	105.7	½	1
Muon neutrino	ν_μ	$\overline{\nu}_\mu$	0	< 0.3	½	1
Tau	τ^-	τ^+	-1	1784	½	1
Tau neutrino	ν_τ	$\overline{\nu}_\mu$	0	< 30	½	1

Table 4. 1 Every lepton has a corresponding antilepton. All leptons have lepton number 1, while all antileptons have lepton number -1.

The six leptons are considered to be truly fundamental particles because they do not show any internal structure, and have no measurable size.

b. Quarks

They are **sixquarks** or **flavors** of quarks: **up (u), down (d), strange (s), charm (c),bottom (b)**and **top (t) quarks** and they each have their partner **anti-quarks** (designated by a line over the letter symbol).

Quarks	Flavor	mass (MeV/c^2)	Rest energy (MeV)	Charge Q	spin ($\hbar$)	Baryon number	Strange-ness
u	up	5	360	$+\frac{2}{3}e$	½	$\frac{1}{3}$	0
d	down	7	360	$-\frac{1}{3}e$	½	$\frac{1}{3}$	0
c	charmed	1500	1500	$-\frac{1}{3}e$	½	$\frac{1}{3}$	+1

s	strange	150 000	540	$+\frac{2}{3}e$	½	$\frac{1}{3}$	-1
t	top	176000 ± 13000	1 7 3 000	$-\frac{1}{3}e$	½	$\frac{1}{3}$	+1
b	bottom	4.8 G	5 000	$+\frac{2}{3}e$	½	$\frac{1}{3}$	-1

Table 4. 2 Quarks are characterized by properties known as flavor (up, down, charm, strange, top, or bottom) (Antiquarks have opposite sign Q, B, S, c, b, t)

Quarks combine to form hadrons or meson**.** The hadrons are a composite particle made of **quarks** (u, d, c, s, t, b) held together by the strong nuclear force. Hadrons can also interact by weak nuclear force, gravitational force and electromagnetic forces but at short distances ($<<10^{-15}\ m$).

Hadrons are categorized into families distinguished by their masses and *spins*: **Hadrons and baryons**

a. Mesons

Mesons are particle made of one quark and one anti quark ($q\bar{q}$) giving them a baryon number of $B=0$. The **pion (**$\pi^{-}=\bar{u}d$ **and** $\pi^{+}=u\bar{d}$**)** is the lightest of known mesons, with a mass of about $140\ MeV/c^2$ and a spin of 0 hence the mesons, are bosons.

Another is the **K meson** (Positive kaon $\kappa^{+}=u\bar{s}$ and negative **kaon** $\kappa^{-}=\bar{u}s$**)** with a mass of about $500\ MeV/c^2$ and spin 0 and $\kappa^{0}=d\bar{s}$ as shown in Fig.4.1

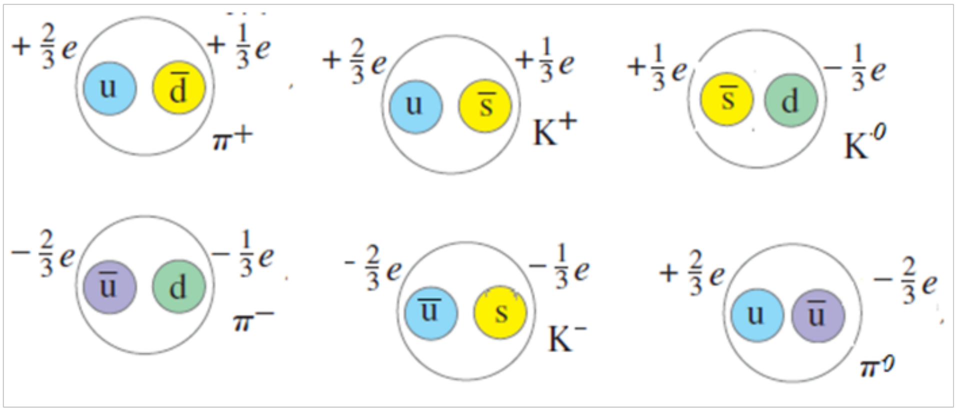


Fig.4. 1 Some mesons

b. Baryons

Baryons made of three quarks (qqq). Each antibaryon of three antiquarks ($\overline{q}\overline{q}\overline{q}$).

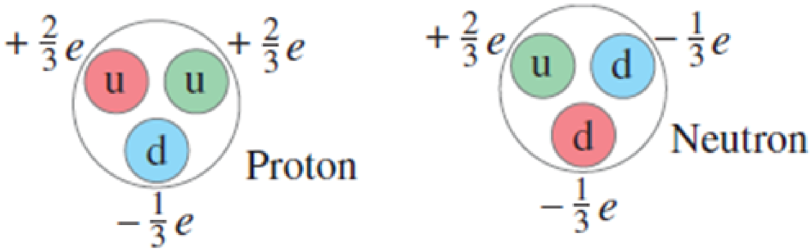


Fig.4. 2 Some baryons

4.2.2 Gauge Bosons

The particles in the gauge boson category include:

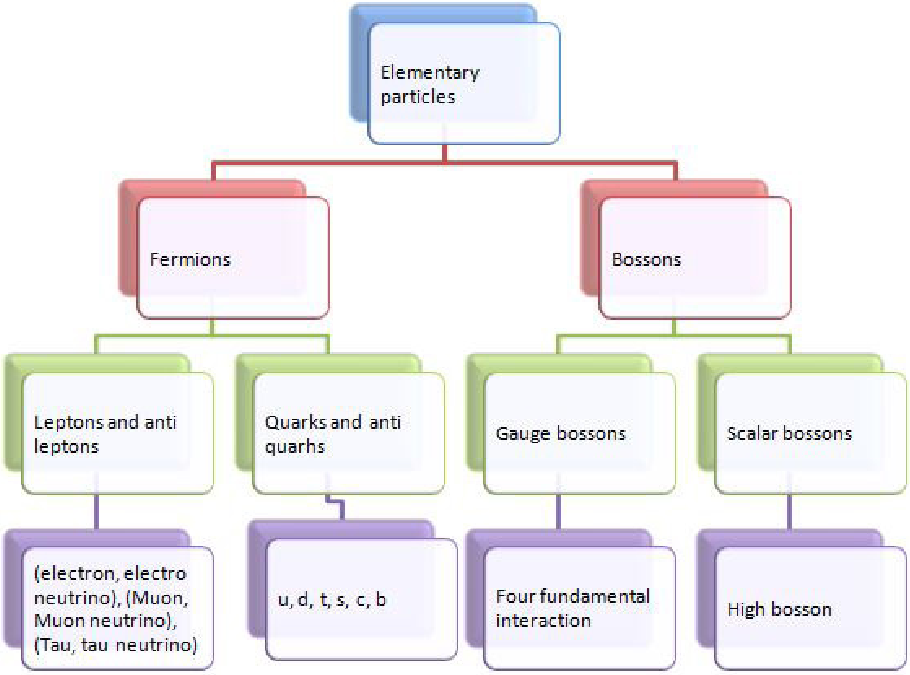
- The **gauge bosons** include the **gluons**, the particles that mediate (or "carry") the strong,
- the **photon** which carries the electromagnetic force and $S=1$, The photon interacts only with charged particles, and the interaction is only via the electromagnetic
- the $W^{\pm}$ and **Zbosons**; these are the particles that mediate weak interactions
- **Graviton** is the hypothetical particle that carry the gravitational force withspin 2

The table below show gauge bosons

Force	Carriers	Symbol	Antiparticle	Rest mass (MeV/c2)	Spin	Life time (s)
Electromag-netic	Photon	γ	Self	0	1	Stable
Weak	W Z	W^{+}	W^{-}	80.3×10^{3}	1	3×10^{-25}
	Z	Z^{o}	Z^{o}	91.2×10^{3}	1	3×10^{-25}
Strong	Gluons	g		0	0	
Gravitational	Graviton	G		0	0	

Table 4. 3 Bosons

In summary, the following diagram shows some classes of elementary particles



Application activity 4.2

1. A proton is made up of

   A. one up quark and two down quarks

   B. an up quark and down antiquark

   C. two up quarks and a down quark

   D. strange quark and an anti-strange quark

2. Particles that are unaffected by strong nuclear force are

   A. protons C. neutrons

   B. leptons D. bosons

3. Particle which explains about mass of matter is called

   A. Higgs boson C. protons

   B. Leptons D. neutrons

4. Each hadron consists of a proper combination of a few elementary components called

A. Photons
B. Vector bosons
C. quarks
D. meson-baryon pairs.

5. The proton, neutron, electron, and the photon are called

   A. secondary particles
   B. fundamental particles
   C. basic particles
   D. initial particles

6. The exchange particle of the electromagnetic force is the

   A. gluon.
   B. muon.
   C. proton.
   D. photon.

7. Particles that interact by the strong force are called

   A. leptons
   B. hadrons
   C. muons
   D. electrons

8. At the present time, the elementary particles are considered to be the

   A. Photons and baryons.
   B. Leptons and quarks.
   C. Baryons and quarks.
   D. Baryons and leptons.

9. The electron and muon are both

   A. Hadrons.
   B. Leptons.
   C. Baryons.
   C. Mesons.

10. Particles that make up the family of hadrons are

    A. Baryons and mesons.
    B. Leptons and baryons.
    C. Protons and electrons.
    D. Muons and leptons.

11. Is it possible for a particle to be both:

    A. A lepton and a baryon?
    B. A baryon and hadron?
    C. A meson and a quark?
    D. A hadron and a lepton?

12. Distinguish between (a) fermions and bosons, (b) leptons and hadrons and (c) mesons and baryon number

13. Which of the four interactions (strong, electromagnetic, weak, and gravitational) does an electron take part in? A neutrino? A proton?

14. Describe the types and the characteristics of the quarks as well as their interaction properties.

4.3 FUNDAMENTAL FORCES AND INTERACTIONS

Activity 4.3

From the previous lessons, you have learned that the particles have different charges and masses.Basing on that, explain the magnitude of force that may rise between these elementary particles depending on:

a) Masses (You can apply newton's law of gravitation)

b) Charges (You can use coulombs law of charges)

4.3.1 Antiparticle and antimatter

Antiparticles are produced in nuclear reactions when there is sufficient energy available to produce the required mass, and they do not live very long in the presence of matter.

Antimatter is a term referring to material that would be made up of "antiatoms" in which antiprotons and antineutrons would form the nucleus around which positrons (antielectrons) would move. The term is also used for antiparticles in general. **Anti-matter** is a material composed of anti-particles.

We use the term **antiparticle** for a particle that is related to another particle as the positron is to the electron. Each kind of particle has a corresponding antiparticle. For a few kinds of particles (necessarily all neutral) the particle and antiparticle are identical, and we can say that they are their own antiparticles. The photon is an example; there is no way to distinguish a photon from an antiphoton.

Pair production and pair annihilation

Positrons do not occur in ordinary matter. **Electron–positron** pairs are produced during high-energy collisions of charged particles or γ-rays with matter. This process is called (e^{+}, e^{-}) *pair production*.

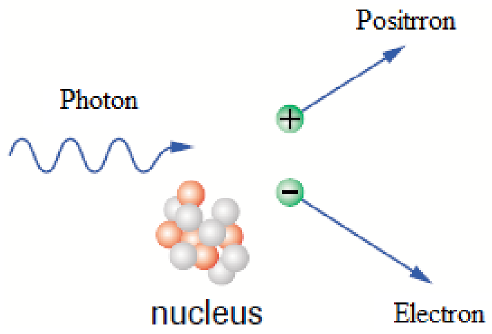


Fig.4. 3 Pair production

When a particle meets its antiparticle, the two can ***annihilate*** each other and release a large amount of energy. That is, the particle and antiparticle disappear and their combined energies reappear in other forms. For an electron annihilating with a positron, this energy reappears as two gamma-ray photons:

$$e^{-} + e^{+} \rightarrow \gamma + \gamma$$

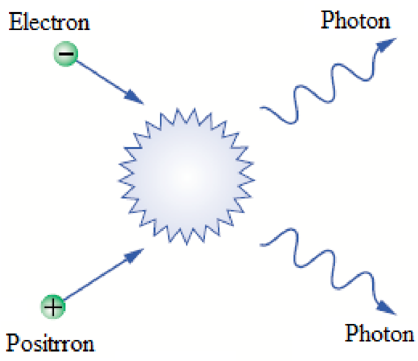


Fig.4. 4 Pair annihilation

4.3.2 Fundamental Interactions and Force Mediators

In nature they are two types of forces, fundamental and non-fundamental forces. Fundamental (basic) forces are the ones that are truly unique, in the sense that all other forces can be explained in terms of them.

By 1940, Physicists have long recognized for forces of nature (***fundamental* forces)**:

- **The gravitational force**

The **gravitational force** is an inherent attraction between two masses. Gravitational force is responsible for the motion of the planets and Stars in the Universe. It is carried by **Graviton**but its existence has not been detected and it may not be detectable. By Newton's law of gravitation, the gravitational force is directly proportional to the product of the masses and inversely proportional to the square of the distance between them. Gravitational force is the weakest force among the fundamental forces of nature but has the greatest large-scale impact on the universe. Unlike the other forces, gravity works universally on all matter and energy, and is universally attractive.

- **The electromagnetic interaction**

In Classical Physics we describe the interaction of charged particles in terms of **electric** and **magneticforces**. The **electric force** is a force between charges. The **magnetic force** is a force between magnets or between magnetic body and ferromagnetic body.

In quantum mechanics we can describe this interaction in terms of emission and absorption of **photons.** Two electrons repel each other as one emits a photon and the other absorbs it, just as two skaters can push each other apart by tossing a heavy ball back and forth between them (Fig. 4.5).

Fig.4. 5 Two skaters exert repulsive forces on each other by tossing a ball back and forth.

For an electron and a proton, in which the charges are opposite and the force is attractive, we imagine the skaters trying to grab the ball away from each other (Fig. 4.6). The **electromagneticinteraction** between two charged particles is *mediated* or transmitted by **photons.**

Fig.4.6 Two skaters exert attractive forces on each other when one tries to grap the ball out of the other's hands

In the 1860s, the Scottish physicist James Clerk Maxwell developed a theory that ***unified*** the electric andmagnetic forces into a single **electro*magnetic force.*** Maxwell's electromagnetic force was soon found to be the "glue" holding atoms, molecules, and solids together. It is the force between charged particles such as the force between two electrons, or the force between two current carrying wires. It is attractive for unlike charges and repulsive for like charges. The electromagnetic force obeys inverse square law. It is very strong compared to the gravitational force. It is the combination of electrostatic and magnetic forces.

A simple diagram describing this photon exchange is shown in Fig.4.7. Such a diagram, called a **Feynman diagram** after its inventor, the American physicist Richard Feynman (1918–1988), is based on the theory of **quantum electrodynamics** (QED).

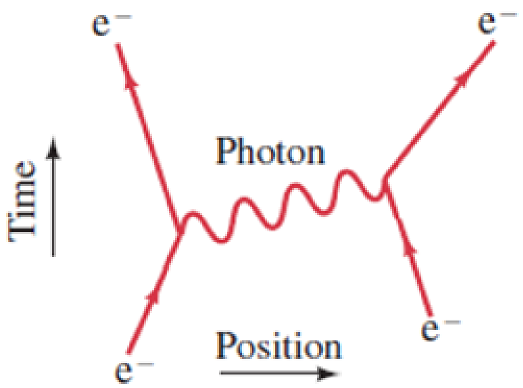


Fig.4. 7 Feynman diagram showing a photon acting as the carrier of the electromagnetic force between two electrons

- **Strongnuclear force**

In 1935 the Japanese physicist Hideki **Yukawa** suggested that a hypothetical particle that he called a **meson** might mediate the **strongnuclear force.** The **strong nuclear force** is the force that holds the protons and neutrons together in the nucleus of an atom. It plays a primary role in stability of the nucleus of the atoms. It is the strongest of all the basic forces of nature. It, however, has the shortest range, of the order of 10^{-15} m (the size of the nucleus). This force only acts on quarks. Quarks carry electric charge so they experience electric and magnetic forces. It binds quarks together to form **baryons** and **mesons** such as protons and neutrons. The strong force is mediated by **Gluons**. However, the force between nucleons is more easily described in terms of **mesons** as the mediating particles**.**

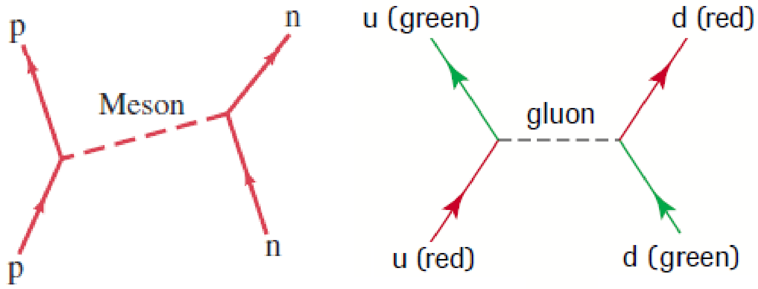


Fig.4. 8 Early model showing meson exchange when a proton and neutron interact via the strong nuclear force (Today, as we shall see shortly, we view the strong force as carried by gluons between quarks)

- ### The weak force

In the 1939, Physicists found that thenuclear radioactivity called ***beta decay*** could not be explained by either the electromagnetic or the strong force. The strength of this force is less than either the strong force or the electromagnetic force, so this new force was named ***the weak force.*** Weak nuclear force is important in certain types of nuclear process such as β-decay. This force is not as weak as the gravitational force. The weak force acts on both **leptons** and **quarks** (and hence on all hadrons). The weak force is carried by W^+, $W^-$and Z^0boson. Leptons – the electrons, muons and tau – are charged so they experience electric and magnetic forces. Of these, our everyday world is controlled by **gravity** and **electromagnetism**. The **weak force** is responsible for the radioactive decay of unstable nuclei and for interactions of neutrinos and other leptons with matter.

By 1980, Scientists developed a theory that unifies electromagnetism and weak force into **electroweak force mediated by particles, the $W^{\pm}$ and Z^0 bosons.** Hence, our understanding of the forces of nature is in terms of **three** fundamental forces: the **gravitational force**, the **electroweak force**, and the **strong force.**

The table below summaries the fundamental forces:

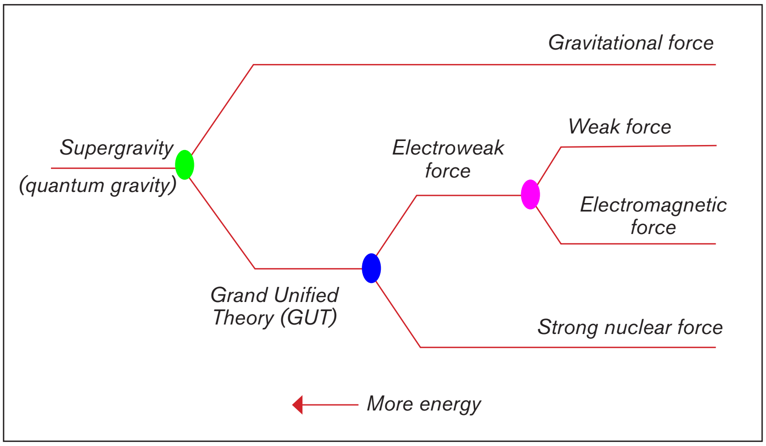


Fig.4.9 Unification of electromagnetism and weak force

The **intrinsic strengths** of the forces can be compared relative to the *strong* force, here considered to have **unit strength**(i.e., = 1). In these terms, the ***electromagnetic*force** has an intrinsic strength of (1/137). The ***weak force*** is a billion times weaker than the ***strong force***. The weakest of them all is the ***gravitational force***. This may seem strange, since it is strong enough to hold the massive Earth and planets in orbit around the Sun! But we know that the gravitational force between two bodies a distance ***r*** apart is proportional to the product of the two masses (*M* and *m*) and inversely proportional to the distance ***r*** squared:

$$F_G = G\frac{Mm}{r^2}$$

We see now what is meant by ***intrinsic* strength**. It is given by the magnitude of the universal force constant, in this case, ***G***, independent of the masses or distances involved.

In similar terms, the electromagnetic force between two particles is proportional to the product of the two charges (*Q* and *q*) and inversely to the distance ***r*** squared:

$F_G = k\frac{Qq}{r^2}$, here the universal constant, *k*, gives the intrinsic strength.

We can compare the relative strengths of the electromagnetic *repulsion* and the gravitational *attraction* between two protons of unit charge using the above equations.

FORCE	Relative Strength	Gauge Boson	Mass (rel. to proton)	Charge	Spin
Strong	1	Gluon (g)	0	0	1
Electromagnetic	1/137	Photon (γ)	0	0	1
Weak	10^{-9}	$W^{\pm}, Z$	86, 97	$\pm 1, 0$	1
Gravity	10^{-38}	Graviton (G)	0	0	2

Table 4. 4 Forces and their quanta, the gauge bosons. Charge is in units of electron charge.

Example 4.1

The 2 up quarks (u) in a proton are separated by $r = 1\times10^{-15}\ m$. These quarks each have an electric charge $+\frac{2}{3}e$, so they repel each other through an electric force obeying Coulomb's law. They also attract each other through a gravitational force. What is the ratio of the magnitude of the electric and gravitational forces between these 2 quarks?

Answer

Gravitational force: $F_G = G\dfrac{m_u m_u}{r^2}$ (1)

Electric force: $F_{el} = G\dfrac{q_u q_u}{r^2}$ (2)

(1) Divided by (2): $\dfrac{F_G}{F_{el}} = \dfrac{G}{k}\dfrac{m_u m_u}{q_u q_u} = \dfrac{9Gm^2}{4ke^2} = \dfrac{9(6.67\times10^{-11})(7\times10^{-30})^2}{4(8.99\times10^{9})(1.6\times10^{-19})^2} = 3\times10^{-41}$

Thus, the gravitational is the weakest of the fundamental forces.

Application activity 4.3

1. If gravity is the weakest force, why is it the one we notice most? Choose the letter correspond to the correct answer

A. Our bodies are not sensitive to the other forces.

B. The other forces act only within atoms and therefore have no effect on us.

C. Gravity may be "very weak" but always attractive, and the Earth has enormous mass. The strong and weak nuclear forces have very short range. The electromagnetic force has a long range, but most matter is electrically neutral.

D. At long distances, the gravitational force is actually stronger than the other forces.

E. The other forces act only on elementary particles, not on objects our size.

2. The two basic interaction forces that have finite ranges are:

A. electromagnetic and gravitational

B. electromagnetic and strong

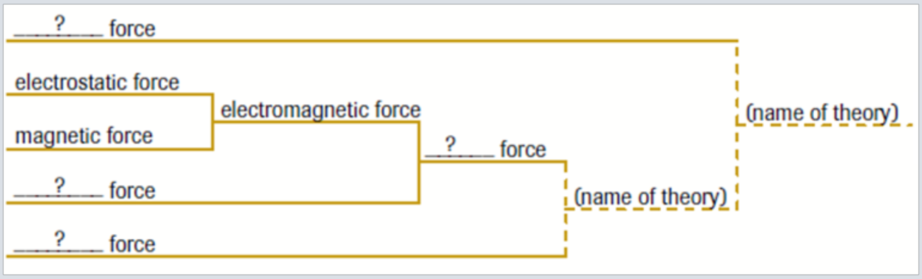
C. electromagnetic and weak

D. gravitational and weak

E. weak and strong

3. Name the four fundamental interactions and the particles that mediate each interaction.

4. State two differences between a proton and a positron.
5. Copy figure below into your notebook. Complete the diagram by filling in the names of the fundamental forces and the names of the unification theories.



Skills Lab 4

In this activity, you make a comprehensive research about nature of particles and their interactions.

Materials needed: Computer set, internet and reference books.

What to do.

a) Using internet, make general studies about the following
   - Classification of particles and antiparticles.
   - Properties of fundamental particles (Charges, spin, quark contents)

b) Compile your findings and make a report. Relate your findings to what you have studied in this unit.

c) You can compare your report to your friends' report and check whether the information you have is related to your friends work.

d) You and your classmates may prepare a session of presentation so that you can harmonize what you got in your research. Present using PowerPoint presentations.

e) In case you find new points from other presentations, include it to your report.

End of unit 4 assessment

1. Which of the following are today considered fundamental particles (that is, not composed of smaller components)? Choose as many as apply.

   A. Atoms. C. Protons. E. Quarks. G. Higgs boson

   B. Electrons. D. Neutrons. F. Photon

2. The electron's antiparticle is called the positron. Which of the following properties, if any, are the same for electrons and positrons?

   A. Mass. C. Lepton number

   B. Charge. D. None of the above.

3. The strong nuclear force between a neutron and a proton is due to

   A. The exchange of π mesons between the neutron and the proton.
   B. The conservation of baryon number.
   C. The beta decay of the neutron into the proton.
   D. The exchange of gluons between the quarks within the neutron and the proton.
   E. Both (*A*) and (*D*) at different scales.

4. Which of the following will interact via the weak nuclear force *only*?

   A. Quarks. C. Neutrons E. Electrons G. Higgs boson.

   B. Gluons. D. Neutrinos. F. Muons.

5. Messenger particles of the weak interaction are called:

   A. gluons D. gravitons

   B. photons E. pions

   C. W and Z

6. Messenger particles of the electromagnetic interaction are called:

   A. gluons D. gravitons

   B. photons E. pions

   C. W and Z

7. The pair annihilation of an electron and a positron has been investigated for many years at CERN in Switzerland. Two gamma-ray photons are produced during this annihilation. What is a positron?

8. True or false: if the statement is true, explain why it is true. If it is false, give a counterexample.
   (a) leptons are fermions
   (b) all baryons are hadrons
   (c) all hadrons are baryons
   (d) mesons are spin ½ particles
   (e) leptons consist of three quarks
   (f) the times for decays via the weak interaction are typically much longer than those for decays via the strong interaction
   (g) the electron interacts with the proton via the strong interaction

UNIT 5

X-RAYS AND ITS EFFECTS

Key Unit Competence:

Suggest and criticize possible effects of X-rays

Introductory activity

Technology has advanced and man has made all advancements to see that human problems are solved with ease and using technology. Among other areas where technology has been emphasized is in medicine (in hospitals).

For example, CT scans (Computerized tomography scans) and X-rays machines are commonly used in hospitals to examine internal structures of a patient if needed. When a person goes to the hospital with pain in her/his chest, or with an internal fracture of the bone, physicians do normally recommend the patient to pass by radiology service (Radiology means there are radiations).

1. Why do you think physicians recommend patients to pass by radiology service?
2. Discuss different types of radiations that are found in there?
3. From your physics knowledge, how do you think these radiations specifically X-rays are produced.
4. Like any other electromagnetic radiations, what do you think are some of the properties of X-rays?
5. As seen from the statement X-rays are used in hospitals, other than being used in medicine, discuss other areas/fields where X-rays are applied.
6. What are the positive and negative effects of X-ray radiation on the human body do you know?
7. Having seen that these radiations have negative effects on human body, what are your recommendations to a technician works in areas that use X-rays.

5.1 PRODUCTION OF X-RAYS

Activity 5.1

X-rays are produced when the electrons are suddenly decelerated upon collision with the metal target; these x-rays are commonly called “braking radiation”. If the bombarding electrons have sufficient energy, they can knock an electron out of an inner shell of the target metal atoms.

Discovery of X-rays: Becquerel’s discovery wasn’t the only important accidental one. In the previous year W.C. Roentgen unexpectedly discovered X-rays while studying the behavior of electrons in a high-voltage vacuum tube.

In that instance, a nearby material was made to fluoresce. Roentgen named them X- rays because he didn’t know what they were. Within twenty years of this discovery, diffraction patterns produced using X-rays on crystal structureshad begun to show the finer structure of crystals while, at the same time, giving evidence that X-rays had a wave nature. Since then, X-ray radiation has become an indispensable imaging tool in medical science and other fields.

Questions:

1. According to the text, why do you think the electrons need to be accelerated and decelerated to produce X-rays?
2. Imagine the energy of bombarding electrons is varied, do you think the type X-ray emitted would remain same?
3. According to the text, do you think that it is possible to produce X-rays in our local laboratories? Defend your suggestion.

5.1.1 X-ray production

X-rays: These are short wavelength electromagnetic radiations that are produced when fast moving electrons strike matter.

They were first produced in 1895 by Wilhelm Rontgen (1845-1923), using an apparatus similar in principle to the setup shown in Fig.5.1. Electrons are emitted from the heated cathode by thermionic emission and are accelerated toward the anode (the target) by a large potential difference V_h. The bulb is evacuated (residual pressure 10^{-7}atm or less), so that the electrons can travel from the cathode to the anode without colliding with air molecules. It was observed that when V_h is a few thousands volts or more, a very penetrating radiation is emitted from the anode surface.

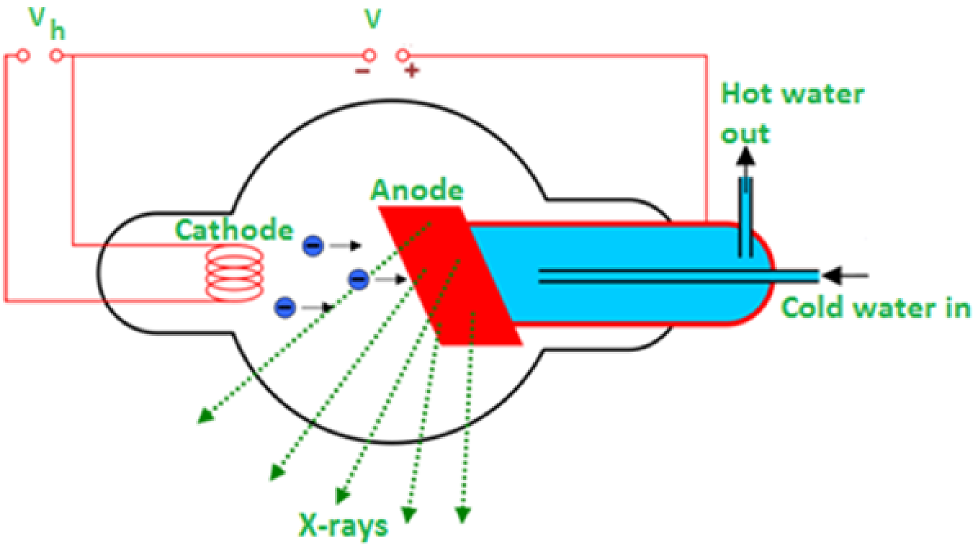


Fig.5. 1. The Coolidge tube, also called hot cathode tube or x-ray tube.

The above figure is an illustration of the Coolidge tube which is the most widely used device for the production of X-rays. The electrons are produced by thermionic effect from filament, which is the cathode of the tube, heated by an electric current. These electrons are accelerated towards a metal target that is the anode due to the high potential voltage between the cathode and the anode. The target metals are normally Tungsten or Molybdenum and are chosen because they have high melting point and higher atomic weights. The accelerated electrons interact with both electrons and nuclei of atoms in the target and a mysterious radiation is emitted. This radiation was referred to as X-rays.

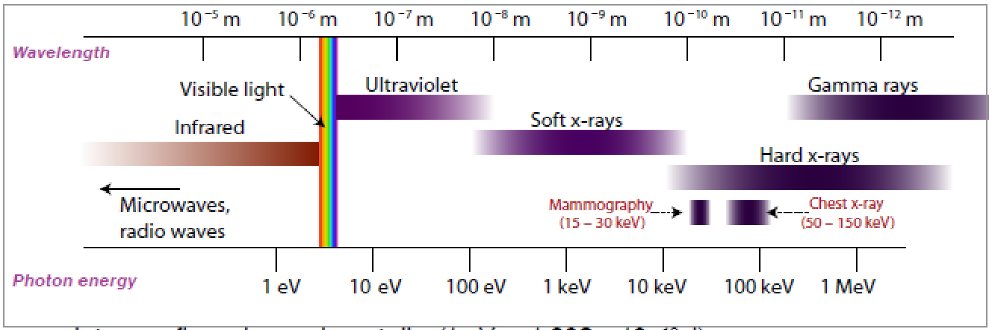
About 98% of the energy of the incident electron is converted into heat that is evacuated by the cooling system and the remaining 2% come out as X-rays.

5.1.2 Types of x-rays

Sometimes x-rays are classified according to their penetrating power. Two types are mentioned:

- **Hard X-rays: those are X-rays on upper range** of frequencies or shorter wavelength. They have greater energy and so they are more penetrating.
- **Soft X-rays: they are X-rays on lower range** of frequencies or longer wavelength. They have lower energy and they have very low penetrating power. The Fig.5.2 below shows the relative location of the different types of x-rays.

Hard x-rays are produced by high accelerating potential. They have high penetrating power and short wavelength while soft x-rays are produced by lower accelerating potential, have relatively low penetrating power and relatively long wavelength.



later confirmed experimentally. (1 eV = 1.602×10^{-19} J)

Fig.5. 2:The location of x-ray in the electromagnetic spectrum.

Application activity 5.1

1. With the aid of a diagram, describe how X-rays are produced in a laboratory.
2. a) Discuss the two types of X-rays and how they are produced.

   b) In the two types of X-rays mentioned in b) above, which one can be used to

      i) Examine or kill cancer cells in a breast.

      ii) Examine minerals beneath a hard rock.

5.2 PROPERTIES OF X-RAYS AND CHARACTERISTIC FEATURES OF X-RAY SPECTRUM

Activity 5.2

With reference to electromagnetic spectrum, what do you think are the properties of X-rays?

5.2.1 Properties of x-rays

The following are the main properties of X-rays:

(a) X-rays can penetrate through most substances. However, their penetrating power is different.

(b) X-ray can produce fluorescence in different substances.

(c) X-rays can blacken photographic plate. The degree of blackening depends upon the intensity of x-rays incident upon the plate. Thus, X-ray intensity can be measured with the help of photographic plates.

(d) X-rays ionize the gas through which they travel. The ionizing power depends on the intensity of the x-ray beam. Thus, X-ray intensity can also be measured by measuring their ionizing power.

(e) X-rays are not deflected by electric or magnetic fields. This proves that unlike cathode rays or positive rays they are not a beam of charged particles.

(f) X-rays travels on a straight line like ordinary light.

(g) X-ray are both reflected and refracted.

(h) X-rays can be diffracted with the help of crystalline substances. They can also be polarized.

From the above characteristics it can be seen that X-rays have the properties that are common to all electromagnetic radiations.

5.2.2 The origin and characteristic features of an x-ray spectrum

Variation of the X-ray intensity with wavelength

Depending on the accelerating voltage and the target element, we may find sharp peaks superimposed on a continuous spectrum as indicated on Fig.5.3. These peaks are at different wavelengths for different elements; they form what is called a characteristic x-ray spectrum for each target element.

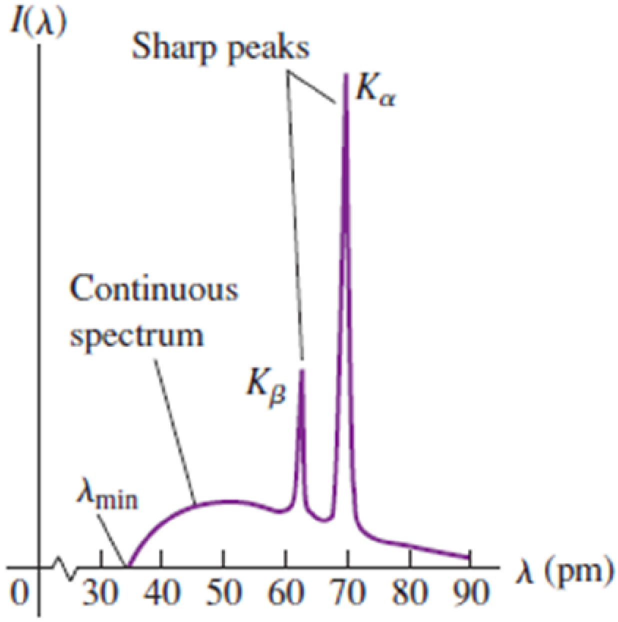


Fig.5. 3 Intensity as a function of the wavelength of x-rays emitted at a particular voltage.

X-rays of different wavelengths are emitted from x-ray tube. If the intensity is measured as a function of the wavelength and the variation is plotted graphically then a graph of the nature shown on the figure above is obtained. The graph has the following features,

(a) Minimum wavelength

(b) Continuous spectrum

(c) Characteristic peaks

Origin of the continuous spectrum

It is known that when charged particles such as electrons are accelerated or decelerated, they emit electromagnetic radiation of different frequencies. In doing so a part of their kinetic energy is transformed in the energy of the emitted radiation. Electrons inside the x-ray tube decelerate upon hitting the target and as a result they emit electromagnetic radiations with a continuous distribution of wavelength starting from a certain minimum wavelength. This mechanism of producing electromagnetic radiation from an accelerated or decelerated electron is called **bremsstrahlung**.

The energy of the emitted photon is given by:

$$E = hf = \frac{hc}{\lambda}$$

Where $h = 6.6260 \times 10^{-34}\ J \cdot s$ is the Planck constant and $c = 3.0 \times 10^{8}\ m/s$ is the speed of light in vacuum.

The maximum energy of the emitted photons is therefore equal to the energy of the incident electron:

$$E = eV = \frac{hc}{\lambda_{\min}}$$

Where is the minimum wavelength, V is the potential difference between anode and cathode and e the charge of the electron.

Example 5.1

1. What is the energy of the laser light that propagates with a frequency of 10^{10} Hz in gaseous medium? (Given that the plank's constant h=6.63 $\times 10^{-34}$ Js)
2. Electrons are accelerated from rest through a potential difference of 10 kV in an x -ray tube. Take charge $e = 1.6 \times 10^{-19} C$ and speed of electromagnet rays $3 \times 10^{8}\ m/s$ and calculate:
   a) The resultant energy of the electrons.
   b) The wavelength of the associated electron waves.

Answer:

1. $E = hf = 6.63 \times 10^{-34} \times 10^{10} = 6.63 \times 10^{-24} J$
2. a) $E = eV = 1.6 \times 10^{-19} \times 10 \times 10^{3} = 1.6 \times 10^{-15} J$

   b) $E = \frac{hc}{\lambda} \Leftrightarrow \lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-15}} = 1.24 \times 10^{-10} m$

Origin of characteristic lines

The peaks observed in wavelengths distribution curves as shown in Fig. 5.3 are spectral lines in the x-ray region. Their origin lies in the transition between energy levels in the atoms of the target.

The electrons in the atoms are arranged in different atomic shell of these, the first two electrons occupy the K-shell followed by 8 electrons in the L-shell, 18 electrons in the M-shell and so on until the electron in the target are used up. A highly accelerated electron may penetrate atom in the target and collide with an electron in K-shell. If such electron is knocked out it will leave an empty space that is immediately filled up by another electron probably from the L-shell or M-shell. This transition will be accompanied by the emission of the excess energy as a photon.

The energy of the emitted photon is a characteristic of the energy levels in the particular atom and is given by:

$$hf_{KL} = \frac{hc}{\lambda_{KL}} = E_K - E_L$$

For a transition between K and L-shells.

Thus, the energy of the emitted photon depends on the binding energies in the K and L shells and hence the x-ray spectral lines have definite frequencies and wavelengths which are characteristic of the target atom.

For a given target material more than one spectral lines are observed as transitions may occur between different energy levels.

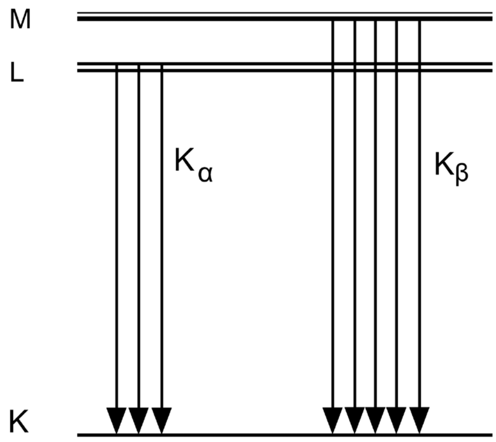


Fig.5. 4 X-ray emission line due to transition of electron between levels.

The x-ray lines originating from the transition between the different electron levels are usually labelled by the symbols α, β, γ, etc.

From L-level to K-level transition produces $K\alpha$-line

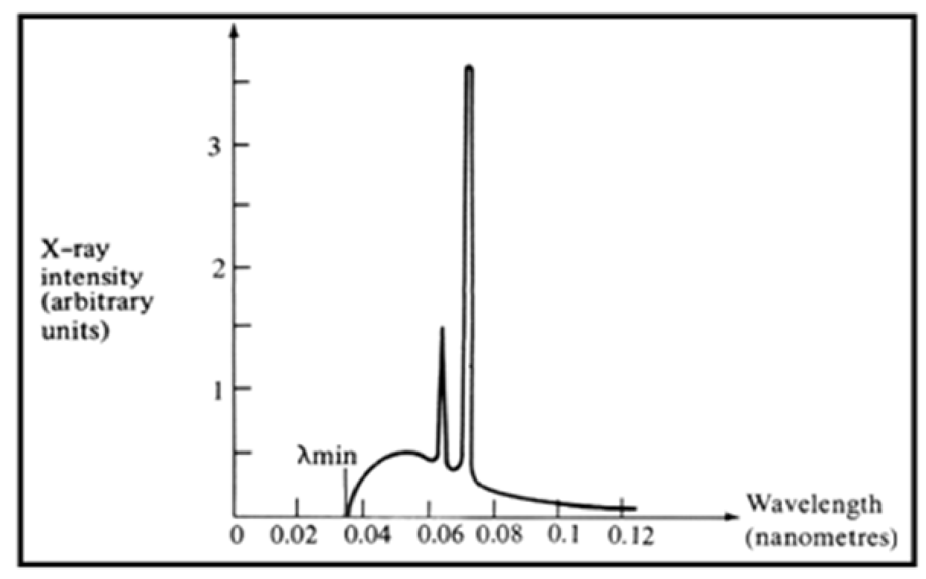
From M-level to K-level transition produces $K\beta$ –line

From M-level to L-level transition produces $L\alpha$ –line

From N-level to L- level transition produces $L\beta$ –line

Application activity 5.2

1. X-rays are electromagnetic waves produced when fast moving electrons strike the matter. Discuss the properties of X-rays.
2. A plot of x-ray intensity as a function of wavelength for a particular accelerating voltage and a particular target is shown in figure below.



a. There are two main components of this x-ray spectrum: a broad range of x-ray energies and a couple of sharp peaks. Explain how each of these arises.

b. What is the origin of the cut-off wavelength λ_{min} of the Figure shown above? Why is it an important clue to the photon nature of x-rays?

c. What would happen to the cut-off wavelength if the accelerating voltage was increased? What would happen to the characteristic peaks? Use a sketch to show how this spectrum would look if the accelerating voltage was increased.

d. What would happen to the cut-off wavelength if the target was changed, keep the same accelerating voltage? What would happen to the characteristic peaks? Use a sketch to show how the spectrum would look if some other target material was used, but the accelerating voltage was kept the same.

3. Electrons are accelerated from rest through a potential difference of 10 kV in an x ray tube, calculate:

   i) The resultant energy of the electrons in eV.

   ii) The wavelength of the associated electron waves.

   iii) The maximum energy and the minimum wavelength of the x ray radiation generated (assume, $m_e = 9.11\times10^{-31} kg, e = 1.6\times10^{-19} C$, $h = 6.62\times10^{-34}\ J\cdot s$, $c = 3\times10^{8}\ m/s$)

5.3. APPLICATIONS AND DANGERS OF X-RAYS

Activity 5.3

1. Basing on the nature and properties, what do you think are the uses of X-rays in real life?

2. If during your internship as a student teacher in a certain primary school, one of the pupils tells you that her father who is a medical doctor told her that X-rays are useful and miss-used. That pupil seeks information from you on how these dangers can be avoided. Provide relevant information to him/her on how dangers caused by X-rays can be avoided.

5.3.1 Applications

X rays have many practical applications in medicine and industry. Because x-ray photons are of such high energy, they can penetrate several centimetres of solid matter. Hence, they can be used to visualize the interiors of materials that are opaque to ordinary light, such as broken bones or defects in structural steel.

a. In medicine

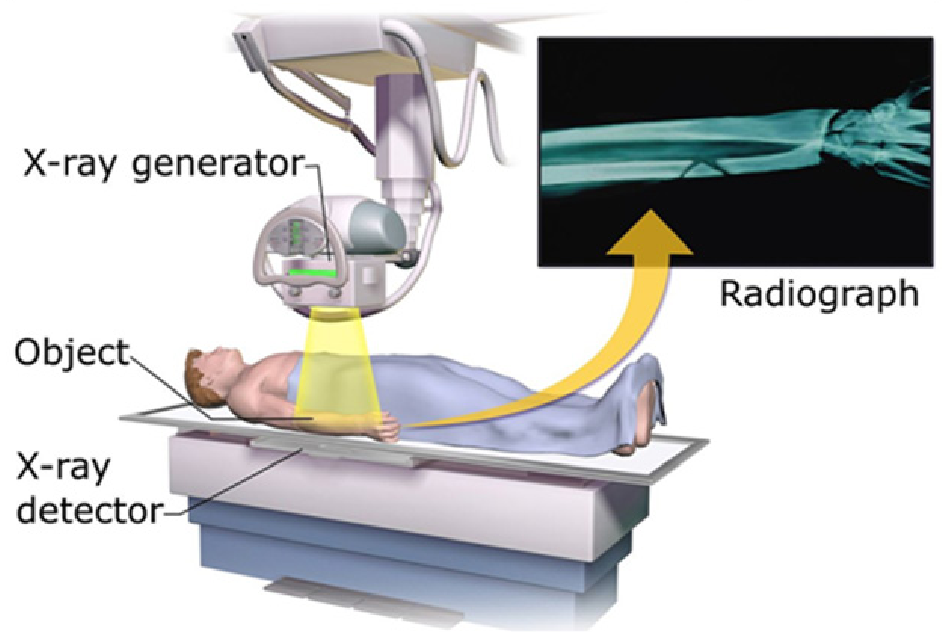


Fig.5. 5 The radiology of human body using x-rays

X-ray imaging utilizes the ability of high frequency electromagnetic waves to pass through soft parts of the human body largely unimpeded. For medical applications, parts of the human body are exposed to moderated X-rays intensity and images are produced in similar way as light on a photographic plate or digital recorder to produce a radiograph (See Fig.5.5). By rotating both source and detector around the patient's body a "slice" image can be produced in what is called computerized tomography (CT). Although CT scans expose the patient to higher doses of ionizing radiation the slice images produced make it possible to see the structures of the body in three dimensions.

In 1895, the Dutch Wilhelm Roentgen (See Fig.5.6) discovered that light energy could be used to take photographs through substances such as paper, cloths and wood. Roentgen also discovered that this invisible form of light energy, called X-rays could be used to take the pictures of structures inside the body as shown in Fig. 5.6. Bone tissue appears clearly on an X-rays.

The object to be visualized is placed between an x-ray source and an electronic detector (like that used in a digital camera) or a piece of photographic film. The darker area in the recorded images by such a detector, the greater the radiation exposure. Bones are much more effective x-ray absorbers than soft tissue, so bones appear as light areas. A crack or air bubble allows greater transmission and shows as a dark area.

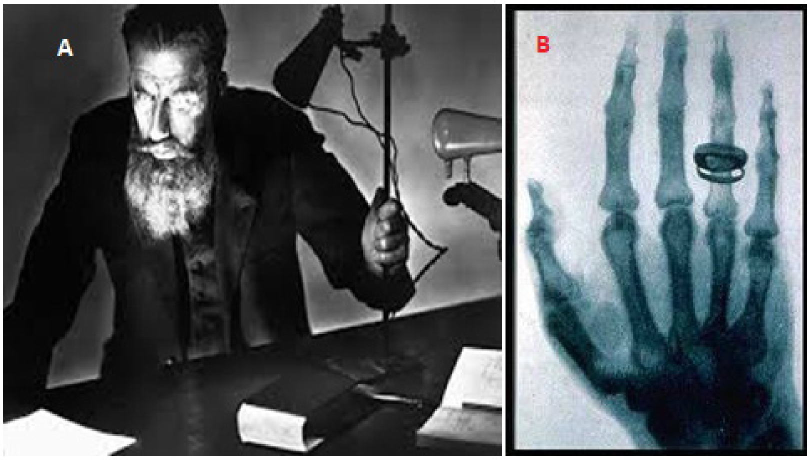


Fig.5. 6. An X-ray picture (B) (radiograph) taken by Rontgen (A) of Albert von Kölliker's hand.

A widely used and vastly improved x-ray technique is *computed tomography;* the corresponding instrument is called a *CT scanner.* The x-ray source produces a thin, fan-shaped beam that is detected on the opposite side of the subject by an array of several hundred detectors in a line. Each detector measures absorption along a thin line through the subject. The entire apparatus is rotated around the subject in the plane of the beam, and the changing photon-counting rates of the detectors are recorded digitally. A computer processes this information and reconstructs a picture of absorption over an entire cross section of the subject. In the middle 1970, CT (Computer Tomography) scanning machines were introduced in medicine.

X-rays are also used in the following:

- Killing of cancerous cells
- Radiography is also used in industry for examining potentially damaged machinery to ascertain the cause of damage and to verify castings or welded joints
- X-rays are used to study the structure of crystals (crystallography).

When a handgun is fired, a cloud of gunshot residue (GSR) is ejected from the barrel. The x-ray emission spectrum of GSR includes characteristic peaks from lead (*Pb*), antimony (*Sb*), and barium (Ba). If a sample taken from a suspect's skin or clothing has an x-ray emission spectrum with these characteristics, it indicates that the suspect recently fired a gun.

b. Examining luggage cargo and security.

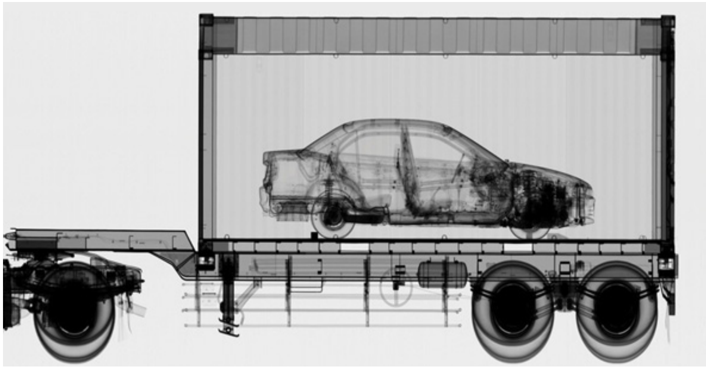


Fig.5. 7 Trailer carrying a car on check by X-rays

X-rays are being used in airports to examine luggage for weapons or bombs.

Note that the metal detector that you walk through in the airport does not use x-rays to examine you instead it uses magnetic waves to detect metal objects. X-rays are also being used to examine cargo luggage for illegal or dangerous material as in Fig.5.7.

c. In industry

They can be used to detect structural problems and cracks in metals that cannot be seen from the outside. X-rays are used on commercial airplanes, bridges metals and pipe lines, to make sure there are no stress fractures or other dangerous cracks in the material.

d. In scientific research

- X-ray diffraction provides one of the most important tools for examining the three-dimensional (3D) structure of biological macromolecules and cells.
- They are also used in crystallography, where X-ray diffraction and scattered waves show the arrangement of atoms in the crystal.

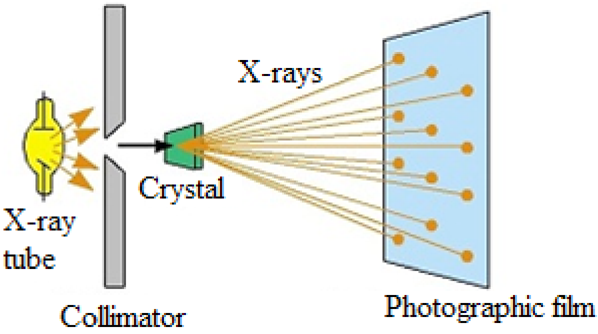


Fig.5. 8 Schematic diagram of the technique used to observe the crystal structure by x-rays diffraction.

The array of spots formed on the film is called a Laue pattern and show the atom structure of the crystal.

5.3.2 Dangers

- **X rays cause damage to living tissues**. As X-ray photons are absorbed in tissues, their energy breaks molecular bonds and creates highly reactive free radicals (such as neutral *H* and *OH*), which in turn can disturb the molecular structure of proteins and especially genetic material. Young and rapidly growing cells are particularly susceptible, which is why X-rays are useful for selective destruction of cancer cells.
- Because X-rays can kill living cells, they must be used with extreme care. When improperly used they can cause severe burns, cancer, leukemia, and cataracts. They can speed aging, reduce immunity to disease, and bring about disastrous changes in the reproductive cells.
- Lead screens, sheets of lead-impregnated rubber, and leaded glass are used to shield patients and technicians from undesired radiation.
- The effect of X-ray radiations is cumulative. That is, many minor doses over a number of years is equivalent to a large dose at one time.
- Unnecessary exposure to x-rays should be avoided. MRI (Magnetic Resonance Imaging) uses magnets and sound energy to form pictures of the internal organs without exposing patients to harmful X-rays.
- When they are used in hospitals, the sources should be enclosed in lead shields.

A careful assessment of the balance between risks and benefits of radiation exposure is essential in each individual case.

5.3.3 Safety precaution measures of dangers caused by x-rays

Medical and dental X-rays are of very low intensity, so that the hazard is minimized. However, X-ray technicians who go frequently behind the lead shield while operating X-rays need to be protected because of the frequency of exposure. A person can receive many medical or dental X-rays in a year with very little risk of getting cancer from it. In fact, exposure to natural radiation such as cosmic rays from space poses a greater risk.

The following are some of the precautions:

i) Protective suits and wears such as gloves and eye glasses made of *lead* are used always when handling these radiations. These shields protect the workers from X-ray exposure.

ii) Workers who operate equipment's that use X-rays must wear special badges which detect the amount of radiation they are exposed to.

iii) Food and drinks are not allowed in places where X-radiations are present.

iv) Experiments that involve these radiations (X-rays) substances should be conducted in a room surrounded by thick concrete walls or lead shields.

v) Equipment that use X-rays should be handled using remote-controlled mechanical arms from a safe distance.

Application activity 5.3

1. Using relevant examples, explain how X-rays are applied in different fields.
2. Examine the dangers that may arise if these radiations are not handled with care.
3. As a year III student- teacher, advise an internee having internship in an area that has X-rays on what to do to avoid the dangers that may be caused by X-rays.

Skills Lab 5

In this activity you will visit a nearest Laboratory that uses X-rays. It may be a hospital or an industry. In your visit, try to focus on the following

a. How do technicians obtain the x-rays?

b. Why is the room where radiology services done isolated?

c. What are some of the rules followed while in a room where radiology services are provided?

d. How is X-ray machine operated to achieve results?

e. What are safety precautions to the dangers that may be due to exposure of X-rays.

You can ask any question of your choice you think is relevant and can make you understand this unit.

As you come back to the school, make sure you make a comprehensive report on what you studied from the hospital. Compare the findings to what you discussed in physics classes.

Present your final findings to the whole class and then finally to your physics tutor.

End of unit 5 assessment

Where necessary use the following constants.

Speed of electromagnetic particles in vacuum $c = 3.0 \times 10^{8} m/s$

Planck's constant $h = 6.63 \times 10^{-34} Js$

Electronic charge $e = 1.6 \times 10^{-19} C$

Mass of an electron $M_e = 9.11 \times 10^{-31} kg$

Mass of a proton $M_p = 1.627 \times 10^{-27} kg$

1. Choose the letter that best matches the true answer:

(i) X-rays have

A. short wavelength
C. both A and B
B. high frequency
D. longest wavelength

(ii) If fast moving electrons rapidly decelerate, then rays produced are

A. alpha rays
C. beta rays
B. x-rays
D. gamma rays

iii) Energy passing through unit area is

A. intensity of x-ray
C. wavelength of x-ray
B. frequency of x-ray
D. amplitude of x-ray

iv) X-rays are filtered out of human body by using

A. cadmium absorbers
C. copper absorbers
B. carbon absorbers
D. aluminum absorbers

v) Wavelength of x-rays is in range

A. 10^{-8} m to 10^{-13} m
C. 10^{-10} m to 10^{-15} m
B. 10^{-7} m to 10^{-14} m
D. 10^{2} m to 10^{9} m

2. An x-ray operates at 30 kV and the current through it is 2.0 mA. Calculate:

(i) The electrical power output

(ii) The number of electrons striking the target per second.

(iii) The speed of the electrons when they hit the target

(iv) The lower wavelength limit of the x-rays emitted.

3. An x-ray machine can accelerate electrons of energies 4.8 x 10^{-15} J. The shortest wavelength of the x- rays produced by the machine is found to be 4.1 x 10^{-11}m . Use this information to estimate the value of the plank constant.

4. You have decided to build your own x-ray machine out of an old television set. The electrons in the TV set are accelerated through a potential difference of 20 kV. What will be the λ_{min} for this accelerating potential?

5. A tungsten target (Z = 74) is bombarded by electrons in an x-ray tube. The *K*, *L*, and *M* atomic x-ray energy levels for tungsten are -69.5, -11.3 and -2.30 keV, respectively.

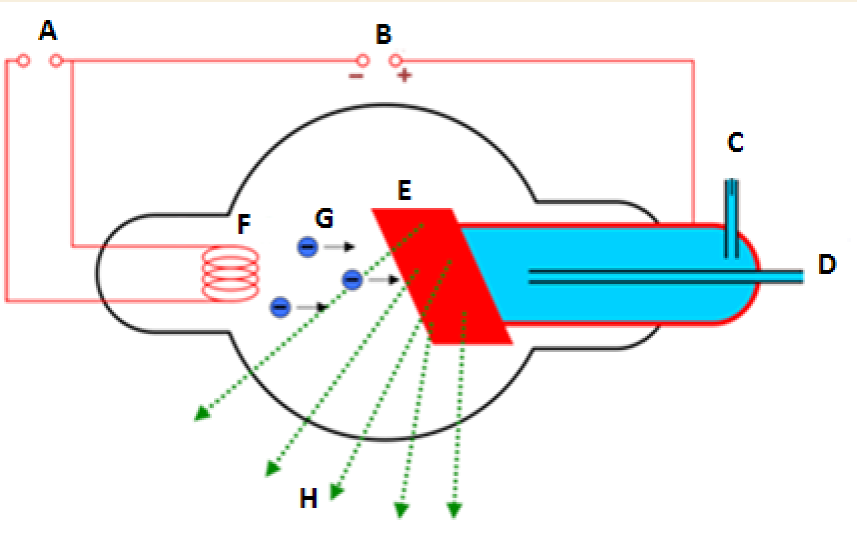
   a) Why are the energy levels given as negative values?

   b) What is the minimum kinetic energy of the bombarding electrons that will permit the production of the characteristic and lines of tungsten?

   c) What is the minimum value of the accelerating potential that will give electrons this minimum kinetic energy?

   d) What are the and wavelengths?

6. Using the following illustration, name each part marked by letter from A to H and explain the function of each part A, B, C, D, E, F and H.



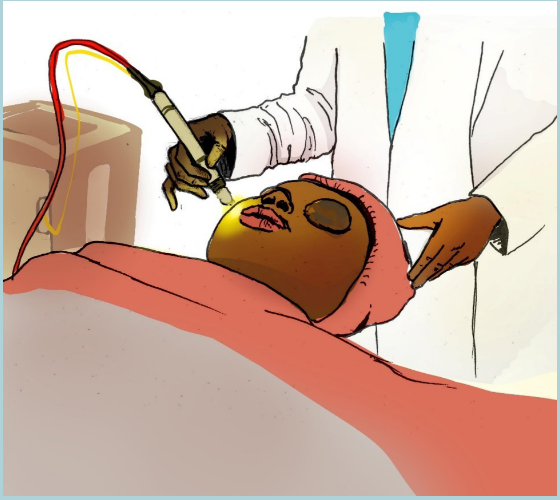
UNIT 6

LASER AND ITS EFFECTS.

Key Unit Competence:

Point out effects of LASER beam.

Introductory activity



Man has tried all forms of advancements from traditional methods of solving problems to advanced methods by use of different technologies. Among other technological advancements, discovery of Laser that is a part of visible light under electromagnetic waves has had a great impact in solving many of our problems. In the picture above a doctor is examining internal part of a patient using LASER beam. This work has been made easy by use of strong radiations like LASER beam.

Note: **LASER** stands for **Light Amplifier by Stimulated Emission of Radiation**.

a) From the diagram, what is the nature of LASER light?

b) What do you think are characteristics of a LASER beam as observed from the figure above?

c) LASER beam is used in different fields. These include, industry, Agriculture, Medicine and Scientific research. Can you explain how these radiations are useful to these fields?

d) Though these radiations are useful in real life, but they are also dangerous if miss-used. Can you guess some of the dangers of LASER beam?

e) With relevant examples, what do you think are dangers caused by these LASER beam radiations if not well controlled?

6.1 PRODUCTION OF LASER

Activity 6.1

The laser is a special device that uses the ability of some substances to absorb electromagnetic energy and re-radiate it, as a highly focused beam of monochromatic and synchronized wavelength radiation. Laser has to be produced in laboratory so that people benefit from its uses.

a) From your own understanding, explain how a LASER light can be produced.

b) Does its production, need source of energy like electricity? Explain your reasoning.

c) In energy levels, particles are either in ground or excited states. Is laser formed when particles or electrons are in ground or excited states? Explain your reasoning.

d) From question in c) it is clearly indicated that particles are either in ground state or excited state. Explain the changes in number of particles (electrons) in each level as they energy is absorbed.

The acronym **LASER** stands for **Light Amplifier by Stimulated Emission of Radiation**. This expression means that the light is formed by stimulating a material's electrons to give out the laser light or radiation.

In 1953 Charles H. Townes, with graduate students James P. and Herbert J., produced the first **Microwave Amplifier by Stimulated Emission of Radiation** (MASER), as a device operating in the same way as a laser, but amplifying microwave radiations. This system could release stimulated emissions without falling to the ground state, and thus maintaining a population inversion. A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. That is, the **laser** is a light source that produces a beam of highly coherent and very nearly monochromatic light because of cooperative emission from many atoms.

6.1.1 Absorption, Spontaneous emission and Stimulated emission

a. Absorption

During the process of absorption, a photon from the source is losingits entire energy to the atom which was at the ground state and then the atom is promoted to the excited state.

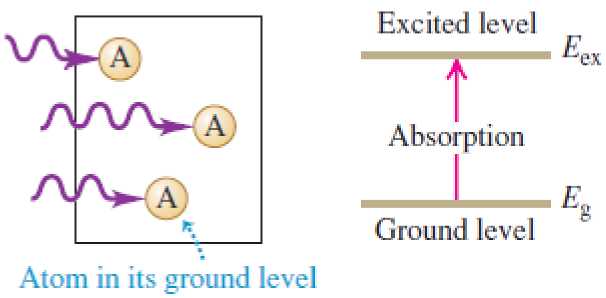


Fig.6. 1:Absorption process

b. Spontaneous emission.

An atom or an electron can move from one energy level to another. A photon is released when an electron moves from a higher energy level to a lower energy level. The release of photon (a particle of light) is called **spontaneous emission.**

At the excited state, an atom will drop to a lower level by emitting a photon of radiation in a process called spontaneous emission. It emits the photon spontaneously after an average time τ called the **spontaneous lifetime** of the level. This time depends on the atomic species; some levels have long lifetime measured in seconds, whereas others are relatively short on the order of nanoseconds or less. This lifetime determines the ability of the emitting atom to store energy and will affect the efficiency of sources.

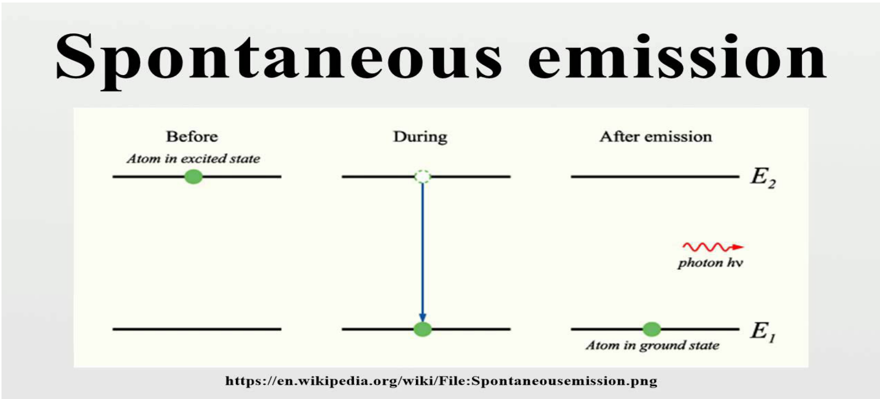


Fig.6. 2 Process of spontaneous emission

When an excited atom, depending on its lifetime at the higher energy level, comes down to lower energy level, a photon is emitted, corresponding to the equation,

$$hf = E_2 - E_1$$
$$or\ hv = E_2 - E_1$$

where

- h is the Planks constant,
- $f\ or\ v$ is the frequency of the emitted photon
- E_2 and E_1 correspond to higher and lower energy levels respectively.

This process of spontaneous emission is a random process and the probability of such transition depends on the number of atoms in the excited state .The number of such transition per unit volume per second is A_{21} where A is known as the Einstein's constant.

c. Stimulated emission

Stimulated emission occurs when a photon strikes an atom that is in excited state and makes the atom emit another photon

In **stimulated emission** (Fig. 6.3), each incident photon encounters a previously excited atom. A kind of resonance effect induces each atom to emit a second photon with the same frequency, direction, phase, and polarization as the incident photon, which is not changed by the process. For each atom there is one photon before a stimulated emission and two photons afterthus the name *light amplification.* Because the two photons have the same phase, they emerge together as *coherent* radiation.

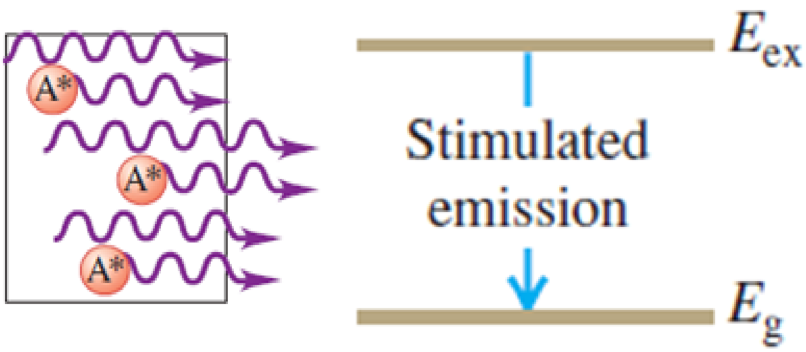


Fig.6. 3 Stimulated emission process

6.1.2 Population inversion

Population inversion: This is the process of increasing excited electrons in higher energy levels.

Normally, most atoms are in ground state, so most of the incident energy or photon will be absorbed. To achieve a coherent light from stimulated emission, there are some conditions that should be satisfied.

In the first case, the atoms must be excited to the higher state and so an **inverted population** is produced. One in which more atoms are in upper state than in lower one.

The emission of photons will dominate over absorption.

In the second case, the higher state must be a **metastable state.** This is a state in which the electrons remain longer than usual so that transition to the lower state occurs by stimulated emission rather than spontaneously.

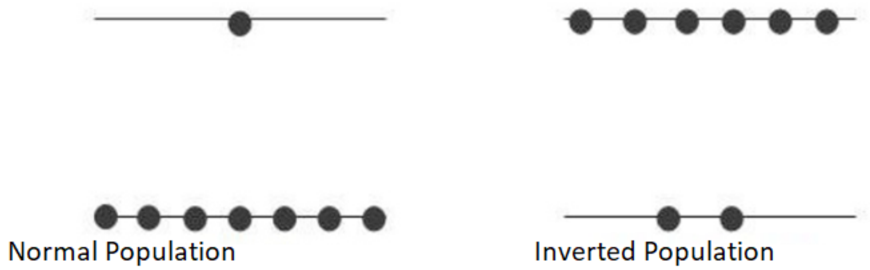


Fig.6.4. Population inversion

This is the redistribution of atomic energy levels that takes place in a system so that **laser action can occur.**

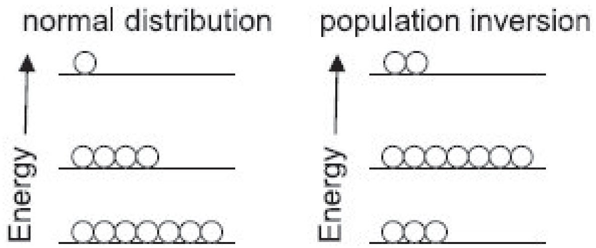


Fig.6.5 Process of population inversion.

There are different methods of achieving population inversion in atomic states that is essential requirement to produce laser beam.

Normally, most of the atoms in a medium are in the ground state of energy E_0. There are four different methods of making these atoms to get to excited states:

i) **Excitation with the help of photons**: If the atoms are exposed to an electromagnetic radiation of high frequency, then there is selective absorption of energy and thus atoms are raised to excited state.

ii) **Excitation by using electrons:** This method is used in some gas lasers. Electrons are released from the atoms due to high voltage electric discharge through a gas. These electrons are then accelerated to high velocities due to high electric field inside a discharge tube. When they collide with neutral gas atoms, a fraction of these atoms are raised to excited state

$$e + X \rightarrow X^{*} + e$$

Where X is an atom in ground state and X^{*} is an atom in excited state

iii)Inelastic collision between atoms: If a gas contains two different kinds of atoms X and Y, then during electric discharge through the gas some of the atoms are raised to excited state.

iv) Excitation by chemical energy: Sometimes, an atom or a molecule can be a product of a chemical reaction and can be produced in its excited state. An example is hydrogen combining with fluorine to form hydrogen fluoride HF that is in excited state.

6.1.3 Laser structure

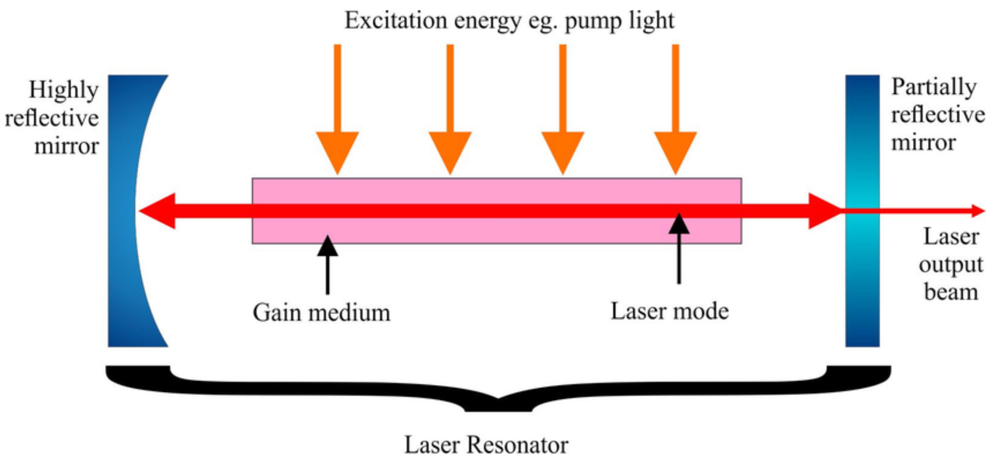


Fig.6. 6 General structure of Laser

In general case laser system consists of three important parts: **Active medium** or **amplifying medium,** the energy source referred as the **pump** or pump source and the **optical resonator** consisting of mirrors or system of mirrors.

Pumping Mechanism

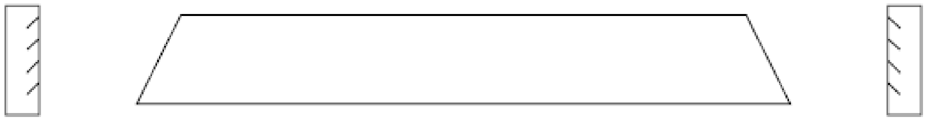
Pumping is the process of supplying energy to the laser medium to excite to the upper energy levels. To have this mechanism, it depends on the existence of interactions between light from pump source to constituents of active medium. Usually, pump sources can be: electrical discharges, flash lamps, arc lamps, light from another laser, chemical reactions and even explosive devices. Most common lasers use electrical or optical pumping. The type of pump source used depends essentially on the gain medium.

Active Medium

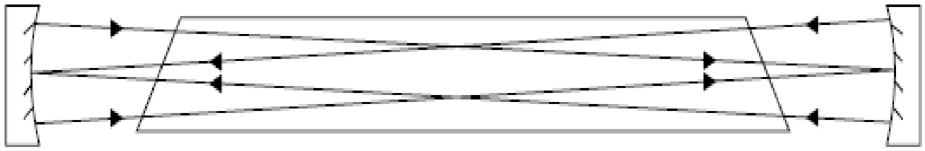
The active medium is the major determining factor of the wavelength of operation, and other properties of the laser. The gain medium is excited by the pump source to produce a population inversion, and it is where the spontaneous and stimulated emission of photons take place, leading to the phenomenon of optical gain or amplification. The gain medium may be a solid crystal like a ruby, a liquid dye, gases like CO_2 or He-Ne or semiconductors. The gain medium for some lasers like gas lasers is closed by a window under the Brewster's angle to allow the beam to leave the laser tube.

Optical resonator or Optical cavity

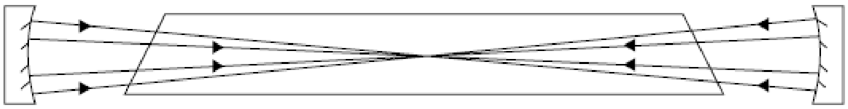
The optical resonator or optical cavity is a system of two parallel mirrors placed around the gain medium that provide reflection of the light beam. Light from the medium produced by the spontaneous emission is reflected by the mirrors back into the medium where it may be amplified by the stimulated emission. Mirrors are required for most lasers to increase the circulating power within the cavity to the point where gains exceed losses, and to increase the rate of stimulated emission. One of the mirrors reflects essentially 100% of the light, while the other less than 100% and transmits the remainder. Mirrors can be plane, spherical or a combination of both. Here represented are the common cavities configuration that can be used:



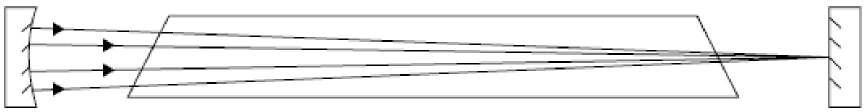
(*a*) Plane Mirror Resonator



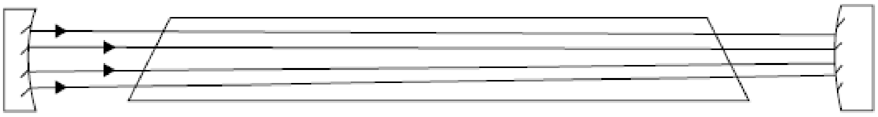
(*b*) Confocal Resonator



(*c*) Concentric Resonator



(*d*) Spherical-Plane Resonator



(e) Concave–Convex Resonator

Fig 6. 7. Optical resonators

Application activity 6.1

1. Write in full the acronym L.A.S.E.R
2. What do you understand by the term LASER?
3. In your own words, explain how laser light is produced.
4. Explain the meaning of population inversion and discuss how an atom can be put into excited state.
5. a) What are the three major components of laser?
   b) Using diagrams, explain all the types of optical cavity.
6. With the aid of diagrams explain the meaning of the following terms as applied in LASERs
   i) Stimulated Absorption
   ii) Stimulated Emission
   iii) Spontaneous Emission
   iv) Population inversion

6.2 PROPERTIES OF LASER BEAM

Activity 6.2

Lasers emit light that is highly directional. Laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as coming from the sun, a light bulb, or a candle, is emitted in many directions away from the source.

a) By analyzing how a laser pointer works, discuss characteristics of laser light?
b) Do you think all different kinds of laser light have the same properties? Give reasons to support your answer.

The laser light is not like any other light emitted by usual sources found in nature. This special light emitted by the laser, has three properties according to its usefulness in many applications: Coherence, Monochromaticity and Collimation or Directionality.

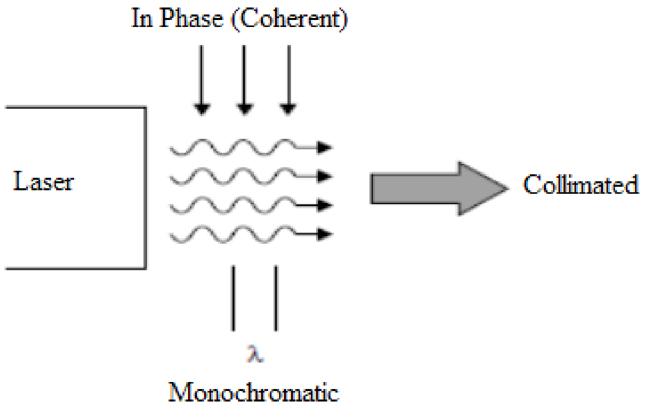


Fig.6. 8 Properties of laser light

6.2.1 Coherence

Coherence is the most interesting property of laser light. All photons emitted, are exactly in the same phase, they are all **crest** and **valley** at the same time. It is brought about by the mechanism of the laser itself in which photons are essentially copied.

The good temporal coherence is essentially for Interferometry like in Holography. Coherence is not trivial and is brought about by the amplification mechanism of the laser.

6.2.2 Monochromaticity

Monochromaticity is the ability of the laser to produce light that is at one wavelength λ. It is a requirement for coherence since photons of different wavelengths cannot be coherent. When white light is dispersed through a prism, you note that it is composed of an infinite number of wavelengths of light covering the entire visible spectrum as well as into the UV and IR regions. However, no light source is perfectly monochromatic. Lasers tend to be relatively monochromatic and this depends on the type of laser. Monochromatic output, or high frequency stability, is of great importance for lasers being used in Interferometry.

6.2.3 Collimation or Directionality

Collimation or directionality is the property of laser light that allows it to stay in one direction at the strait line, confined beam for large distances. This property makes it possible to use the laser as a **level** in construction or to pinpoint speeders on a highway. This highly directional laser light is determined by the mechanism of the laser itself.

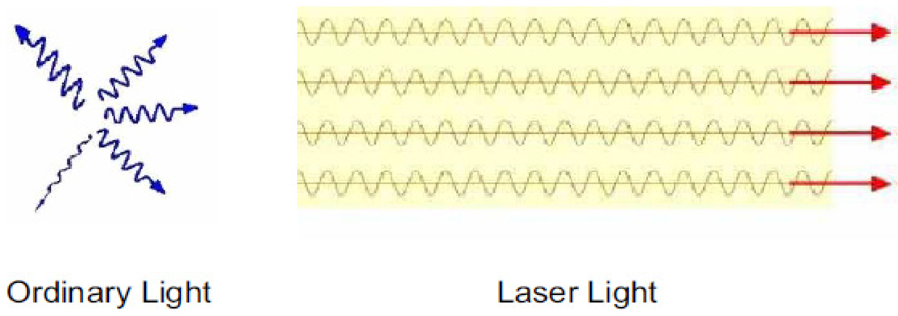


Fig.6. 9 Specific direction of laser light

Application activity 6.2

1. Choose the correct group of terms that are properties of laser light.
   A. Coherent, unpolarized, monochromatic, high divergence
   B. Monochromatic, low divergence, polarized, coherent
   C. Polychromatic, diffuse, coherent, focused
   D. Monochromatic, birefringent, nonpolarized, coherent
2. Which of the following properties of laser light enables us to use it to measure distances with great precision?
   A. All the light waves emitted by the laser have the same direction
   B. The light waves are coherent
   C. The light waves are monochromatic
   D. The individual waves effectively work like a single wave with very large amplitude.
3. Explain how coherence, monochromatic and collimation are interconnected.
4. All light in laser light are produced and found to be in the same phase. How does this help in the formation of 3D images?
5. Laser light can be used as a level. Which special feature that makes it be used as a level. Explain your answer
6. Explain the meaning of the following properties of LASERS
   i) Monochromaticity
   ii) Coherence
   iii) Directional/collimation.

6.3 APPLICATIONS AND DANGERS OF MISUSE OF LASER

Activity 6.3

You can use the figure above to answer the following questions

a) Starting from the figure indicated above, where do you think in real life LASERS are helpful?

b) From your experience, have you ever used LASER light?

c) Other than using it by yourself, what are other places where laser light is applied

6.3.1 Applications of lasers.

There are many interesting uses for lasers, depending on the special characteristic being applied. Laser Diodes are used in a wide range of applications. Partial lists of those applications include:

i) They are used in common consumer devices such as DVD players, bar code scanners; CD ROM drivers; laser disc and other optical storage drivers; laser printers and laser fax machines; sighting and alignment scopes; measurement equipment; free space communication systems; pump source for other lasers; high performance imagers; and typesetters. CD players have lasers. Light from the laser in CD player reflects off patterns on CD's surface. The reflected light is converted to a sound wave.

ii) Laser beams can be used in diverse fields of science and technology. Like in the control of motion of moving objects like aircrafts or missiles. This method thus makes it possible for a missile to hit a certain target.

iii) Because of high directional property, lasers are used to measure distances accurately. A laser beam is sent, and the time taken for it to be reflected back is measured. Using this idea, the distance can thus be measured.

iv) Because laser beam can be focused into a small spot, it can thus be used to cut minute holes onto a material.

v) The very high intensity of laser beam means that the amplitude of the corresponding electromagnetic wave is very large. So it is possible to investigate the nonlinear optical properties of different materials with the help of laser light.

vi) Lasers are also used in industry for cutting materials such as metal and cloths. and welding materials

vii) Doctors use lasers for surgery and various skin treatments

viii) They are used in military and law enforcement devices for marking targets and measuring range and speed.

ix) Laser lighting displays use laser light as an entertainment medium.

x) Lasers also have many important applications in scientific research

In a tabular way, we can have a summary of different types of lasers and their applications.

The following are types of lasers and their applications

a. Gas Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Helium-neon laser	632.8nm	Electrical discharge	Holography, spectroscopy, barcode scanning, alignment, optical demonstrations
Argon laser	454.6 nm, 488.0 nm, 514.5 nm	Electrical discharge	Retinal phototherapy (for diabetes), lithography, confocal microscopy, spectroscopy pumping other lasers
Carbon dioxide laser	10.6 μm, (9.4 μm)	Electrical discharge	Material processing (cutting, welding, etc.), surgery

Excimer laser	193 nm (ArF), 248 nm (KrF), 308 nm (XeCl), 353 nm (XeF)	Excimer recombination via electrical discharge	Ultraviolet lithography for semiconductor manufacturing, laser surgery

Table 6. 1 Gas lasers and their applications

b. Solid State Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Ruby laser	694.3nm	Flash Lamp	Holography, tattoo removal. The first type of visible light laser invented; May 1960.
Nd: YAG laser	1.064 µm, (1.32 µm)	Flash Lamp, Laser Diode	Material processing, laser target designation, surgery, research, pumping other lasers. One of the most common high power lasers.
Erbium doped glass lasers	1.53-1.56 µm	Laser diode	um doped fibers are commonly used as optical amplifiers for telecommunications.
F-center laser	Mid infrared to far infrared	Electrical current	Research purposes.

Table 6. 2 Solid state lasers characteristics and their applications.

c. Metal-vapor Lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Helium-cadmium (HeCd) metal-vapor laser	441.563 nm, 325 nm	Electrical discharge in metal vapor mixed with helium buffer gas.	Printing and typesetting applications, fluorescence excitation examination
Copper vapor laser	510.6 nm, 578.2 nm	Electrical discharge	Dermatological uses, high speed photography, pump for dye lasers

Table 6. 3 Metal-vapor lasers characteristics and their applications

d. Other types of lasers:

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Dye lasers	Depending on materials, usually a broad spectrum	Other laser, flash lamp	Research, spectroscopy, birthmark removal, isotope separation.
Free electron laser	A broad wavelength range (about 100 nm - several mm)	Relativistic electron beam	Atmospheric research, material science, medical applications

Table 6. 4 Other kinds of lasers characteristics and their applications

6.3.2 Dangers of lasers

You should be careful when dealing with lasers, because they can have a negative impact when exposed to your body. Among other negative effects, some of them are discussed below

i) If directly exposed to our skin, it burns the skin

ii) When absorbed by skin, Laser light reacts with body cells causing cancer.

iii) Because of their high energy, it affects eyes if exposed to them

iv) Lasers can affect cells of a human being. This leads to mutation

Because of the negative effects of lasers, care must be taken to avoid all the risks of being affected by lasers.

6.3.3 Precaution measures to avoid negative effects of lasers

The following are some of the measures one can take to avoid the negative effects of lasers.

i) For any one working in places where there are incidences of being exposed to laser light, one should wear protective clothes, glasses and shoes so that there is no direct exposure of these radiations on to the body.

ii) One should minimize the time of working with lasers.

iii) Areas that are exposed to these radiations should be warning signs and labels so that one can be aware of places/areas where laser light is used.

iv) Safe measures like Use of remote control should be used to avoid direct exposure of these radiations (LASER light).

v) People should be given trainings on how to handle lasers.

vi) There should also access restrictions to laboratories that use laser

Application activity 6.3

1. i) Discuss applications of Laser Light in daily life

   ii) Though LASER light is important in day today life but if miss-used it can be dangerous to our lives. Discuss dangers that may arise if it is miss-used.

   iii) . Using vivid examples, explain how one can prevent him or herself of all dangers caused by laser light.

2. We have seen that laser light is good and at the same time bad. Using your personal judgment, which side outweighs the other? Give scientific reasons.

3. Depending on your judgment in (2) do you think man should continue using laser light?

4. Lasers are classified depending on either how they are produced or the material that makes up laser. Discuss

i) Types of lasers

ii) Examples of lasers.

Skills Lab 6

This activity intends to make you analyze how LASER light is produced and used.

What to do?

Visit a nearby hospital Laboratory where they do LASER surgery.

Note: Before you make a visit make sure that you inform them like a week before through class leaders or your physics tutor.

In your visit focus on the following:

a. How laser light is produced
b. How LASER beam is used to do surgery.
c. Why do they adopt using this type of surgerybut not other forms?

For each case compile out your findings and a full report about lasers.

End of unit 6 assessment

Copy the questions below to your exercise books and chose the best alternative that answers the question.

1) What does the acronym LASER stand for?
   A. Light Absorption by Stimulated Emission of Radiation
   B. Light Amplification by Stimulated Emission of Radiation
   C. Light Alteration by Stimulated Emission of Radiation

2) The acronym MASER stands for?
   A. Microwave Amplification by Stimulated Emission of Radiation
   B. Molecular Absorption by Stimulated Emission of Radiation
   C. Molecular Alteration by Stimulated Emission of Radiation
   D. Microwave amplification by Stimulated Emission of Radio waves

3) Which of the following is true about population inversion
   A. Number of electrons in excited levels reduces
   B. Number of electrons in excited levels increase
   C. Number of electrons in ground levels reduces
   D. Electrons remain completely in ground state

4) Which of the following determines the color of light?
   A. its intensity
   B. its wavelength
   C. its source
   D. Some information missing

5) Among the three examples of laser listed below, which one is considered "eye safe"?
   A. Laser bar-code scanners
   B. The excimer laser
   C. Communications lasers
   D. YAG

6) Why are lasers used in fiber optic communications systems?
   A. The government has mandated it
   B. They can be pulsed with high speed data
   C. They are very inexpensive
   D. They are not harmful

7) Lasers are used in CDs and DVDs. What type of laser is used in these players?
   A. Semiconductor
   B. YAG
   C. Alexandrite
   D. All the above

8) The best reason why lasers used in "Laser Printers" is
   A. They can be focused down to very small spot sizes for high resolution
   B. They are cheap
   C. They are impossible to damage
   D. They are locally available

9) As wavelength gets longer, the laser light can be focused to…
   A. Larger spot sizes
   B. Smaller spot sizes
   C. Large and small spot sizes
   D. None of the above

10) Among the following, which color of laser has the shortest wavelength?

A. Yellow	C. Blue
B. Red	D. Green

11) What property of laser light is used to measure strain in roadways?
   A. Intensity
   B. Power
   C. Coherence
   D. All the above

12) What is the type of laser used most widely in industrial materials processing applications?

A. Dye Laser	C. YAG laser
B. Ruby Laser	D. Carbon Dioxide Laser

13) Why are lasers used for cutting materials?

A. It never gets dull	D. It has a small "heat affected zone"
B. Accuracy	E. Smoother cuts
C. Repeatability	F. All of the above

14) The Excimer laser produces light with what wavelength?
   A. Visible
   B. Ultraviolet
   C. Infrared
   D. All the above.

15) Most lasers are electrically inefficient devices.
   A. True
   B. False

16) Chemical lasers use………………. to produce their beams.
   A. Excessive amounts of electrical power
   B. Small amounts of electrical power
   C. No electrical power
   D. Other lasers

17) What type of laser could cause skin cancer if not used properly?
   A. Red semiconductor laser
   B. Excimer laser
   C. Blue semiconductor
   D. YAG laser.

18) a) what do you understand by term **LASER**?

   b) Depending on the nature and what laser is made of, Laser is classified into different types. Discuss at least 5 types of lasers

19) a) Laser light have been employed in different areas. This has helped man in solving different problems. What are some of the areas where laser light is employed?

   b) Though laser light is very important in different activities, it can also cause harm if miss-used in what ways is laser light harmful?

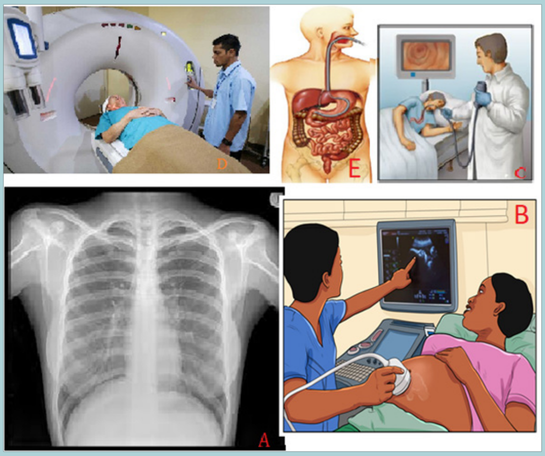
UNIT 7

MEDICAL IMAGING

Key Unit Competence:

Generate the processes in medical imaging.

Introductory activity



Years ago, the only way to get information from inside of human bodies was through surgery. In modern medicine, medical imaging has undergone major advancements and this ability to obtain information about different parts of the human body and has many useful clinical applications.

Observe and interpret, clearly the pictures above and answer to the following questions:

1. Describe the phenomena happening in each figures above (A, B, C, D and E)
2. Propose the technique that is being used for each image?
3. Suggest a detailed working principle of the mentioned techniques in each image
4. Are there other techniques that are not indicated in the figure above? If yes, state and explain them.
5. In your own view, what do you think are the effects of these techniques in general?

7.1. CONCEPT OF MEDICAL IMAGING.

Activity 7.1

Imagine you were in internship in a certain primary school in your district and while teaching in P3, a pupil happens to swallow a 20 Francs coin. You and fellow teachers gave her first aid and later your Head teacher assigned you to take her to the nearest hospital.

a) In your own view, how do you think a doctor will be able to locate the swallowed coin without operating her?

b) Explain using scientific reasoning, why a doctor needs to use method(s) you suggested in (a) above.

The technique and process of producing visual representations of the interior areas inside the human body (function of some organs or tissues) to diagnose medical problems and monitor treatment is known as **Medical imaging**.

There are many types of medical imaging, and more methods for imaging are being invented as technology advances. The main types of imaging used in modern medicine include

- Radiography.
- Mammography
- Magnetic resonance imaging.
- Nuclear medicine.
- Ultrasound.
- Endoscopy
- Elastography.
- Photoacoustic imaging.
- Tomography.
- Echocardiography, etc

In this unit, we shall focus on only the following:Radiography and Mammography,Magnetic Resonance Imaging,Ultrasound and Endoscopy.

SPECIFIC PURPOSES OF IMAGING TECHNIQUES

Each technique is used in different conditions. For example:

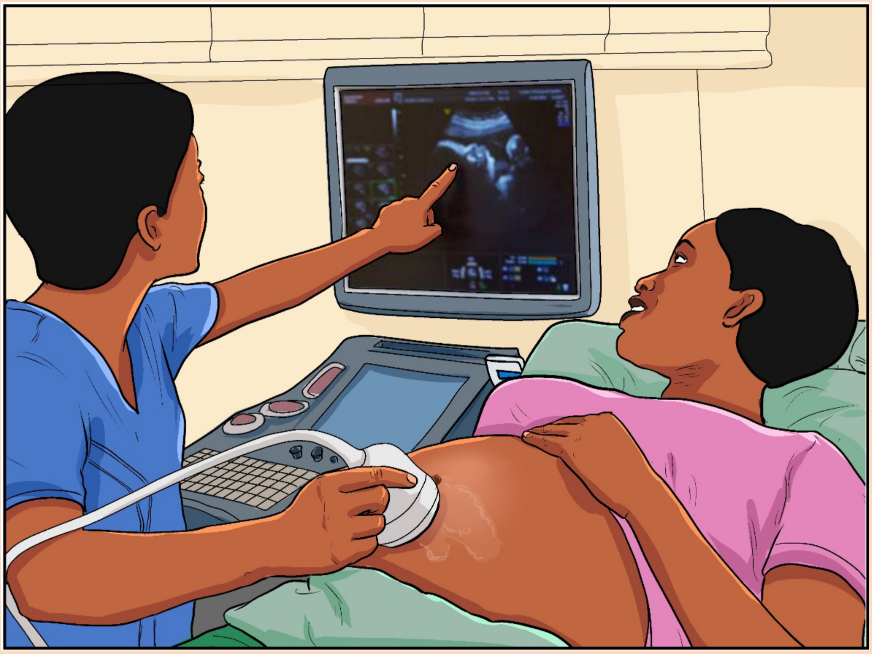
- Ultrasound is used to study the development of fetus in the mother's womb and to take images of internal organs when high resolution is not needed.
- Radiography is often used when we want images of bone structures to look for breakages.
- MRI scanners are often used to take images of the brain or other internal tissues, particularly when high-resolution images are needed.
- Nuclear medicine is used when you need to look inside the digestive or circulatory systems, such as to look for blockages. It uses radioactive materials that are injected or swallowed.

Application activity 7.1

1. Explain the meaning of medical imaging
2. Medical imaging being a new technique of examining internal parts of a body under examination, has been emphasized and used in different medical places. What are different methods of medical imaging you know and where are they used?
3. Highlight the purpose(s) of each of the methods mentions in question 2 above.

7.2 ULTRASONIC IMAGING

Activity 7.2



Mutesi is a young mother who was pregnant used to feel pain in her lower abdomen and she happened to go to the hospital for medical checkup. As she reached the hospital, she underwent a medical testing and her doctor referred her to undergo ultrasound scan.

What she noticed was a doctor moving a piezoelectric crystal on her abdomen. At the end, she was given image of affected part.

a) As a physics student, explain why the technique used is regarded as ultrasound?
b) From your understanding, how the emitted rays are used to capture the image of intended part and feed it back to the computer.
c) If you were a doctor, would you advise someone to always visit ultrasound scans every time he/she feels pain? If No explain why? If yes, defend your opinion.

7.2.1 Interaction of sound waves with different structure inside the body

Ultrasound imaging uses ultra-high-frequency sound waves to produce cross-sectional images of the body. Ultrasound is actually sound with a frequency in excess of 20 kHz, which is the upper limit of human hearing. The frequency range of normal person hearing is between 20 Hz to 20 KHz. In fact, the frequencies used in medicine are much higher than this, typically between 1 MHz and 15 MHz like all sound waves, ultrasound consists of longitudinal, elastic or pressure waves, capable of traveling through solids, liquids and gases. This makes them ideal for penetrating the body, unlike transverse mechanical waves, which cannot travel to any great extent through fluids.

Different tissues in a human or animal body alter the ultra sound waves in different ways. Some waves are reflected directly while others scatter the waves before they return to the transducer as echoes. The reflected ultrasound pulses detected by the transducer need to be amplified in the scanner or ultrasonic probe. The echoes that come from deep within the body are more attenuated than those from the more superficial parts and therefore required more amplification. When echoes return to the transducer, it is possible to reconstruct a two-dimensional map of all the tissues that have been in the beams. The information is stored in a computer and displayed on a video (television) monitor. Strong echoes are said to be of the high intensity and appear as brighter dots on the screen.

Normally in medicine, Doctors commonly use **ultrasound** to study a developing fetus (unborn baby), a person›s abdominal and pelvic organs, muscles and tendons, or their heart and blood vessels

7.2.2 Reflection of ultrasound

When the pulse of ultrasound is sent into the body and meets a boundary between two media, of different specific acoustic impedance Z, the sound wave needs to change gear in order to continue. If the difference in Z across the boundary is large the wave cannot easily adjust: there is an "acoustic mismatch". Most of the wave is reflected and a strong echo is recorded. The fraction of intensity reflected back (I_r) to that incident (I_i) at the normal incidence, is known as the **intensity of reflection coefficient** α

$\alpha = \frac{I_r}{I_i}$ which in turn reduces deduces to $\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$

where Z_1 is acoustic impedance of the first material and Z_2 is acoustic impedance of the second material

The specific acoustic impedance Z of a medium is given by

$$Z = \rho \times v$$

Where ρ is the density of the medium and v is he velocity of sound in medium.

Substances	$\rho \quad (kg/m^3)$	$v \quad (m/s)$	$Z \quad (kg/m^2 \cdot s)$
Air	1.29	3.31×10^2	430
Water	1.00×10^3	14.8×10^2	14.8×10^6
Fat	0.952×10^3	14.5×10^2	1.38×10^6
Muscle(average)	1.075×10^3	15.9×10^2	1.70×10^6
Blood	1.06×10^3	1.57×10^3	1.59×10^6
Brain	1.025×10^3	1.54×10^3	1.58×10^6
Soft tissue(average)	1.06×10^3	1.54×10^3	1.63×10^6
Bone(varies)	$1.4 \times 10^3 \ to \ 1.9 \times 10^3$	4.08×10^3	$5.6 \times 10^6 \ to \ 7.78 \times 10^6$

Table 7. 1 Values $\rho, v \ and \ Z$ for various substances

Note that large differences in Z give rise to large values for **intensity of reflection coefficient** (α), producing strong echoes.

Example 7.1:

Estimate the percentage of incidence intensity reflected back at fat per muscle boundary. If $Z_{fat} = 1.38 \ kg \ m^{-2} s^{-1} \quad and \ Z_{musc} = 1.70 \ kg \ m^{-2} s^{-1}$

Answer:

we need to calculate the value of for the boundary using the equation

$$\alpha = \frac{(Z_{mus} - Z_{fat})^2}{(Z_{musc} + Z_{fat})^2} = \frac{(1.70 - 1.38)^2}{(1.70 + 1.38)^2} = 0.011 = 1.1\%$$

Hence, 1.1% of the incidence intensity is reflected back.

7.2.3 Attenuation of ultrasound

The combined effect of scattering and absorption is called ***attenuation.*** The attenuation of the waves describes the reduction in its intensity as they travel through a medium. This loss is due to a number of factors:

- The wave simply "spreads out" and suffers an "inverse square law type" reduction in intensity.
- The wave is scattered away from its original direction
- The wave is absorbed in the medium.

The amount of **absorption** of ultrasound beam in a medium is described by the absorption coefficient, which is intensity level per unit length. It is expressed in decibels per cm and it firstly depends on the type of medium the wave is propagating into. As example whilst water absorbs very little ultrasound, bone is a strong absorber, putting it at risk, for example, during high- power ultrasound therapy.

Secondly, higher frequencies suffer greater absorption. In fact if the frequency is doubled, the absorption increases by the factor of four.

7.2.4 Ultrasonic imaging techniques

The basic component of the ultrasound probe is the piezoelectric crystal. Excitation of this crystal by electrical signals causes it to emit ultra-high-frequency sound waves; this is the piezoelectric effect. The emitted ultrasound waves are reflected back to the crystal by the various tissues of the body. These reflected sound waves also called the **"echoes"** act on the piezoelectric crystal in the ultrasound probe to produce an electric signal, again by the piezoelectric effect. It is this electric signal which is analysed by a computer produces a cross-sectional image.

The process of imaging is the same as the echo-locating sonar of a submarine or a bat. The observer sends out a brief pulse of ultrasound and waits for an echo. The pulse travels out, reflects off the target and returns. The ultrasound machine uses pulses because the same device acts as both transmitter and receiver. If it continually sent out sounds, then the receiver would not hear the much softer echo over the louder transmission.

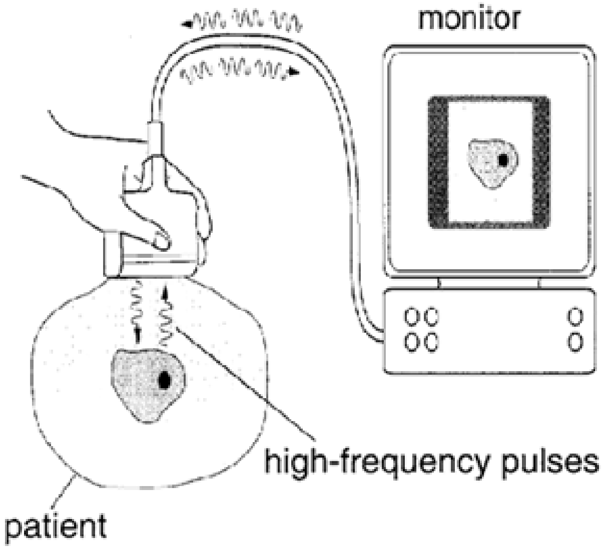


Fig.7. 1 Typical set up of ultrasound system

Sonar is an acronym for **So**und **N**avigation and **R**anging. It relies on the reflection of ultrasound pulses. A short pulse of ultrasound is directed towards the object interest, which then reflects it back as an echo. The total time between transmission of pulse and reception of an echo is measured, often using a **cathode ray oscilloscope (CRO).** The sonar principle is used to estimate the depth of a structure, using

$$d = \frac{vt}{2}$$

Where **t** is the time taken to go and back and is the velocity of ultrasound in the medium.

The factor of 2 is necessary because the pulse must travel "there and back"

An ultrasound beam structure is directly into the body. The reflection or echoes from different body structure are then detected and analyzed, yielding information about the locations. For example if the time delays between the reception of echo pulse1 and 2 (**Figure below**) is, then the diameter of the baby's head can be found using the above formula.

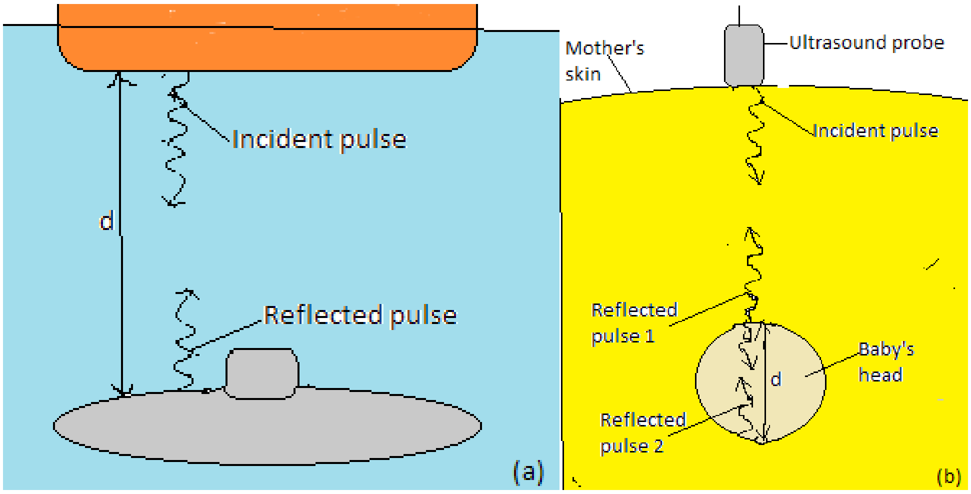


Fig.7. 2: Echo location: (a) conventional sonar; (b) medical imaging

Example 7.2:

1. The time Used for an echo to investigate an ultrasound is $125\ ms$, depth of the structure is 12.5 mm. find the average velocity of ultrasound in the eye

Answer:

$$v = \frac{2d}{t} = \frac{2\times12.5\times10^{-3}}{125\times10^{-3}} = 0.2\ \ m/s$$

2. During an investigation using ultrasound, the time delay for an echo to return from a structure is $25\ \mu s$. If the average velocity of ultrasound in the eye is 3000 m/s. Calculate the depth of the structure.

Answer

$$d = \frac{vt}{2} = \frac{(3000\,m/s)(25\times10^{-6}\ s)}{2} = 3.75\times10^{-3}\ m = 3.75\ \ mm$$

As ultrasound imaging uses sound waves to produce pictures of inside of the body. It is used to help diagnose the cause of pain, swelling and infection in the body's internal organs and to examine a baby in pregnant woman and the brain and hips in infants. It is also used to help guide biopsies, diagnose heart conditions and assess damage after a heart attack.

Ultrasound examinations do not use ionizing radiation (x-rays), there is no radiation exposure to the patient. Because ultrasound images are captured in real time, they can show the structure and movement of the body's internal organs, as well as blood flowing through blood vessels.

7.2.5 Risk and benefit associated to ultrasounds

Ultrasound imaging uses high-frequency sound waves, not used x-ray and no radiation exposure to the patient does not mean theat ultrasound is mostly safe. It has some dangers.

Some of them are:

- Cannot penetrate bone, so the adult skeletal system and head cannot be imaged.
- Clarity of image is poorer than in many other techniques.
- It cannot be used in areas that contain gas (such as lungs)
- Scan can take a long time and demand greater skills and experience to produce a clear result.Etc.

Apart from its dangers, ultrasound is helpful because:

No known harmful effects of diagnostic ultrasound.

Clear examination of soft tissues, e.g.Obstetric and abdomen studies

More cost effective than other imaging modalities

Real time imaging means required quick procedure.

It is noninvasive (of medicine procedures not involving the introduction of instruments into the body)

- Lack of ionizing radiation.
- Equipment is safe, easy to handle, can be operated and be portable.Etc.

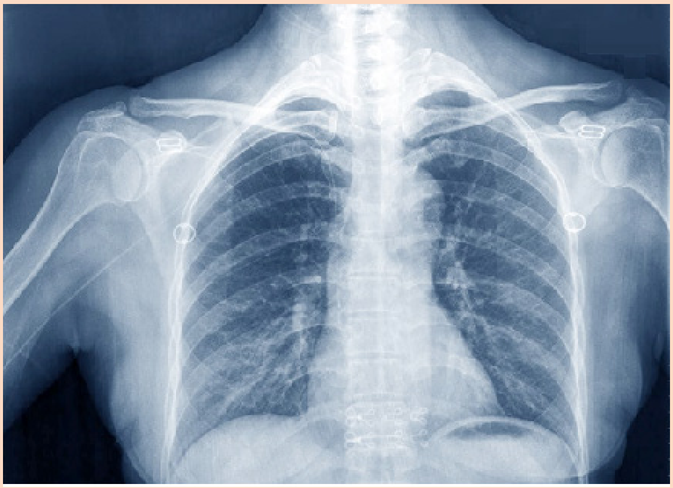
Application activity 7.2

1. Calculate the percentage of incidence intensity reflected back at:
   a) Air per soft tissues boundary
   b) Bone per softy tissues boundary.
2. Discuss on the purpose of using ultrasound in medicine
3. Outline the application of ultrasound scan?
4. Why ultrasound is performed

7.3 X-RAY IMAGING.

Activity 7.3

1. The figure below is what a Doctor got after X-rays scan in order to check a problem that was suspected to be in ribs.



a) Using the picture above, how do you think the doctor was able to get the image

b) Why do you think devices like cameras cannot give such images?

2. One day a girl suffering from the breast tells her mother about the problem. And her mother advises her to go to the hospital to consult a doctor. After examined by the doctor, she was referred to the X-ray room for further checking.

a) Imagine you are the doctor operating the X-ray device, explain all that you can do to detect the problem a girl had.

b) There are many methods of X-ray imaging techniques that may be used. Can you suggest one that can be used to examine breast problems? Defend your suggestion.

7.3.1 Interaction of X-rays with matter.

a. Introduction

In unit 5, we learnt that X-rays are electromagnetic radiation produced by focusing a beam of high energy electron on a target material in x-ray tube. Since the major part of the energy of the electrons is converted into heat in the target (only about 1% will appear as X-rays), the target material should have a high melting point and good heat conduction ability. To get a high relative amount of X-ray energy, the anode material should be of high atomic number. Tungsten is the dominating anode material and is in modern X-ray tubes often mixed with Rhenium.

In X-ray diagnostics, radiation that is partly transmitted through and partly absorbed in the irradiated object is utilized. An X-ray image shows the variations in transmission caused by structures in the object of varying thickness, density or atomic composition.

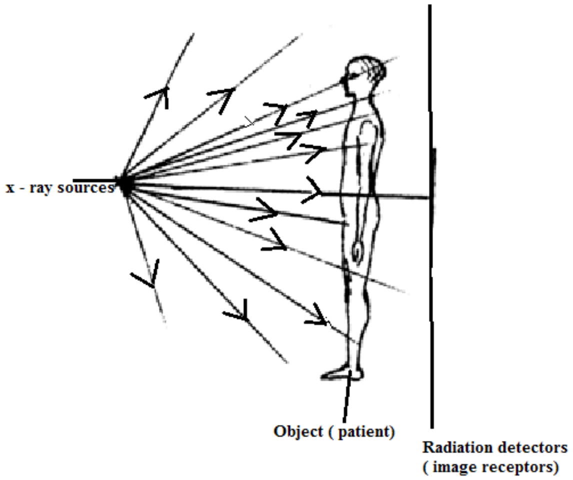


Fig.7. 3.The necessary attributes for X-ray imaging are shown: X-ray source, object (patient) and a radiation detector (image receptor).

b. Attenuation and Absorption of X-rays

There are principally two interaction processes that give rise to the x-ray attenuation (variation in photon transmission) through the patient which is the basis of X-ray imaging. These are photoelectric absorption and scattering processes.

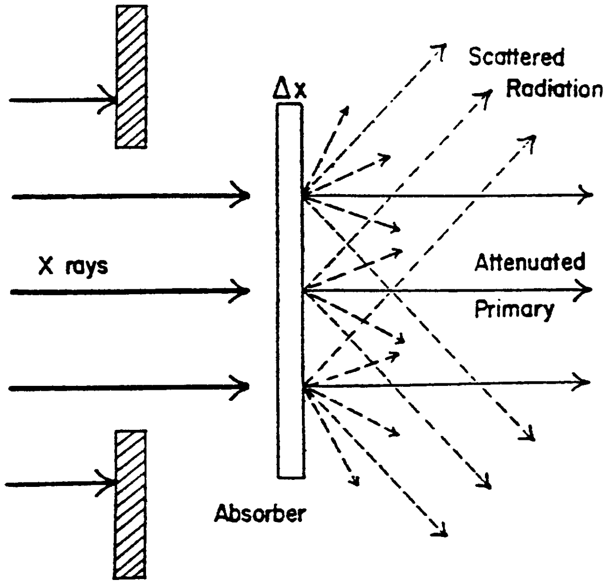


Fig.7. 4 Attenuation of mono -energeticX-ray photons in a thin layer of a given material

A photon which has experienced an interaction process has either been absorbed or has changed its energy and/or direction of motion. A photon that changes its direction of motion is called a scattered photon. For mono-energetic x-ray photons, the number of photons that experience such interactions and therefore removed from the primary beam when this is incident on a thin layer of material is proportional to the number of incident photons (N) and the thickness of the layer (dx) following the expression :

$$dN = -\mu \, Ndx$$

where μ is a constant of proportionality called **the linear attenuation coefficient**.

Integrating the above equation will result in

$$N(x) = N_o e^{-\mu x}$$

Where N_o is the initial number of photons in the incident beam.

It can be seen that the incident beam photons (or the beam energy) is attenuated exponentially as the x-rays travel through the material. The different interaction processes involved, that are absorption, coherent and incoherent scattering and pair production, add their contributions to the total linear attenuation coefficient

$$\mu = \mu_a + \mu_{coh} + \mu_{incoh} + \mu_p$$

Where μ_a, μ_{coh}, μ_{incoh} and μ_p are the contributions to the attenuation from photoelectric absorption, coherent scattering, incoherent scattering and pair production.

7.3.2 X-rays Imaging Techniques

a. Conventional Radiography

X-rays are able to pass through the human body and produce an image of internal structures. The resulting image is called **a radiograph**, more commonly known as an '**X-ray'** or **'plain film'**. The common terms **'chest X-ray'** and **'abdomen X-ray'** are widely accepted and abbreviated to **CXR** and **AXR**.

As a beam of X-rays passes through the human body, some of the X-rays photons are absorbed or scattered producing reduction or attenuation of the beam with the internal human structure acting as contrasting details. Therefore, tissues of high density and/or high atomic number cause more X-ray beam attenuation and are shown as lighter grey or white on radiographs. Less dense tissues and structures cause less attenuation of the X-ray beam, and appear darker on radiographs than tissues of higher density. The figure below shows the typical conventional radiograph of a human body.

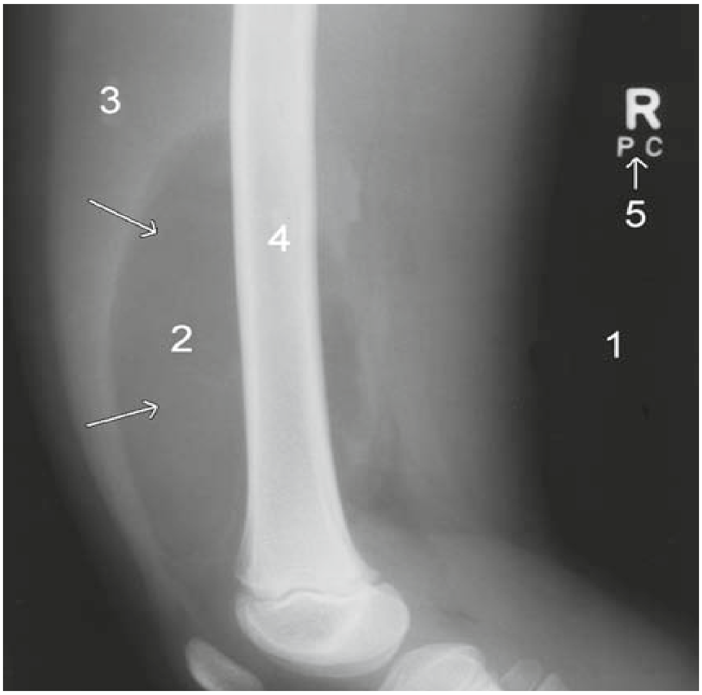


Fig.7. 5: The five principal radiographic densities(David, 2012).

Five principal densities are easily recognized on this plain radiograph due to the increase in their densities:

- Air/gas appears as black, e.g. lungs, bowel and stomach
- Fat is shown by dark grey, e.g. subcutaneous tissue layer, retroperitoneal fat
- Soft tissues/water appears as light grey, e.g. solid organs, heart, blood vessels, muscle and fluid-filled organs such as bladder
- Bone appears as off-white
- Contrast material/metal: bright white.

In the past, X-ray films were processed in a darkroom or in freestanding daylight processors. In modern practice, radiographic images are produced digitally using one of two processes, computed radiography (CR) and digital radiography (DR). DR uses a detector screen containing silicon detectors that produce an electrical signal when exposed to X-rays. This signal is analyzed to produce a digital image. Digital images obtained by CR and DR are sent to viewing workstations for interpretation. Images may also be recorded on X-ray film for portability and remote viewing.

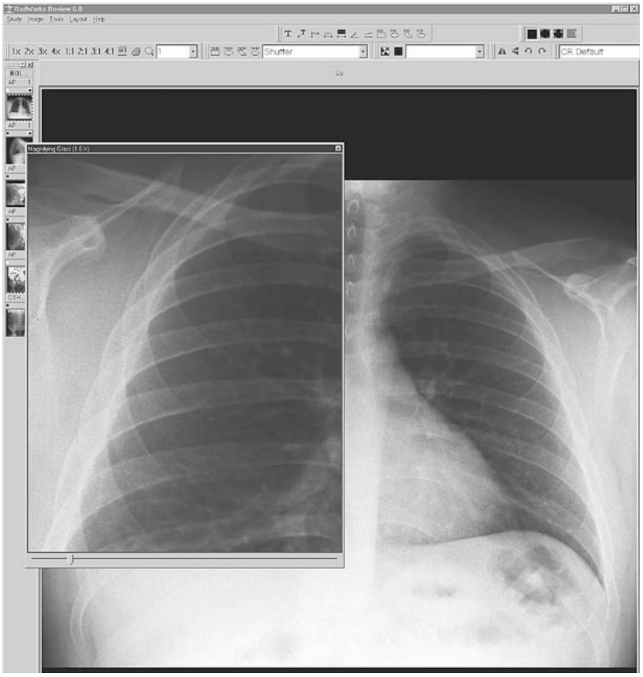


Fig.7. 6Computer radiography image.

The image given by a computer radiography may be reviewed and reported on a computer workstation. This allows various manipulations of images as well as application of functions such as measurements of length and angles measurements.

The relative variance of the shadows depends upon the density of the materials within the object or body part. Dense, calcium – rich bone absorbs X-rays to a higher degree than soft tissues that permit more X-rays to pass through them, making X-rays very useful for capturing images of bone.

In projection radiography, there is much room for adjusting the energy level of the X-rays depending on the relative densities of the tissues being imaged and also how deep through a body the waves must travel in order to achieve the imaging.

- Images of bones (for instance, to examine a fracture or for diagnostic measures related to bone conditions like osteoarthritis or certain cancers) require high-energy X-rays because of the high density of bone.
- Images of soft tissues like lungs, heart and breasts (both chest X-rays and mammography are very common diagnostic applications of X-rays) require relatively less energy from the X-rays in order to penetrate properly and achieve excellent images.
- In order to achieve these different energies, technologists use X-ray generators of different voltages and equipped with anodes made of different metals.

Advantages and disadvantages of conventional radiography.

Advantages	Disadvantages
▪ Short exposure. ▪ Large area image ▪ Low cost ▪ Low radiation exposure (3-4 mR) ▪ Excellent contrast and spatial resolution. ▪ etc	▪ Processing the film ▪ Use of high radiation dose ▪ The image cannot be changed (not be adjusted once it is made) ▪ Sensitive variation in exposure ▪ Less sensitive to detect early osseous changes ▪ Lack of depth resolution. ▪ Requires physical handling and storage. Etc

b. Mammography

Mammography is a specialized medical imaging that uses low-dose X-rays to investigate the internal structure of the breast. A mammography exam, called a mammogram, helps in the early detection and diagnosis of women's breast diseases such as breast cancer before even experiencing any symptom. Below is a typical mammography test showing the presence of abnormal areas of density, mass, or calcification that may indicate the presence of cancer.

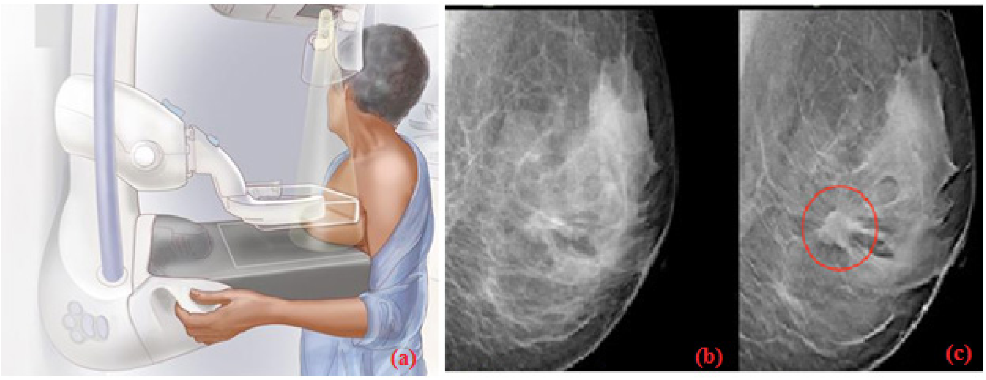


Fig.7. 7Mammography :(a) the breast is pressed between two plates x-rays are used to takes pictures of breast tissues,(b)photographic image of breast tissues, (c)Breast with cancer.

A mammography unit is a rectangular box that houses the tube in which X-rays are produced. The unit is used exclusively for X-ray exams of the breast, with special accessories that allow only the breast to be exposed to the X-rays. Attached to the unit is a device that holds and compresses the breast and positions it so images can be obtained at different angles.

In **conventional film** and **digital mammography**, a stationery X-ray tube captures an image from the side and an image from above the compressed breast. **Breast tomosynthesis**, *also* called **three-dimensional (3-D)** mammography and digital breast tomosynthesis (DBT), is an advanced form of breast imaging where multiple images of the breast from different angles are captured and reconstructed ("synthesized") into a three-dimensional image set. In this way, 3-D breast imaging is similar to computed tomography (CT) imaging in which a series of thin "slices" are assembled together to create a 3-D reconstruction of the body.

Advantages and disadvantages of mammography

Advantages are:

- Non-invasive procedure
- Minimum hazard of radiation.
- Increase in cancer detection rate.
- Improved positive predictive values for recall and biopsy.
- Etc.

Disadvantages are:

- May increase radiation dosage patient receivers.
- May require new equipment / training for techs and radiologist
- Is inconclusive in women under 35 years old due to dense breast tissue.
- Etc.

c. Computer Tomography scan (CT scan)

i) CT terminology

In 1970s, a revolutionary new X-ray technique was developed called Computer tomography (CT), which produce an image of a slice through the body. The word tomography comes from the Greek: tomos =slice, graph= picture.)

A **computed tomography scan** also known as **CT scan**, makes use of computer-processed combinations of many X-ray measurements taken from different angles to produce cross-sectional (tomographic) images (virtual "slices") of specific areas of a scanned object, allowing the user to see inside the object without cutting it. Other terms include computed axial tomography (CAT scan) and computer aided tomography

The term "computed tomography" (CT) is often used to refer to X-ray CT, because it is the most commonly known form but many other types of CT exist.

CT is an imaging technique whereby cross-sectional images are obtained with the use of X-rays. In CT scanning, the patient is passed through a rotating gantry that has an X-ray tube on one side and a set of detectors on the other. Information from the detectors is analysed by computer and displayed as a grey-scale image. Owing to the use of computer analysis, a much greater array of densities can be displayed than on conventional X-ray films. This allows accurate display of cross-sectional anatomy, differentiation of organs and pathology, and sensitivity to the presence of specific materials such as fat or calcium. As with plain radiography, high- density objects cause more attenuation of the X-ray beam and are therefore displayed as lighter grey than objects of lower density.

ii) Principle behind of computer tomography scan (CT scan).

Computer Tomography is shown in below figure: a thin collimated beam of X- ray (" to collimate" means to "make straight") passes through the body to a detector that measures the transmitted intensity. The apparatus is rotated slightly about the body axis and again scanned; this is repeated at 1° intervals for 180°. The intensity of the transmitted beam for the many points of each scan, and for each angles, are sent to a computer that reconstructs the image of the slice. Note that the imaged slice is perpendicular to the long axis of the body. For this reason, CT is sometimes called computerize axial tomography.

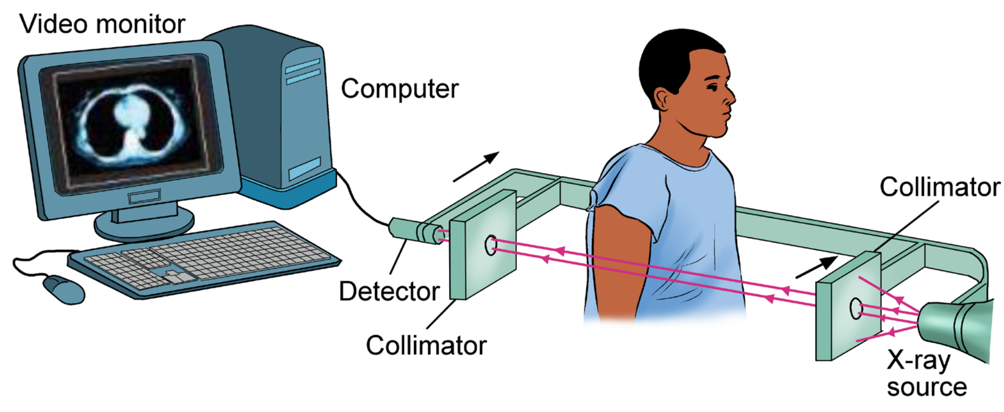


Fig.7. 8 Tomography image

The use of single detector would require a few minutes for many scans needed to form a complete image. Much faster scanner use a fan beam in which passing through the entire cross section of the body are detected simultaneously by many detectors.The x-ray source and the detectors are rotated about the patient and an image requires only few seconds to be seen. This means that rays transmitted through the entire body are measured simultaneously at each angle where the source and detector rotate to take measurements at different angles.

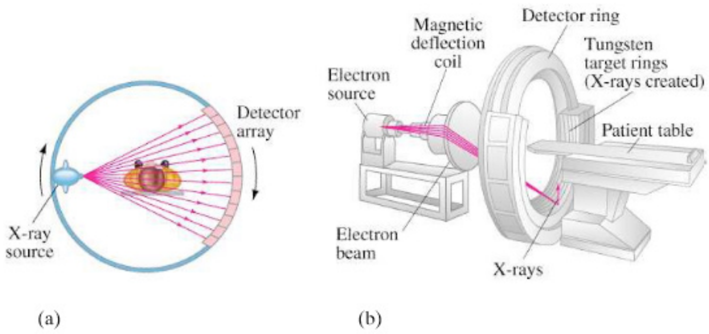


Fig.7. 9 computer tomography scan

CT images of internal organs, bones, soft tissue, and blood vessels provide greater clarity and more details than conventional X-ray images, such as a chest X-Ray.

iii) Function of CT scan

- A motorized table moves the patient through a circular opening in the CT imaging system.
- While the patient is inside the opening, an X-ray source and a detector assembly within the system rotate around the patient. A single rotation typically takes a second or less. During rotation the X-ray source produces a narrow, fan-shaped beam of X-rays that passes through a section of the patient's body.
- Detectors in rows opposite the X-ray source register the X-rays that pass through the patient's body as a snapshot in the process of creating an image. Many different "snapshots" (at many angles through the patient) are collected during one complete rotation.
- For each rotation of the X-ray source and detector assembly, the image data are sent to a computer to reconstruct all of the individual "snapshots" into one or multiple cross-sectional images (slices) of the internal organs and tissues.

Note that, it is advisable to avoid unnecessary radiation exposure; a medically needed CT scan obtained with appropriate acquisition parameter has benefits that outweigh the radiation risks.

iv) Advantages and disadvantages of CT-Scan

CT-Scan has Advantages and disadvantages.

Disadvantages include:

- Risk to the patient because of the high radiation dose.
- Very expensive.
- Not commonly used to image painful joints modality
- Poor soft-tissue contrast.

- Higher radiation exposure.
- Involves exposure to ionising radiation(gamma-rays)
- Radiation material may cause allergic injection-site reactions in some people.
- etc

Advantages include:

- Images can be scored in a computer memory.
- The computer can also be used to construct a slide in a different plane using other visual data.
- Widely available
- Quick exam.
- CT-Scan give a good contrast images
- High spatial resolution (bone/lung).
- Unlike most other imaging types, can show how different parts of the body are working and can detect problem earlier.
- Can check how far a cancer has spread and how well treatment is working.
- etc

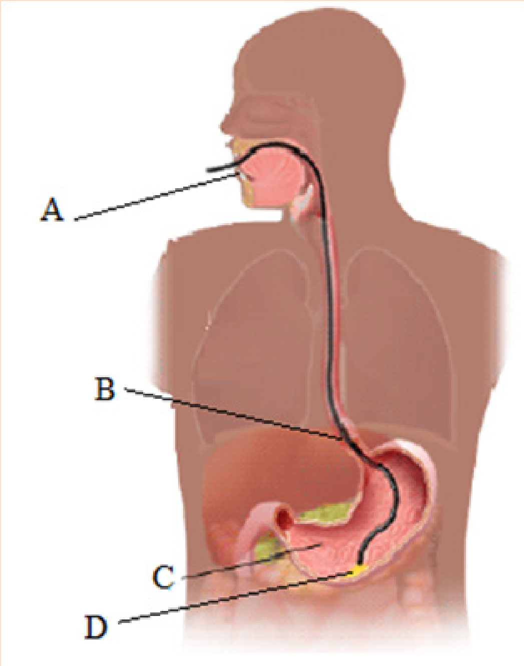
Application activity 7.3

1. Outline the advantages and disadvantages of CT scan
2. Explain the types of x-ray imaging used in mammography.
3. In mammography exams, is the breast compression necessary? Why
4. A beam of X-rays passes through the human body of tissues with different densities; explain the production of X-rays on less dense tissues?
5. If you are getting a mammogram for the first time, what are the specific questions you are expected to be asked by a doctor.
6. What does a biopsy mean?
7. Explain reasons why people do not attend breast screening (screening mammography)

7.4 ENDOSCOPY

Activity 7.4

The picture below show the procedure that enables doctor to examine the lining of esophagus and stomach. Examine it well and answer the following question.



1. Name parts labelled letters A, B, C and D.
2. How do you call the examination technique taken by a doctor?
3. How can we examine inside the stomach by using light rays?
4. How is endoscopy performed?
5. What do you think are the advantages and disadvantages of this technique?

7.4.1 Description

Endoscopy is a nonsurgical procedure used to examine a person's digestive tract. Using an endoscope, which is a flexible tube with a light and camera attached to it, the specialist can view pictures of your digestive tract on a monitor. During an upper endoscopy, an endoscope is easily passed through the mouth and throat and into the esophagus, allowing the specialist to view the esophagus, stomach, and upper part of the small intestine. Similarly, endoscopes can be passed into the large intestine (colon) through the rectum to examine this area of the intestine.

7.4.2 Upper endoscopy

Upper Endoscopy (also known as gastroscopy, EGD, or esophagogastroduodenoscopy) is a procedure that enables your surgeon to examine the lining of the esophagus (swallowing tube), stomach and duodenum (first portion of the small intestine). A bendable, lighted tube about the thickness of your little finger is placed through your mouth and into the stomach and duodenum.

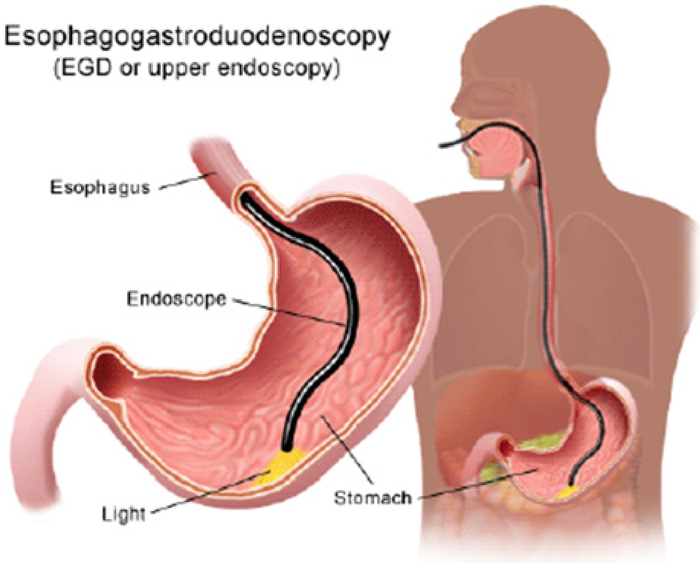


Fig.7. 10 Endoscopy exam

How is the upper endoscopy performed?

Upper endoscopy is performed to evaluate symptoms of persistent upper abdominal pain, nausea, vomiting, difficulty swallowing or heartburn. It is an excellent method for finding the cause of bleeding from the upper gastrointestinal tract. It can be used to evaluate the esophagus or stomach after major surgery. It is more accurate than X-rays for detecting inflammation, ulcers or tumors of the esophagus, stomach and duodenum. Upper endoscopy can detect early cancer and can distinguish between cancerous and noncancerous conditions by performing biopsies of suspicious areas.

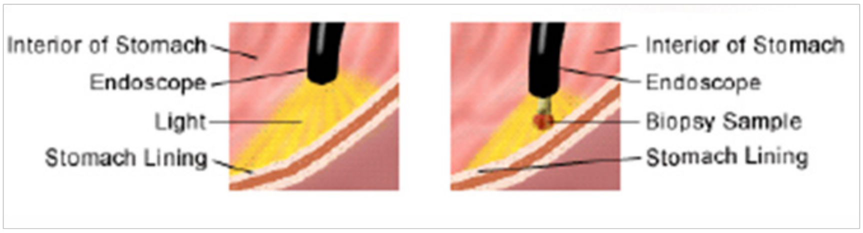


Fig.7. 11 Interior of a stomach

A variety of instruments can be passed through the endoscope that allows the surgeon to treat many abnormalities with little or no discomfort, remove swallowed objects, or treat upper gastrointestinal bleeding. Safe and effective control of bleeding has reduced the need for transfusions and surgery in many patients.

7.4.3 Advantages and disadvantages of endoscopy

Advantages

- Complete visualization of the entire stomach or digestive tract.
- It is very safe and effective tool in diagnosis
- Does not leave any scar because it uses natural body openings.
- It is cost effective and has low risk
- They are generally painless.
- Can do therapeutic interventions
- Allows for sampling/biopsying of small bowel mucosa
- Allows for resection of polyps.

Overall, endoscope is very safe; however, the procedure has a few potential complications which may include:

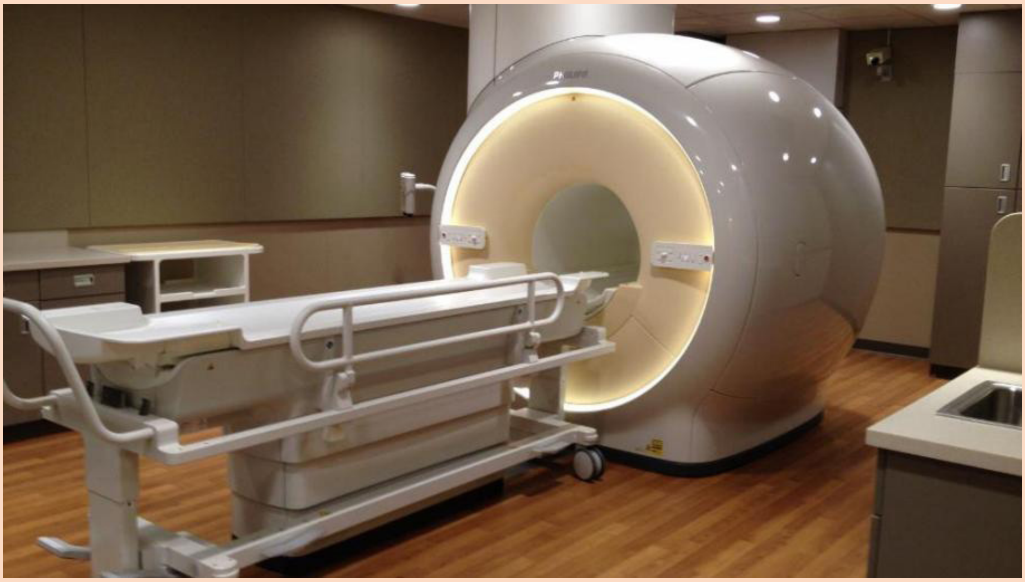
- Bleeding
- Perforation (tear in the gut wall)
- Infection
- Reaction to sedation (action of administering a sedative drug to produce a state of calm or sleep.
- Technically difficult procedure
- Very time consuming (Procedure can take > 3 hours)
- Patient may need to be admitted to the hospital
- Higher risk of small bowel perforation
- Case reports of pancreatitis and intestinal necrosis
- Reported incidents of aspiration and pneumonia

Application activity 7.4

1. What are instruments used to view the oesophagus, stomach and upper small intestine of human
2. Discuss different functions of endoscope in medicine.
3. Compare and contrast colonoscopy and gastroscopy
4. What are some of negative effects of using endoscopy?

7.5 MAGNETIC RESONANCE IMAGING (MRI)

Activity 7.5



i) The diagram above is a Magnetic Resonance Imaging (MRI) machine. Basing on its name, explain what it does.

ii) Comparing it to other imaging techniques, explain how this machine is different from other imaging machines.

iii) Would you advise a pregnant woman to always use this machine for a medical checkup? Explain your view

iv) From your reasoning in iii) above, suggest advantages and disadvantages of using MRI machine

Historically, Magnetic Resonance Imaging as with all medical imaging techniques, is a relatively new technology with its foundations beginning during the year of 1946.

Felix Bloch and Edward Purcell independently discovered the magnetic resonance phenomena during this year, Up until the 1970s MRI was being used for chemical and physical analysis. Then in 1971 Raymond Damadian showed that nuclear magnetic relaxation times of tissues and tumors differed motivating scientists to use MRI to study disease. MRI began in the central nervous system, but it has now extended to all regions of the body. It is involving three very complex topics in physics like: Nuclear, Magnetic and Resonance (NMR). In MRI, a particular type of nucleus is selected and its distribution in the body is monitored. Hydrogen is the most commonly imaged element, not only due to its abundant in the body, but also because it gives the strongest MRI signal.

7.5.1. Concepts MRI

Magnetic Resonance (MRI) Imaging has become the dominant clinical imaging modality with widespread, primarily noninvasive, applicability throughout the body and across many disease processes. The progress of MR imaging has been rapid compared with other imaging technologies and it can be attributed in part to physics and in part to the timing of the development of MR imaging, which corresponded to an important period of advances in computing technology.

Initially let us described how magnetic resonance can be demonstrated with a pair of magnets and a compass. If a compass happens to find itself near a powerful magnet, the compass needle will align with the field. In a normal pocket compass, the needle is embedded in liquid to dampen its oscillations. Without liquid, the needle will vibrate through the north direction for a period before coming to rest. The frequency of the oscillations depends on the magnetic field and of the strength of the magnetic needle.

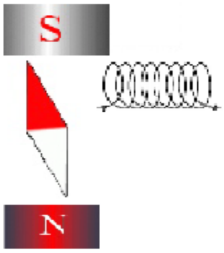


Fig.7. 12 small coil placed to the magnetic needle

Let us focus on what made the needle oscillate. It was the small movements of the magnet, back and forth, or more precisely the oscillation of a weak magnetic field perpendicular to the powerful stationary magnetic field caused by the movement of the magnet. But oscillating magnetic field is what we understand by “radio waves”, which means that in reality, we could replace the weak magnet with other types of radio wave emitters. This could, for example, be a small coil subject to an alternating current, as shown in figure above. Such a coil will create a magnetic field perpendicular to the magnetic needle. The field changes direction in synchrony with the oscillation of the alternating current, so if the frequency of the current is adjusted to the resonance frequency of the magnetic needle, the current will set the needle in motion. This is also applied in an MR scanner. In summary, the needle can be set in motion from a distance by either waving a magnet or by applying an alternating current to a coil. In both situations, magnetic resonance is achieved when the magnetic field that motion or alternating currents produce, oscillates at the resonance frequency. When the waving or the alternating current is stopped, the radio waves that are subsequently produced by the oscillating needle will induce a voltage over the coil.

MRI uses the magnetic properties of spinning hydrogen atoms to produce images. The first step in MRI is the application of a strong, external magnetic field. For this purpose, the patient is placed within a large powerful magnet. Most current medical MRI machines have field strengths of 1.5 or 3.0 Tesla. The hydrogen atoms within the patient align in a direction either parallel or antiparallel to the strong external field. A greater proportion aligns in the parallel direction so that the net vector of their alignment, and therefore the net magnetic vector, will be in the direction of the external field. This is known as longitudinal magnetization. A second magnetic field is applied at right angles to the original external field. This second magnetic field is known as the radiofrequency pulse (RF pulse), because it is applied at a frequency in the same part of the electromagnetic spectrum as radio waves. A magnetic coil, known as the RF coil, applies the RF pulse. The RF pulse causes the net magnetization vector of the hydrogen atoms to turn towards the transverse plane, i.e. a plane at right angles to the direction of the original, strong external field. The component of the net magnetization vector in the transverse plane induces an electrical current in the RF coil. This current is known as the MR signal and is the basis for formation of an image. Computer analysis of the complex MR signal from the RF receiver coils is used to produce an MR image.

7.5.2. The magnetism of the body

Let's see how magnet needles with and without spin are affected by radio waves, we now turn to the "compass needles" in our own bodies.

a) Most frequently, the MR signal is derived from hydrogen nuclei (meaning the atomic nuclei in the hydrogen atoms). Most of the body's hydrogen is found in the water molecules. Few other nuclei are used for MR.

b) Hydrogen nuclei (also called protons) behave as small compass needles that align themselves parallel to the field.

c) The compass needles (the spins) are aligned in the field, but due to movements and nuclear interactions in the soup, the alignment only happens partially.

d) The nuclei in the body move among each other (thermal motion) and the net magnetization in equilibrium is thus temperature dependent.

e) Due to the number of hydrogen nuclei (about 10^{27}) found in the body, the net magnetization still becomes measurable. It is proportional to the field: A large field produces a high degree of alignment and thus a large magnetization and better signal to noise ratio.

7.5.3 Magnetic Resonance Imaging (MRI).

The hydrogen nucleus is the most use in MRI.The technique uses a very powerful magnet to align the nuclei of atoms inside the body, and a variable magnetic field that causes the atoms to resonate, a phenomenon called nuclear magnetic resonance. The nuclei produce their own rotating magnetic fields that a scanner detects and uses to create an image.

MRI is used to diagnose a variety of disorders, such as strokes, tumors, aneurysms, spinal cord injuries, multiple sclerosis and eye or inner ear problems. It is also widely used in research to measure brain structure and function, among other things.

Fig.7. 13A patient entering a MRI set up for exam.

An MRI scan can be used to examine almost any part of the body, including the:

- brain and spinal cord
- bones and joints
- breasts
- heart and blood vessels
- internal organs, such as the liver, womb or prostate gland ,etc

The results of an MRI scan can be used to help diagnose conditions, plan treatments and assess how effective previous treatment has been.

7.5.4. Functional of MRI Scan

There are many forms of MRI, some of them are:

a) Diffusionweighted imaging.

Diffusion-weighted imaging (DWI) is sensitive to the random Brownian motion (diffusion) of water molecules within tissue. The greater the amount of diffusion, the greater the signal loss on DWI. Areas of reduced water molecule diffusion show on DWI as relatively high signal. **Diffusion-weighted imaging is the most sensitive imaging test available for the diagnosis of acute cerebral infarction.** With the onset of acute ischaemia and cell death there is increased intracellular water (cytotoxicoedema) with restricted diffusion of water molecules. An acute infarct therefore shows on DWI as an area of relatively high signal.

b) Perfusion-weighted imaging

In perfusion-weighted imaging (PWI) the brain is rapidly scanned following injection of a bolus of contrast material (gadolinium). The data obtained may be represented in a number of ways including maps of regional cerebral blood volume, cerebral blood flow, and mean transit time of the contrast bolus. PWI may be used in patients with cerebral infarct to map out areas of brain at risk of ischaemia that may be salvageable with thrombolysis.

c) Magnetic resonance spectroscopy

Magnetic resonance spectroscopy (MRS) uses different frequencies to identify certain molecules in a selected volume of tissue, known as a voxel. Following data analysis, a spectrographic graph of certain metabolites is drawn. Metabolites of interest include lipid, lactate, NAA (N-acetylaspartate), choline, creatinine, citrate and myoinositol. Uses of MRS include characterization of metabolic brain disorders in children, imaging of dementias, differentiation of recurrent cerebral tumour from radiation necrosis, and diagnosis of prostatic carcinoma.

d) Blood oxygen level-dependent imaging

Blood oxygen level-dependent (BOLD) imaging is a non-invasive functional MRI (fMRI) technique used for localizing regional brain signal intensity changes in response to task performance. BOLD imaging depends on regional changes in concentration of deoxyhemoglobin, and is therefore a tool to investigate regional cerebral physiology in response to a variety of stimuli. BOLD fMRI may be used prior to surgery for brain tumor or arteriovenous malformation (AVM), as a prognostic indicator of the degree of postsurgical deficit.

7.5.5 Advantage and disadvantages of MRI.

Advantages of MRI in clinical practice include:

1. Excellent soft tissue contrast and characterization
2. Lack of ionizing radiation.
3. Noninvasive machine.
4. Lack of artefact from adjacent bones, e.g. pituitary fossa

Disadvantages of MRI:

1. High capital and running costs.
2. Image selected and interpretation is complex.
3. Examination can be difficult for some people who are claustrophobic
4. The examination is noisy and takes long.
5. Hazards with implants, particularly pacemakers.
6. Practical problems associated with large superconducting magnets.

In additional to that, out of imaging the techniques discussed above there other imaging techniques called "radionuclide imaging/nuclear medicine/ scintigraphy". A radionuclide is used to collect in areas where there is a lot of bone activity. This method uses gamma radiation to form images by injection of various radiopharmaceuticals. The most commonly used radionuclide in clinical practice is technetium, written in this text as ^{99m}Tc where m stands for metastable. Other commonly used radionuclides include gallium citrate (^{66}Ga), thallium (^{201}Tl), indium (^{11}In) and iodine (^{131}I).

Application activity 7.5

1. With clear explanations, explain the benefit and limitation of MRI machine.
2. What is meant by relaxation in the context of MRI?
3. Give the reasons why the hydrogen nucleus is most used in MRI.
4. What does NMR stand for? Explain carefully the role of the three terms involved
5. With the aid of drawing, discuss the basic steps in the formation of MRI image.

Skills Lab 7

In this activity you will make a visit to the nearest hospital.

Note: Make inquiry either through your class leaders or class tutor to know whether the hospital has the following.

- Ultrasound machine
- X-ray machine
- Endoscopy
- Magnetic Resonance Imaging (MRI) machine.

The main aim of the visit is to understand how these machines work.

The following are guiding questions you may ask either laboratory technician or the doctor.

a. What is the main objective(s) of using these machines?
b. What does one need to do to use these machines?
c. What are the precautions that must be taken before using any of these machines?
d. Are there regulations guiding any person working in the rooms where these machines are installed?
e. Could there be negative effects of these machines on human body if used regularly?

You can also ask any question you feel can make you understand this concept better.

Make sure you note down something as the doctor or laboratory technician explains the asked questions.

After leaving the hospital, Make a comprehensive report and compare the information you got from the hospital to the one learnt in this unit.

Present your findings (in the report) to your class and to your tutor.

End of unit 7 assessment

I-5: Choose the correct answer.

1. One of the medical imaging using X-ray is:
   A. thermography
   B. CT Scan
   C. endoscopy
   D. both of them
2. Magnetic Resonance Imaging uses:
   A. x-rays
   B. Light
   C. Magnetization
   D. both of them
3. The medical imaging techniques used injection of various radiopharmaceuticals is:
   A. Mammography
   B. Radiography
   B. Radionuclide.
   D. Endoscopy
4. Mammography is used to detect:
   A. Brain diseases
   B. Baby diseases
   C. Breast diseases
   D. None of them
5. A radionuclide scan may be done for one reason:
   A. A radionuclide is used to collect the areas where the infrared are synchronized.
   B. A radionuclide is used to collect in areas where there is a lot of bone activity.
   C. A radionuclide is use to collect the areas where gamma camera are produced image
   D. A radionuclide is used to collect information from the exam of lining of esophagus.
6. Write the missing word or words on the space before each number.
   A. The best human ears can respond to frequencies from about **20Hz** to almost **20 000Hz.** This frequency is called the ……….

B. A variety of instruments can be passed through the endoscope that allows the surgeon to treat many abnormalities with little or no discomfort, remove swallowed objects

C. Equipment is safe, easy to handle, can be operated and be portable. This in one of the ……. of ultrasound

D. When the pulse of ultrasound is sent into the body and meets a boundary between two media, most of the wave is reflected and a strong …… is recorded.

E. Transducers used are different depending on …… of a patient, one has 5 MHz and other 3.5 MHz.

F. Hydrogen nuclei (also called protons) behave as small .... that align themselves parallel to the field.

G. In…………………. there are appearance three words: nuclear, magnetic and resonance.

H. Lack of ……. radiationis one of the advantages of MRI.

7. Answer by True if it is true and by False if it is False

A. The use of gamma radiation to form images following the injection of various radiopharmaceuticals is known as Scintigraphy.

B. This decision to scan or not to scan a normal pregnancy must be made only by the photographer. There are universally accepted guidelines at present.

C. Tissue in the body absorbs and scatters ultrasound in the same ways. Lower frequencies are more rapidly absorbed (attenuated) than higher frequencies.

D. Upper endoscopy uses light and camera to view the esophagus, stomach, and upper part of the small intestine.

E. Ultrasound is both generated and detected through high frequency oscillations in piezoelectric crystals so there is ionizing radiation exposure associated with ultrasound imaging.

8. When the sound intensity $I_i = 1.0\,Wm^{-2}$ is incident at the boundary between materials of acoustic Impedance Z_1 *and* Z_2, it is reflected. The speed of sound of the first material is $v_1 = 1500\ m/s$, Speed of sound the second material is $v_2 = 1550\ m/s$, Density of the first material is $\rho_1 =\ 900\ kg/m^3$ and that of the second material is $\rho_2 =\ 1000\ kg/m^3$

i) Find the magnitude of the acoustic impedance of each material.

ii) Calculate the intensity of the wave reflected at the boundary.

iii) Determine the values of intensity of reflection coefficient

iv) Calculate the intensity of the wave transmitted into the second material.

9. The distance between pulse representing ultrasonic reflections from opposite sides of a fetus head was recorded on a screen of a cathode ray oscilloscope as 5.6 cm when the time base was set to $25\mu s\ cm^{-1}$. Calculate the head size assuming the speed of ultrasound in the head is $1.5\ km\ s^{-1}$.

10. Compare and contrast endoscopy imaging and radionuclide imaging

11. What are the advantages of MRI in clinical practice?

12. Why areas of the body can be imaged by ultrasound??

13. In mammography exams, is the breast compression necessary? Why

14. Historically, MRI began in the central nervous system, but it is now extended to all regions of the human body. The excellent resolution and contrast available in any chosen plane in the body, makes the MRI an invaluable diagnostic tool with which to study body structure, function and chemistry, as well as disease. Discuss the application of MRI.

UNIT 8

RADIATIONS AND MEDICINE

Key Unit Competence:

Categorize hazards and safety precautions of radiation in medicine

Introductory activity

Radiation has always been present and is all around us. Life has evolved in a world containing significant levels of ionizing radiation. Our bodies are adapted to it.

People are constantly exposed to small amounts of ionizing radiation from the environment as they carry out their normal daily activities; this is known as background radiation. We are also exposed to radiations through some medical treatments and through other activities involving radioactive substances.

The figure above identifies four major sources of public exposure to natural radiation: cosmic radiation, terrestrial radiation, inhalation and ingestion. Brainstorm and try to answer the following questions:

a) From your own understanding, how is artificial source of radiation different from natural source of radiation?
b) Using your physics knowledge, what do you think are major sources of radiation that are mostly preferred to be used in medicine? Defend your opinion.
c) Do you think exposure to heavy ions at the level that would occur during deep-space missions for a long duration pose a risk to the integrity and function of the central nervous system? Explain to support your idea.
d) As a physics student-teacher, what do you think are the symptoms, effects and jeopardy of radiation exposure to human body?

8.1. RADIATION DOSE

Activity 8.1

Radiation is the emission of particles or electromagnetic waves from a source. Radiation from radioactive materials has the ability to interact with atoms and molecules of living objects.

a) From your understanding, what makes these radiations able to penetrate matter?
b) Do you think any amount of radiation should be applied to human body in case it is to be used to examine a certain part under study or investigation? Defend your reasoning.
c) Using your prior knowledge about use of radiation in hospitals, what are common used radiations?
d) Suggest the possible side effects of these radiations to human body.
e) From your suggestions in (d) above, what do you think are precaution measures one should take to avoid dangers that may be caused by these radiations?

8.1.1 Ionization and non-ionization radiations.

Radiation is the emission of particles or electromagnetic waves from a source. Also it is amount of energy deposited in a given mass of medium by ionization radiation. Radiation from radioactive materials has the ability to interact with atoms and molecules of living objects

In a neutral atom, the positive charge of the nucleus is equal and opposite to the total negative charge of the orbital electrons. If such an atom loses or gains an electron, it becomes an ion. The atom will now have a net positive or negative charge and is called an ion. This process is called ionization, and the radiation responsible for it is called **ionizing radiation.** When discussing the interaction of radiations with matter in particularly in relation to health, two basic types of radiation can be considered.

a. Ionizing radiation.

Ionization radiation refers to a radiation that carries sufficient energy to release electrons from atoms or molecules, in that way ionizing them. It is made up of energetic subatomic particles,ion or atoms that moving at high speeds. As the more powerful form of radiation, ionizing radiation is more likely to damage tissue than non-ionizing radiation. The main source of exposure to **ionizing radiation** is the radiation used during **medical exams** such as X-ray radiography or computed tomography scans.

However, the amounts of radiation used are so small that the risk of any damaging effects is minimal. Even when **radiotherapy** is used to treat cancer, the amount of ionizing radiation used is so carefully controlled that the risk of problems associated with exposure is tiny.

All forms of living things emit a certain amount of radiation, with humans, plants and animals accumulating radioisotopes as they ingest food, air and water. Some forms of radiation such as potassium-40 emit high-energy rays that can be detected using measurement systems. Together with the background radiation, these sources of internal radiation add to a person's **total radiation dose**.

Background radiation is emitted from both naturally and man-made sources. Natural sources include cosmic radiation, radon radiation in the body, solar radiation and external terrestrial radiation. Man-made forms of radiation are used in **cancer treatment, nuclear facilities and nuclear weapons.**

Globally, the average exposure to ionizing radiation per year is around **3 milli Sieverts (mSv)**, with the main sources being natural (around 80%). The remaining exposure is due to man-made forms such as those used in medical imaging techniques. Exposure to man-made forms of ionizing radiations is generally much higher in developed countries where the use of **nuclear imaging techniques** is much more common than in developing countries.

b. Non-ionizing radiations

Non-ionizing radiationis any type of electromagnetic *radiation* that does not carry enough energy to *ionize* atoms or molecules. Examples of **non-ionizing** radiations include visible light, microwaves, ultraviolet (UV) radiation, infrared radiation, radio waves, radar waves, mobile phone signals and wireless internet connections.

Although UV has been classified as a non-ionizing radiation but it has been confirmed. High levels of UV-radiation can cause sunburn and increase the risk of skin cancer developing.

Scientific investigations suggest that the use of telecommunications devices such as **mobile phones** may be damaging, but no risk associated with the use of these devices has yet been identified in any scientific studies. This energy is emitted both inside the body and externally, through both natural and man-made processes.

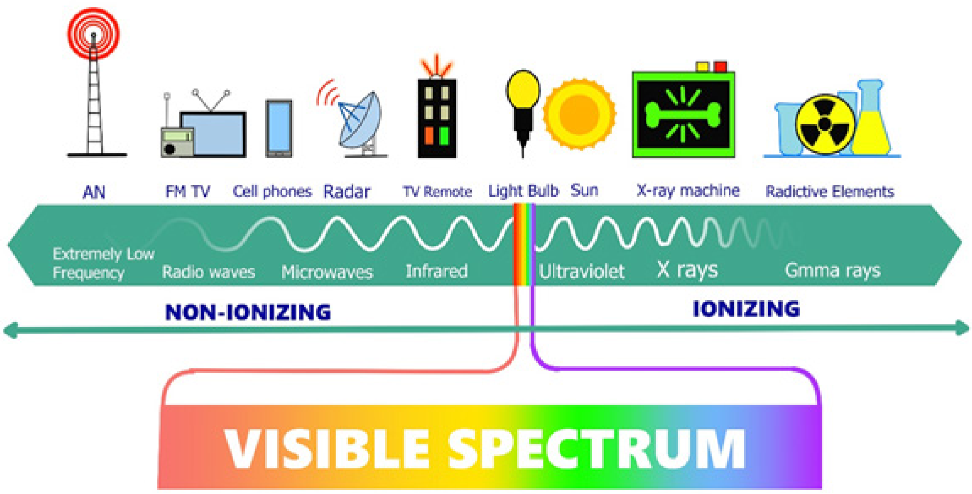


Fig.8. 1 Ionizing vs. non-ionizing radiation

8.1.2 Radiation penetration in body tissue

Radiation cannot be spread from person to person. Small quantities of radioactive material occur naturally in the air, drinking water, food and our own bodies. People can come into contact with radiation through medical procedures. An important characteristic of the various ionizing radiations is how deeply they can penetrate the body tissues. X-rays, gamma rays, and neutrons of sufficient energy described below can reach all tissues of the body from an external source.

- **Alpha Radiation**

Alpha radiationrefers to a form of particle radiation that occurs when an atom undergoes radioactive decay. They consist of two protons and two neutrons (essentially the nucleus of a helium-4 atom). Due to their charge and mass, alpha particles interact **strongly** with matter, and can only travel a few centimeters in air. A thin sheet of paper, on the other hand, stops alpha particles. Alpha radiation can only penetrate the outer layers of human skin. Therefore, radionuclides that emit only alpha particles are harmless unless you take them into the body. This you might do by inhalation (breathing in) or ingestion (eating and drinking).

- **Beta Radiation**

Beta radiation occurs when radioactive atomic nuclei emit electrons (negatively charged) or frequently positron (positively charged particles with the same mass of electron).Due to their smaller mass, they are able to travel further in air, up to a few meters, and can be stopped by a thick piece of plastic, or even a stack of paper i.e can penetrate the skin a few centimeters to metres in air and few millimetres to centimetre in soft tissue and plastic. Posing somewhat of an external health risk. The depth to which beta particles can penetrate the body depends on their energy. High-energy beta particles (several MeV) may penetrate a centimeter of a tissue, although most are absorbed in the first few mm. As a result, beta emitters outside the body are hazardous only to surface tissues such as the skin or the lenses of the eye. When you take beta emitters into the body, they will irradiate internal tissues and then become a much more serious hazard.

- **Gamma Radiation**

In the case of gamma radiation, energy is transferred as an electromagnetic wave. Electromagnetic radiation can be described in terms of its frequency or wavelength (the high frequency and the shorter the wavelength, the more energetic radiation). Gamma radiation is at high energy end of electromagnetic spectrum. Gamma radiation, unlike alpha or beta, does not consist of any particles, instead consisting of a photon of energy being emitted from an unstable nucleus. Having no mass or charge, gamma radiation can travel much farther through air than alpha or beta, losing (on average) half its energy.

Gamma waves can be stopped by a thick or dense enough layer material, with high atomic number. Materials such as lead can be used as the most effective form of shielding.

- **X-Rays**

X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released. X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well.

- **Neutron Radiation**

Neutron radiation consists of a free neutron that is mainly released in nuclear fission. They are able to travel hundreds or even thousands of meters in air, they are however able to be effectively stopped if blocked by a hydrogen material, such as concrete or water.

Neutron radiation occurs when neutrons are ejected from the nucleus by nuclear fission and other processes. The nuclear chain reaction is an example of nuclear fission, where a neutron being ejected from one fission atom will cause another atom to fission, ejecting more neutrons. Unlike other radiations, neutron radiation is absorbed by materials with lots of hydrogen atoms, like paraffin wax and plastics.

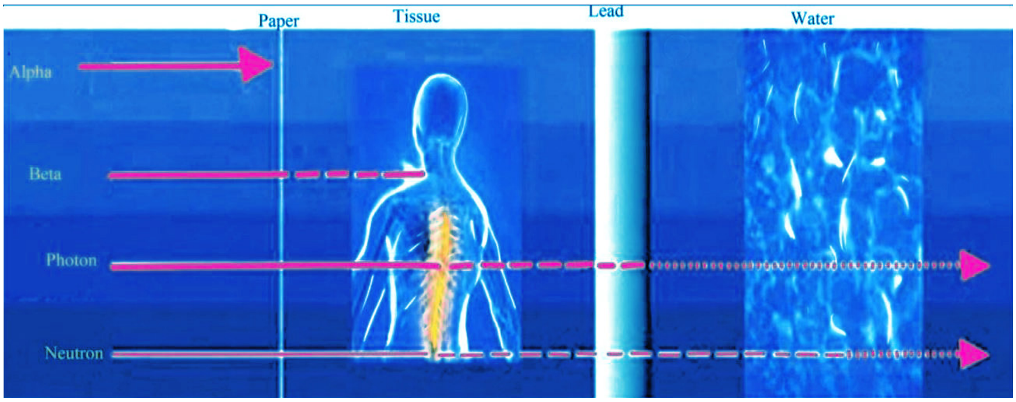


Fig.8. 2:Types of ionizing radiation

8.1.3 Radiation dosimetry

Just as for drugs, the effect of radiation depends on the amount a person has received. Therefore, amounts of radiation received are referred to as **doses**, and the measurement of such doses is known as **dosimetry.**

A radiation dosimeter refers to a device the measures dose uptake of external ionizing radiation. **Dosimeters** are used to monitor your occupational dose from radioactive material or radiation-producing equipment. Most individuals working with X-ray producing equipment in the hospital will be issued with a **dosimeter**. For those individuals working in the research laboratory setting, **dosimeters** will be issued based on the nuclide and total activity that will be used.

Dosimeters are integrating detectors; that is, they accumulate the radiation dose and give off an amount of light which is proportional to that dose.

The energy absorption properties of dosimeters are designed to be very similar to tissue, so they are very effective as personnel dosimeters. These devices are used to measure exposures from **x-ray, gamma ray and high energy beta particles.** Dosimeters are not suitable for measuring exposures to low energy beta particles or alpha particles.

8.1.4. Radiation exposure.

Exposure is a measure of the ionization produced in air by X-rays or gamma rays, and it is defined in the following manner. A beam of X-rays or gamma rays is sent through a mass m of dry air at standard temperature and pressure (stp: $0\ ^{0}C$, 1 atm). In passing through the air, the beam produces positive ions whose total charge is q.

Exposureis defined the total charge per unit mass of air.The SI unit for exposure is coulomb per unit mass (C/kg). The unit for exposure E is the roentgen(R). 1R is the amount of electromagnetic radiation which produces in one gram of air ($2.58\times10^{-7}C$) at normal temperature (22 and pressure (760mmHg) conditions.

$$1\,R = 2.58 \times 10^{-4}\, C / kg$$

Since the **concept of exposure** is defined in terms of the ionizing abilities of X-rays and gamma rays in air, it does not specify the effect of radiation on living tissue. For biological purposes, the absorbed dose is more suitable quantity, because it is the energy absorbed from the radiation per unit mass of absorbing material.

Long-term exposure to small amounts of radiation can lead to **gene mutations** and increase the **risk of cancer**, while exposure to a large amount over a brief period of time can cause **burns** or **radiation sickness**.

Radiation sickness is a damage human body caused by a large dose of radiation often received over a short period of time (acute). It isn't caused by common tests that use low-dose radiation such as x-rays or CT-Scans. Radiation sickness also called **acute radiation syndrome or radiation poisoning.**

8.1.5. Absorbed radiation dose.

Radiation dose is a quantity of the energy measured which is deposited in matter by ionizing radiation per unit mass. A similar approach is used in radiation protection measurements, where the unit of **absorbed dose** is specified in terms of the amount of energy deposited by radiation in 1 kg of material. International system of unit for radiation measurement is the "**gray" (Gy) and "sievert" (Sv).** These units can be expressed into others like "**rad**", "**rem**" or **roentgen(R)**. An absorbed radiation dose of 1 Gray corresponds to the deposition of **1 joule** of energy in **1 kg** of material (air, water, tissue or other).

It describes the physical effect of the incident radiation, but it tells us nothing about the biological consequences of such energy deposition in tissue. Studies have shown that alpha and neutron radiation cause greater biological damage for a given energy deposition per kg of tissue than gamma radiation does. A person who has absorbed a whole body dose of 1 Gy has absorbed one joule of energy in each kg of its body tissue. Absorbed dose is used in calculation of dose uptake in living tissues in both radiationprotections.

In other words, equal doses of, say, alpha and gamma radiation produce unequal biological effects. This is because the body can more easily repair damage from radiation that is spread over a large area than that which is concentrated in a small area. Because more **biological damage** are caused for the same physical dose. When we analyze the effect of radiation on human being is not so much the total dose to the whole system but the dose per kg. That's why a doctor will recommend smaller doses of medicine for children than for adults.

8.1.6 Quality factors

Quality factors are used to compare the biological effects from different types of radiation. For example, fast neutron radiation is considered to be 20 times as damaging as X-rays or gamma radiation. You can also think of fast neutron radiation as being of "**higher quality**", since you need less absorbed dose to produce equivalent biological effects. This quality is expressed in terms of the Quality Factor (Q). The quality factor of a radiation type is defined as the ratio of the biological damage produced by the absorption of 1 Gy of that radiation to the biological damage produced by 1 Gy of X or gamma radiation.

The Q of a certain type of radiation is related to the density of the ion tracks it leaves behind it in tissue; the closer together the ion pairs, the higher the Q.

8.1.7 Equivalent dose

The measure of biological damage that is calculated by multiplying absorbed ***dose*** by quality factor for the type of radiation involved is known as equivalent dose.

The unit of equivalent dose H is the Sievert (Sv). An equivalent dose of one Sievert represents that quantity of radiation dose that is equivalent, in terms of specified biological damage, to one gray of X or gamma rays. Normally, we use the millisievert (mSv) and microsievert (μSv). Few other instruments can read in mGy or μGy, but they measure only gamma radiation.

The Calculation of Equivalent Dose and Effective dose is given by:

$$Effective\ dose(\mathrm{sievert(Sv)}) = \sum (tissue\ weighting\ \ factor \times Equivalent\ dose)$$

The effective dose is a measure of cancer risk, it adjusts the equivalent dose based on the susceptibility of the tissue exposed to the radiation. It is expressed in Sv and mSv.

8.1.8 Radiation protection

The effects of radiation at **high doses** and **dose rates** are reasonably well documented. A very large dose delivered to the whole body over a short time will result in the death of the exposed person within days.

We know from these that some of the health effects of exposure to radiation do not appear unless a certain quite large dose is absorbed. However, many other effects, especially cancers are readily detectable and occur more often in those with moderate doses. At lower doses and dose rates, there is a degree of recovery in cells and in tissues.

Radiation protection sets examples for other safety disciplines in two unique respects:

- First, there is the assumption that any increased level of radiation above natural background will carry some risk of harm to health.
- Second, it aims to protect future generations from activities conducted today.

The use of radiation and nuclear techniques in medicine, industry, agriculture, energy and other scientific and technological fields has brought tremendous benefits to society. The benefits in medicine for diagnosis and treatment in terms of human lives saved are large in size.

No human activity or practice is totally devoid of associated risks. Radiation should be viewed from the perspective that the benefit from it to mankind is less harmful than from many other agents.

Note: The optimization of patients' protection is based on a principle that the dose to the irradiated target (tumor) must be as high as it is necessary for effective treatment while protecting the healthy tissues to the maximum extent possible.

Application activity 8.1

1. a) How ionization differs from non-ionization radiations

   b) Give any two examples of each.
2. What does the following terms mean in medical treatment?
   a) absorbed dose
   b) radiation dose
   c) The quality factor
3. In the application of radiation in medicine, we use the statement "A measure of the risk of biological harm". Clearly explain this statement

8.2. HAZARDS AND SAFETY PRECAUTIONS WHEN HANDLING RADIATIONS

Activity 8.2

1. The picture below show doctors' meeting and they are discussing on a therapeutic treatment due to the wrong exposure to radiation that normally occur in their hospital. These radiations happened in unintended event occurring as a radiation accident.

   a) In your own words, what does radiation accident mean?
   b) What do you think are the radiation accident (unintended events) which may happen due to wrong exposure radiation?
   c) That radiation exposure may be computed in fewer and greater amount. What do you think are the negative effects that may be as a result of exposure of these amounts of radiations?
   d) Based on unintended event you think might have happened in (b) above, what do you think are preventive measures that should be taken to reduce or stop the occurrence of unintended radiation accident?

2. You happen to interact with a man who was diagnosed and found to have cancer cells in one of his fingers. He was advised by the doctor that the cells can be killed by X-rays' radiations. He had previously been told that X-rays have a lot of negative effects if exposed to human body. He at first resisted and was given 2 days to decide. It's one day remaining and you happen to interact with him and he is seeking advice from you. Advise this man on what do.

8.2.1 Deterministic and stochastic effects:

Effects of radiations due to cell killing have a practical threshold dose below which the effect is not evident but in general when the effect is present its severity increases with the radiation dose.

The threshold doses are not an absolute number and vary somewhat by individual. Effects due to **mutations** (such as cancer) have a probability of occurrence that increases with dose.

a. Deterministic effects:

These effects are observed after **large absorbed doses** of radiation and are mainly a consequence of radiation induced cellular death. They occur only if a large proportion of cells in an irradiated tissue have been killed by radiation, and the loss can be compensated by increasing cellular proliferation.

b. Stochastic effects:

They are associated with long term, low level (**chronic**) exposure to radiation. They have no apparent threshold. The risk from exposure increases with increasing dose, but the severity of the effect is independent of the dose.

Irradiated and surviving cells may become modified by induced mutations (somatic, hereditary). These modifications may lead to two clinically significant effects: **malignant neoplasm** (cancer) and **hereditary mutations**.

In evaluating biological effects of radiation after partial exposure of the body further factors such as the varying sensitivity of different tissues and absorbed doses to different organs have to be taken into consideration. The lifetime value for the average person is roughly a 5% increase in fatal cancer after a whole body dose of 1 Sv. It appears that the risk in fetal life, in children and adolescents exceeds somewhat this average level (by a factor of 2 or 3) and in persons above the age of 60 it should be lower roughly by a factor of ~ 5.

Animal models and knowledge of human genetics, the risk of hereditary deleterious effects have been estimated to not be greater than 10% of the radiation induced carcinogenic risk.

All living organisms on this planet, including humans, are exposed to radiation from natural sources. An average yearly effective dose from natural background amounts to about 2.5 mSv. This exposure varies substantially geographically (from 1.5 to several tens of mSv in limited geographical areas).

Various diagnostic radiology and nuclear medicine procedures cover a wide dose range based upon the procedure. Doses can be expressed either as absorbed dose to a single tissue or as **effective dose** to the entire body which facilitates comparison of doses to other radiation sources (such as natural background radiation. Quality assurance and quality control in diagnostic radiology and nuclear medicine play also a fundamental role in the provision of appropriate, sound radiological protection of the patient.

There are several ways that will minimize the risk without sacrificing the valuable information that can be obtained for patients' benefit. Among the possible measures it is necessary to justify the examination before referring a patient to the radiologist or nuclear medicine physician. Failure to provide adequate clinical information at referral may result in a wrong procedure or technique being chosen by radiologist or nuclear medicine specialist.

An investigation may be seen as a useful one if its outcome - positive or negative - influences management of the patient. Another factor, which potentially adds to usefulness of the investigation, is strengthening confidence in the diagnosis. Irradiation for legal reasons and for purposes of insurance should be carefully limited or excluded.

While all medical uses of radiation should be justified, it stands to reason that the higher the dose and risk of a procedure, the more the medical practitioner should consider whether there is a greater benefit to be obtained.Among these special position is occupied by computed tomography (CT), and particularly its most advanced variants like spiral or multi slice CT.

If an examination is typically at the high end of the diagnostic dose range and the fetus is in or near the radiation beam or source, care should be taken to minimize the dose to the fetus while still making the diagnosis. For children, dose reduction in achieved by using technical factors specific for children and not using routine adult factors, because children are small, in nuclear medicine the use of administered activity lower than that used for an adult will still result in acceptable images and reduced dose to the child.

The most powerful tool for minimizing the risk is appropriate performance of the test and optimization of radiological protection of the patient. These are the responsibility of the radiologist or nuclear medicine physician and medical physicist.

The basic principle of patients' protection in radiological X-ray investigations and nuclear medicine diagnostics is that necessary diagnostic information of clinically satisfactory quality should be obtained at the expense of a dose as low as reasonably achievable, taking into account social and financial factors.

8.2.2 Effects of radiation exposure

Some effects may occur immediately (days or months) while others might take tens of years or even get passed to the next generation. Effects of interest for the person being exposed to radiation are called **somatic effects** and effects of interest that affect our children are called **genetic effects**.

i. Radiation Health Effects

Ionizing radiation has sufficient energy to cause chemical changes in cells and damage them. Some cells may die or become abnormal, either temporarily or permanently. By damaging the genetic material (DNA) contained in the body's cells, radiation can cause cancer.

Fortunately, our bodies are extremely efficient at repairing cell damage. The extent of the damage to the cells depends upon the amount and duration of the exposure, as well as the organs exposed.

Exposure to an amount of radiation all at once or from multiple exposures in a short period of time. In most cases, a large acute exposure to radiation causes both immediate (radiation sickness) and delayed effects (cancer or death), can cause sickness or even death within hours or days. Such acute exposures are extremely rare.

ii. Chronic Exposure

With chronic exposure, there is a delay between the exposure and the observed health effect. These effects can include cancer and other health outcomes such as benign tumors, cataracts, and potentially harmful genetic changes.

a. Low levels of radiation exposure

Radiation risks refer to all excess cancers caused by radiation exposure (incidence risk) or only excess fatal cancers (mortality risk). Risk may be expressed as a percent, a fraction, or a decimal value.

For example, a 1% excess risk of cancer incidence is the same as a 1 in a hundred (1/100) risk or a risk of 0.01. However, it is very hard to tell whether a particular cancer was caused by **very low doses** of radiation or by something else.

While experts disagree over the exact definition and effects of "**low dose.**" Radiation protection standards are based on the premise that any radiation dose carries some risk, and that risk increases directly with dose.

Note:

- The risk of cancer from radiation also depends on age, sex, and factors such as tobacco use.
- Doubling the dose doubles the risk.

Acute health effects occur when large parts of the body are exposed to a large amount of radiation. The large exposure can occur all at once or from multiple exposures in a short period of time. Instances of acute effects from environmental sources are very rare.

8.2.3 Safety precautions for handling radiations

Shortening the time of exposure, increasing distance from a radiation source and shielding are the basic countermeasures (or protective measures) to reduce doses from external exposure.

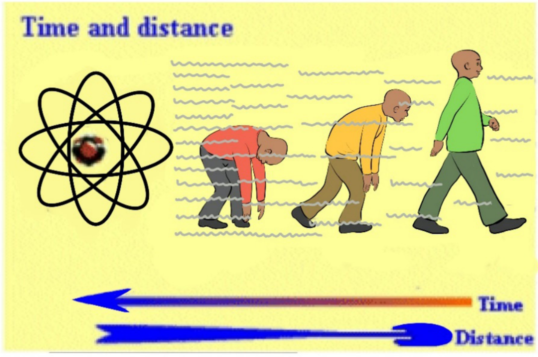


Fig.8. 3Illustration of distance and time from source of radiation

Note:

- **Time:** The less time that people are exposed to a radiation source, the less the absorbed dose.
- **Distance:** The farther away that people are from a radiation source, the less the absorbed dose.

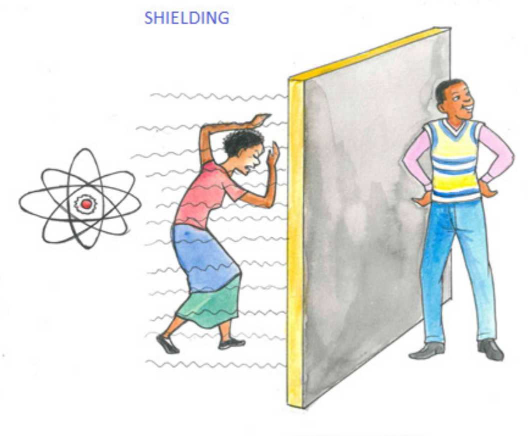


Fig.8.4 Illustration of shielding

Note: Shielding: Barriers of lead, concrete or water can stop radiation or reduce radiation intensity.

There are four main factors that contribute to how much radiation a person absorbs from a source. The following factors can be controlled to minimize **exposure to radiation:**

i. The distance from the source of radiation

The intensity of radiation falls sharply with greater distance, as per the inverse square law. Increasing the distance of an individual from the source of radiation can therefore reduce the dose of radiation they are exposed to.For example, such distance increases can be achieved simply by using forceps to make contact with a radioactive source, rather than the fingers.

ii. Duration of exposure

The time spent exposed to radiation should be limited as much as possible. The longer an individual is subjected to radiation, the larger the dose from the source will be.One example of how the time exposed to radiation and therefore radiation dose may be reduced is through improving training so that any operators who need to handle a radioactive source only do so for the minimum possible time.

iii. Reducing incorporation into the human body

Potassium iodide can be given orally immediately after exposure to radiation. This helps protect the thyroid from the effects of ingesting radioactive iodine if an accident occurs at a nuclear power plant. Taking Potassium iodide in such an event can reduce the risk of thyroid cancer developing.

iv. Shielding

Shielding refers to the use of absorbent material to cover the source of radiation, so that less radiation is emitted in the environment where humans may be exposed to it. These biological shields vary in effectiveness, depending on the material's cross-section for scattering and absorption. The thickness (shielding strength) of the material is measured in g/cm^2. Any amount of radiation that does penetrate the material falls exponentially with increasing thickness of the shield.

Some examples of the steps taken to minimize the effects of radiation exposure are described below;

- The exposed individual is removed from the source of radiation.
- If radiation exposure has led to destruction of the bone marrow, the number of healthy white blood cells produced in the bone marrow will be depleted.
- If only part of the body has been exposed to radiation rather than the whole body, treatment may be easier because humans can withstand radiation exposure in large amounts to non-vital body parts.

In every medicine there is a little poison. If we use radiation safely, there are benefits and if we use radiation carelessly and high doses result, there are consequences.

Ionizing radiation can change the structure of the cells, sometimes creating potentially harmful effects that are more likely to cause changes in tissue. These changes can interfere with cellular processes so cells might not be able to divide or they might divide too much.

Radioactive rays are penetrating and emit **ionizing radiation** in the form of electromagnetic waves or energetic particles and can therefore **destroy living cells.** Small doses of radiation over an extended period may cause cancer and eventually death. Strong doses can kill instantly. Marie Curie and Enrico Fermi died due to **exposure to radiation**.

Several precautions should be observed while handling radioisotopes. Some of these are listed in the following:

- No radioactive substance should be handled with bare hands. Alpha and beta emitters can be handled using thick gloves. Gamma ray emitters must be handled only by remote control that is by mechanical means. Gamma rays are the most dangerous and over exposure can lead to serious biological damage.
- Radioactive materials must be stored in thick lead containers.
- Reactor and laboratories dealing with and conducting experiments with radioactive metals must be surrounded with thick concrete lined with lead.
- People working with radioactive isotopes must wear protective clothing which is left in the laboratory. The workers must be checked regularly with dosimeters, and appropriate measures should be taken in cases of overdose.
- Radioactive waste must be sealed and buried deep in the ground.

Rules to remember when working with radiation

Everyone must take radiation overexposure seriously. Hence, preventive measures and rules must be strictly followed to avoid critical health conditions.

b. Acquire adequate training to better understand the nature of radiation hazards.
a. Reduce handling time of radioactive materials and equipment.
b. Be mindful of your distance from sources of radiation. Increase distance as much as possible.
c. Use proper shielding for the type of radiation.
d. Isolate or contain harmful radioactive materials properly.
e. Armor yourself with appropriate protective clothing and dosimeters.
f. Conduct contamination surveys in the work area.
g. Do not eat, drink, smoke, or apply cosmetics in an area where unsealed radioactive substances are handled.
h. Observe proper radioactive waste disposal.
i. Conduct usual radiation safety self-inspection

8.2.4 Concept of balanced risk

a. Risks of ionizing radiation in medical treatment

Risk in the area of radiation medicine has several dimensions that are less common in other areas of medicine. First, there may be risks from **overexposure** that do not cause immediate injury. For example, the causal connection, if any, may be difficult or impossible to verify for a malignancy that surfaces several years after an inappropriate exposure. Second, the risks associated with the medical use of **ionizing radiation** extend beyond the patient and can affect health care workers and the public.

In amplifying these and other aspects of the risks that attend medical uses of ionizing radiation, the discussion addresses the following issues: human error and unintended events; rates of misadministration in radiation medicine; inappropriate and unnecessary care; and efforts that reduce misadministration and inappropriate care.

b. Human Error and Unintended Events

Errors occur throughout health care: A pharmacist fills a prescription with the wrong medicine; an x-ray technician takes a film of the wrong leg; a surgeon replaces the wrong hip. The advent of complex **medical technology** has increased the opportunity for error even as it has increased the opportunity for effecting cures.

By educating health care workers, and by circumscribing their actions, human error may be minimized. However, some number of mistakes will always, unavoidably, be made, and no amount of training or double-checking can erase that fact.

c. Comparison of risks in the use of ionizing radiation

The comparison of relative risks of misadministration in by-product radiation medicine to error rates and events in other medical practice settings, as well as the comparison of disease and death rates with the risks of the therapeutic administration itself, help to some extent to place ionizing radiation use in a broader context.

To achieve this success requires the highest standards of performance (accuracy of delivered dose), both when planning irradiation for an individual patient and in actual delivery of the dose.

In a large number of cases, decreasing the dose to the target volume is not possible since it would unacceptably decrease the cure rate. In these cases present technological developments aim at optimizing the patients' protection, keeping the absorbed tumor dose as high as is necessary for effective treatment while protecting nearby healthy tissues.

It should be remembered that successful eradication of a **malignant tumor** by radiation therapy requires high-absorbed doses and there is a delayed (and usually low) risk of late complication. The above mention techniques are used to provide the best benefit/risk ratio.

A malignant tumor in a pregnant woman may require **radiotherapy** in attempt to save life of the patient. If a tumor is located in a distant part of the body, the therapy - with individually tailored protection of the abdomen (screening) may proceed.

When thyroid cancer with metastases is diagnosed in a pregnant woman, treatment with I^{131} is not compatible with continuation of the pregnancy. The treatment should then be delayed until delivery if doing so wouldn't put the mother's life in danger. Medical radiation can be delivered to the patient from a radiation source outside the patient. Regardless of how much dose the patient received, they do not become radioactive or emit radiation.

Balancing risks are often summarized in the following:

- The demand for imaging, especially computed tomography, that has increased vastly over the past 20 years
- An estimated 30% of computed tomography tests that may be unnecessary
- Ionizing radiation that may be associated with cancer.
- The risks of radiation exposure that is often overlooked and patients are seldom made aware of these risks
- The requesting doctor who must balance the risks and benefits of any high radiation dose imaging test, adhering to guideline recommendations if possible
- Difficult cases that should be discussed with a radiologist, ideally at a clinic radiological or multidisciplinary team meeting.

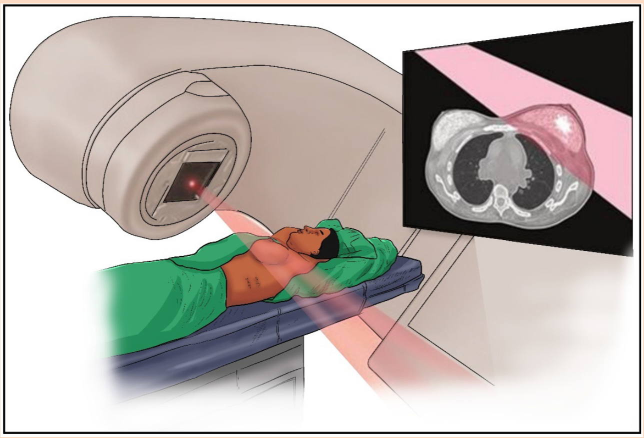
Application activity 8.2

1. How do you understand by the term balance risk?
2. What is magnitude of the risk for cancer and hereditary effects?
3. Is ionizing radiation from medical sources the only one radiation for which people are expected to be exposed?
4. What are typical doses from medical diagnostic procedures?
5. Can radiation doses in diagnosis be managed without affecting the diagnostic benefit? Explain to support your decision.
6. Explain clearly how radiation can be reduced by three principles for radiation safety: time, distance and shielding

8.3. BASICS OF RADIATION THERAPY FOR CANCER TREATMENT

Activity 8.3

The figure below shows the radiotherapy of breast cancer treatment



Use the diagram above to answer the following questions.

i) Use a pencil, re-draw the picture in your notebook and locate points that may be affected by cancer cells.

ii) From your reasoning, does the breast cancer affect only women? Support your answer.

iii) In Medicine, the concern of breast tissue cancer can be solved by radiation therapy. It should be delivered in two ways i.e. External and internal, why do think a doctor may opt one method over another?

8.3.1. Background of Radiation therapy

Radiation therapy plays an important role in curative treatment of many cancers. It can be used alone or in conjunction with the surgery, chemotherapy or both in order to eradicate cancer.

Cancer is the name given to a range of diseases where there is malignant tumour. A malignant tumour may grow slowly for a time and then faster; it infiltrates surrounding structure and will destroy them. Many cancers are treated successfully with radiation.

Radiation therapy (also called radiotherapy) refers to the cancer treatment which uses high dose of radiation to kill cancer cells and tumors. It can be used to cure cancer, control the growth or spread of cancer and to provide comfort by alleviating thesymptoms cancer can sometimes cause.The specification for the radiotherapy lead to the complicated cancer like: painful bone and soft tissue metastases, hemoptysis, dyspnea, dysphagia, brain metastases, and spinal cord compression, etc.

Long exposure of radiation or spent the total dose of radiation over time, allow tissue cells to be destroyed and be damaged by cancer cells. This is not a big issue for palliative radiotherapy, but is critical for curative treatment.

Radiotherapy consists/ focuses of treating cancer without removing organs and tissues. It can be used alone or in conjunction with the surgery and systemic therapies(e.g., chemotherapy, hormones). The intent is either to cure with radical radiotherapy or to control symptoms with palliative radiotherapy.

Radiotherapy is usually given over several minutes and is similar to having an x-ray examination. Patients need to be cooperative and able to lie still for 10 to 15 minutes. As it is a localized treatment, benefits and side effects are generally limited to the areas being treated.

Radiation therapy had the following types:

- 3D conformal radiation therapy
- Intensity-modulated radiation therapy(IMRT)
- Volumetric-guided radiation therapy(VGRT)
- Image-guided radiation therapy(IGRT)
- Stereotactic radiosurgery(SRS)
- Brachytherapy
- Superficial x-ray radiation therapy(SXRT)
- Intraoperative radiation therapy (IORT)

8.3.2 Cancer treatment

a. Destruction

Radiation damages cells through **ionization.** This may bea direct ionization of important molecules such as **DNA**, in the cell nucleus (shown in below figure) or indirect action through ionization of the more abundant water within the cell.

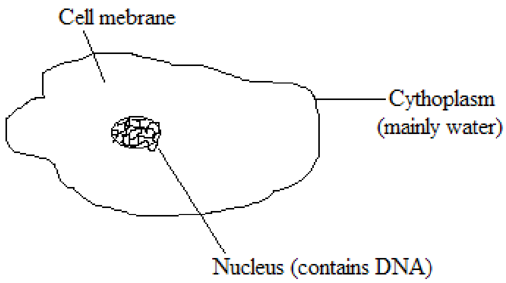


Fig.8. 5 Human cell

DNA is a complex responsible for protein synthesis and growth pattern. In some case, the cells begin to grow uncontrollably (cancer), whilst in others its ability to produce is destroyed(sterilization).

The ionization of water results in the formation of free radicals **H** and **OH**. These are very reactive and potentially damaging, often leading to cell death or onset of mutation. Cells are most vulnerable to radiation damage when they are reproducing, so that fast growing cells are very radiation sensitive, for example the developing fetus, the reproductive organs and bone marrow. In contrast, brain and bone tissues, which do not replace themselvesrapidly, are least affected.

b. The cure

Cancerous cells tend to reproduce more rapidly than normal cell, making them relatively more radiation sensitive and capable of being selectively destroyed through ionization. The target is always the DNA within the nucleus: breaks in the DNA stands can result in cell death or loss of reproductive capacity either of which stops the spread of the disease. Healthy cells recover from irradiation more quickly than cancer cells. In order to achieve the greatest destruction of cancer cells, with the least damaged to surrounding healthy tissue, the radiation should therefore be delivered in short treatment or fractions of relative high doses over a period of time. A typical fractionation scheme might be involved daily treatment for five days in five weeks.

c. The care

Certain organisms in the body are very weak to radiation damage and during therapy, it is important to keep dose delivered to these tissues to a minimum. Such critical organism include the:

- Eye(cataracts)
- Spinal cord(paralysis)
- Reproductive organs(sterility)
- Kidney, liver,rectum.

The treatment depends on the nature of the tumor and its location. There are four basic methods and treatment for any one patient may involve two or more of them.

- Surgery: if the tumor is easily located, it may simply be removed.
- Chemotherapy: the patient is given dose of cell destroying drugs.
- Hormone therapy: some hormone dependent tumorcan be treated by altering the hormone balance within the body.
- Radiotherapy: tumor cells are destroyed with high-energy radiation, either gamma-rays from a radioactive source or x-rays.

There are three steps to follow radiotherapy treatment:

The first step in radiotherapy is to meet with a radiation oncologist so that an informed decision can be made regarding the overall prognosis and goals of treatment and so that patients and physicians can proceed with planning treatment.

The next step is to determine the area to be treated. This process is called **simulation.** The simulation is done with fluoroscopy, x-ray films, CT-Scan and MRIscan.

The third step is treatment. Radiation treatments are usually given 5 days a week over several weeks.

During the treatment planning, the doctor or radiotherapist analyses the information about the size and position of the tumors using various imaging techniques available like x-ray films, CT-Scan and MRI scan, even ultrasound imaging sometime can be applied for example in assessing the thickness of the chest wall when planning breast treatment.

The total quantity of radiation required to destroy the tumors depends on the many factors, such as:

- Types of cell irradiated(some cancer cells are more radiation-sensitive than others)
- Environment of the cell(its blood and oxygen supply are important)
- Extent of cancer
- Fractionation scheme selected (a large total dose is needed for more, smaller fractions).

Treatment for certain condition

a. spinal cord compression

Spinal cord compression coming from tumor growth is an oncologic emergency that should be treated in 24hours of diagnosis with aim of maintaining patient's ability to walk, continence and comfort. People with spinal cord compression (about 95%) had back pain and neurologic signs and symptoms including weakness,paresthesia, Incontinence,spasticity and hyperreflexia.

Patients' neurologic deficits sometimes increase rapidly, and early detection is of highest importance. Magnetic resonance imaging is the modality of choice for this.

A radiation oncologist should be consulted on an emergency basis for spinal cord compression.

Prognosis is largely dependent on a patient's overall condition, pretreatment ability to walk, rate of symptom progression, and the extent of the block. Most patient's ambulatory at diagnosis of spinal cord compression remain ambulatory if treated promptly; only half of those who can move their legs but are not walking become ambulatory after treatment.

Ambulatory means able to walk but ambulatory care or outpatient care is medical care provided on an outpatient basis, including diagnosis, observation, consultation, treatment, intervention, and rehabilitation services. This care can include advanced medical technology and produces even when provided outside of hospitals.

b. Superior vena cava obstruction

Superior vena cava obstruction caused by cancer also requires urgent, though not emergency, treatment. Patients with superior vein cava obstruction present with neck and facial swelling, dilated neck veins, orthopnea, and shortness of breath, and sometimes progress to headaches and cerebral edema. The treatment usually varies within 1 to 2 weeks depending on the severity of presenting symptoms.Some chemotherapy-responsive malignancies, such as lymphomas and small cell lung cancers, can also cause superior vena cava obstruction and are primarily treated with chemotherapy.

c. Bone metastasis

Bone metastases are usuallysign for palliative radiotherapy. About 80% of patients who receive radiation therapy for bone pain experience fewer symptoms; maximum effect is noticed on average 1 to 3 weeks after treatment. Breast, prostate and lung are common primary cancer places for bone metastases. Diagnosis is usually made using bone scans and plain x-ray films, but occasionally magnetic resonance imaging or computed tomography scans are needed.

d. Brain metastasis

Brainmetastases occur around 10% to 30% to all cancer patients. Patient with brain metastases present the symptoms like: headache, cognitive dysfunction, neurologic deficits, and seizures. The diagnosis duration given over 1 to 2 weeks to the entire brain, can improve symptoms and extend survival. Contrast-enhanced computed tomography (CT-Scan) or magnetic resonance imaging (MRI) scans are used to diagnose brain metastases.

Conclusion

Radiotherapyhasfundamentalrole in both curative and palliative management ofcancer patients.So that family physicians will be better aware of the appropriateness of referring patients for such treatment and participating in care of cancer patient can help facilitate for radiotherapy when they encounter patients with oncologic problems or complications amenable to radiotherapy treatment.

Application activity 8.3

1. What does a radiation therapy mean?
2. What is radiotherapy used for?
3. How long does it take for radiation therapy treatment to work?
4. At what stage of cancer is radiotherapy used?

Skills Lab 8

In this activity you will invite a medical doctor that has expertise in radiation and medicine.

What to do?

- Invite the doctor (using a written letter).Your class tutor or class leaders may help you in doing this. You may target different doctors so that if disappointed by one, you do not miss it all. Remember these doctors are always busy at their work.
- When he/she comes, make sure you give him points of discussion. These may include: Radiation and dosimetry, balanced risk, Hazards and safety precautions while handling radiations, and radiation therapy for cancer treatment. You can still send him/her these topics before so that he/she can do enough preparations.
- While he/she is presenting, make sure you note down important information in your notebooks.
- You may ask questions in case you do not understand what the doctor is explaining.
- Compare what the doctor explained to what you have been discussing in this unit.
- Develop a comprehensive report including all what you have been studying and information from the doctor.
- Submit your report to your tutor for marking or checking.

End of unit 8 assessment

1. The large amount of radiation absorbed by the body can lead to the radiation sickness. What do you think is the symptoms and complications of the radiation sickness?
2. Cleary explain what kind of radiation causes radiation sickness.
3. Is it possible that radiation spread from person to person?
4. What are the risks associated with radiation from diagnostic X-ray imaging and nuclear medicine procedures?
5. Does receiving external-beam radiation make a person radioactive or able to expose others to radiation?
6. Is there any risk that internal radiation implants (brachytherapy) will leak or break free from where they are placed and move around my body?
7. I'm having an imaging test using radioactive materials. Will I be radioactive after the test?
8. Are there situations when diagnostic radiological investigations should be avoided? Explain to support your decision.

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