7. WAVES

NATURE OF WAVES

There are essentially two ways of sending energy from one place to another. The first involves actual transfer of matter and the second method involves what we call a wave process. Energy may be transferred through matter by mechanical waves such as sound waves or through space by electromagnetic waves–e.g. passage of light from a distant Star through outer space. Waves travel with a finite speed. Each wave has its own wavelength, frequency, amplitude and form. To sum up, a wave may be defined as a form or pattern of disturbances which travels with a finite velocity through the medium as a result of the continuous periodic motion of the particles of the medium.

MECHANICAL WAVES

Transverse and Longitudinal Waves If the motion of the particles is perpendicular to the direction in which the wave moves, it is called a transverse wave. Waves spreading on the surface of water, vibration of a string, are examples. If the motion of the particles is along the direction of motion of the waves, it is then called a longitudinal wave. Sound in air is an example of such waves.

Transverse waves travel in the form of crests and direction of wave troughs while longitudinal wave travels in the form of compressions and rarefactions.

ELECTROMAGNETIC WAVES

Electromagnetic waves are coupled periodic electrical and magnetic disturbances generated by oscillating electric charges.

Electromagnetic waves include an enormous range of frequencies–from radio waves with frequencies less than 10^5 Hz to gamma ray having frequencies greater than 10^{20} Hz. Visible light is simply electromagnetic radiation in the range of frequencies 4.3×10^{14} to 7×10^{14} Hz.

There is no sharp distinction between various sections, which virtually overlap each other. The descriptive names of various sections of the spectrum are merely historical classification, otherwise all waves, from radio waves to gamma rays are same in nature, differing only in frequency, wavelength, and method of production. Radio and micro waves are produced by oscillating electrical circuits. Infrared waves originate in molecular systems. Visible light, ultraviolet radiation, x-rays arise from disturbances in the electronic structure of atoms. Gamma rays originate in atomic nuclei. All electromagnetic waves have the same speed ($c = 3 \times 10^8$ m/s) in vacuum. The relation Speed = frequency x wavelength holds good for all electromagnetic waves.

If the frequency of radio waves sent out by a radio station is known, the wavelength can be calculated by dividing 3 x 108 m/s by the given frequency. For example, the wavelength of radio waves sent out by a radio station at frequency 819 kHz is 366 m.

The energy associated with an electromagnetic radiation is proportional to its frequency. In the visible spectrum (violet, indigo, blue, green, yellow, orange, and red), violet light has maximum frequency and hence maximum energy, whereas red has minimum frequency and hence minimum energy.

Infrared radiation goes through dry air, but not through water vapour. If passed through a sample of a person's breath, transmission is altered if a person has consumed alcohol. It enables a precise and quick means to determine a person's blood alcohol count. Police use breath analyzers to detect and catch people driving under the influence of alcohol.

Photographic film sensitive to infrared rays shows different temperatures as different colours. Anything having a higher or lower temperature than the surroundings can be detected by infrared photography. Devices called thermo-graphic scanners can produce an on-the-spot T.V. like picture of the infrared emission of various bodies. A person having fever can be spotted in a crowd using such thermo-graphic pictures. Currently, people suffering from H1N1 (swine) flu are being detected at airports by the use of this technique.

Radio frequencies for commercial broadcasting range from 550 to 1500 kHz. Radio broadcasting stations use small crystals of quartz that vibrate hundreds of thousands of time each second ensuring a constant radio frequency. In amplitude modulation (AM) an audible signal frequency of several hundred or thousand Hz is impressed upon a carrier radio wave of MHz frequency, modulating (varying) its amplitude but leaving its frequency unaffected. The signal is received at the receiver end amplified and converted to a sound wave. In frequency modulation (FM) only the frequency of the carrier wave is modulated increasing and decreasing at same rate as the impressed audible signal frequency. Since electrical disturbances in the atmosphere affect only the amplitude and not the frequency of the modulated wave, FM transmission is noise free.

Radio and Television Transmission

Radio waves sent only by radio stations are reflected by the ionosphere (a part of the atmosphere which extends from 60 to 500 km above the earth) and can be received anywhere on the earth. Due to slight absorption in the ionosphere, the radio signals received at far-off places are rather weak. At night, the radio reception improves because the layers of the ionoshphere are not as exposed to sunlight and are more settled.

High-frequency waves carrying television signals penetrate the ionosphere and are not received like radio signals. TV transmission was therefore accomplished on a “line-of-sight” basis. The curvature of the earth and mountainous terrains limited the range of TV reception. However, geostationary satellites are being used these days for television (and telephone) links between places anywhere on the earth.

Direct-to-home (DTH) Television

Nowadays, most TV viewers receive programs through a direct broadcast satellite (DBS) provider, such as DISH TV or DTH platform. Unlike earlier programming, the provider’s broadcast is completely digital, which means it has high picture and stereo sound quality. There are five major components involved in a DTH satellite system: (i) the programming source, (ii) the broadcast centre, (iii) the satellite, (iv) the satellite dish, and (v) the receiver.

Programming sources are simply the channels that provide programs for broadcast. The provider (the DTH platform) does not create programs itself. It pays other companies (STAR TV, ZEE TV, Doordarshan etc) for the right to broadcast their programs via satellite. At the broadcast centre, the TV provider receives signals from various programming sources, compresses these signals using digital compression, and beams a broadcast signal to the proper satellite. The satellite receives the signal from the broadcast station and rebroadcasts them to the ground. The viewer’s dish picks up the signal from the satellite and passes it on to the receiver in the viewer’s house. The receiver processes the signal passes it on to a TV set.

Cable TV networks also work on the same principle except that they receive signals from the satellite on large community dish antennas and transmit to TV sets through fixed optical fibers or coaxial cables.

Night Vision

Night vision is the technology that provides us with vision in total darkness and the improvement of vision in low light environment. The most common methods are:

(i) Low-light imaging
(ii) Thermal imaging
(iii) Near infrared illumination.

The most common applications of night vision are: night driving or flying, night security and surveillance, wild life observation, sleep lab monitoring, search and rescue etc.

(i) Low-light imaging: In low-light imaging the objective lens of a special camera focuses available light (photons) on the photo cathode. The light energy causes electrons to be released from the cathode which are accelerated by an electric field to increase their speed (and energy). These electrons after multiple reflections from the specially coated walls of the camera get multiplied and finally hit a phosphorus screen which glows and shows the desired view.

(ii) Thermal imaging: Different from low-light imaging methods, thermal imaging night vision methods do not require any ambient light at all. They operate on the principle that all objects emit infrared energy as a function of their temperature. A thermal imager collects the infrared radiation from objects in the scene and creates an electronic image. A thermal imager is able to penetrate smoke, fog, and haze. Thermal images are normally black and white in nature where black objects are cold and white objects are hot. Some thermal cameras show images in colour. This false colour is an excellent way of distinguishing between objects of different temperatures.

(iii) Near infrared illumination: A popular method for performing night vision is by infrared illumination. In this method, a device that is sensitive to invisible to near infrared radiation is used in conjunction with an infrared illuminator. Near infrared illuminators are LED type and laser type. The most efficient infrared illuminators are based on an infrared laser diode that emits near infrared energy. The near infrared illuminator allows the observer to illuminate only specific areas of interest while eliminating shadows and enhancing image contrast. The technique permits the use of solid state cameras which have the ability to convert near infrared images to visible.

Radar

Radar (Radio detection and ranging) employs high-frequency radio waves for detecting objects like ships and aeroplanes. A rotating aerial sends out pulses which are reflected from the objects on which they fall. The time interval between the transmission and reception of pulses helps determine the distance of the object. A picture of the scanned area is produced on the screen of a special cathode ray tube.

Microwave Oven

As the name suggests, a microwave oven cooks food using microwaves. Microwaves are generated in the oven at a frequency of about 2450 MHz by means of a magnetron. When the waves fall on the food, these are absorbed by water, fats, sugars and certain other molecules whose consequent vibrations produce heat. Since the heating occurs inside the food, without warming the surrounding air, the cooking time is greatly reduced. Most type of glasses, papers etc. do not absorb the microwaves and hence do not heat up. That is why most microwave utencils are made of glass. Foods cannot be cooked in metal vessels because the metal blocks out the microwaves.

Computed Tomography

Computed Tomography (CT) is a medical imaging method employing tomography. It generates a three-dimensional image of the inside of an object from a series of two-dimensional X-ray images taken around a single axis of rotation. The technique is used in diagnostic studies of internal bodily structures, as in the detection of tumours or brain aneurysms.

SOUND

All sounds are produced by the vibration of material objects. The voice results from the vibration of vocal chords in the larynx. In a sitar the sound is produced by the vibrating string and in a table or a drum by the vibrating stretched skin or membrane. In each of these cases, the frequency of the sound wave is identical to the frequency of the vibrating source.

Sound waves are longitudinal and cannot travel in vacuum. The transmission of sound requires a medium: air, liquid or solid. Compared to solids and liquids, air is relatively poor conductor of sound. The sound of a distant train, which cannot be heard through air, can be heard clearly if the ear is placed against the rail.

SPEED OF SOUND

The speed of sound varies considerably depending on material through which the waves are travelling. In general sound travels more rapidly through liquids than through gases and faster of all through solids. Higher speeds result partly from stronger forces between molecules; as in a tightly stretched 'slinky' spring, the oscillations are passed on more rapidly.

Speed of sound in air …………… 330 m/s (dry air, at 0ºC)

Speed of sound in water …………… 1400 m/s (at 0ºC)

Speed of sound in concrete ……………… 5000 m/s

In the case of gases, for example air: The speed of sound does not depend on the pressure; if atmospheric pressure changes for example, there is no change in the speed of sound. Rise in temperature produces an increase in the velocity of approximately 0.6 m/s per degree C. At high altitude, the speed of sound is less than it is at sea level, because the temperature is lower and not because the pressure is less. It is worth noting that the speed of sound in air is only about one three-millionth of the speed of light.

Sound Characteristics

Pitch and Frequency The pitch (shrillness) of a sound depends on its frequency. A sound of higher frequency has a higher pitch. The pitch of a woman's voice is higher than that of a man.

The human ear is normally sensitive to sounds whose frequencies are between 20 and 20,000 Hz. Sound waves with frequencies below 20 Hz are called **infrasonic** and those with frequencies above 20,000 Hz are called **ultrasonic.** Though normal human beings cannot hear sounds of frequencies higher than 20,000 Hz, animals such as cats and dogs can. Dolphins produce high pitched sounds of frequency as high as 100,000Hz, which enable them to locate each other under water.

Loudness The loudness of a sound is related to the energy of the waves and depends on amplitude. The relative loudness of a sound is measured in decibels (db). Some common sounds and their noise levels are listed in Table. It may be mentioned here that exposure to a noise level of 85 db or above can impair or damage hearing.

Source of sound	Noise level (db)
Whisper	20
Ordinary conversation	65
Traffic on a busy road	70
Amplified rock music	120
Jet aeroplane, 30 m away	140

Sometimes, it is desirable to increase the loudness of a sound. This can be achieved by setting a greater mass of air into vibration.

All stringed instruments, such as the violin, sitar, guitar, etc. have sound boxes attached to increase the loudness. When a string of a sitar is plucked, very little air is set in motion due to the small surface area of the string. But the vibration of the string sets the sound box into forced vibrations. When the box vibrates, it moves a large amount of air and increases loudness.

A loudspeaker has vibrating cone with a large surface area. Thus a large mass of air in contact with the cone is set into vibration producing a loud sound.

Reflection of Sound, Echo

Waves have the property of being reflected when they meet an obstacle. When a sound wave is reflected by a distant obstacle, such as a wall or a cliff, an echo is heard. For an **echo** to be heard separately from the original sound, it must arrive 0.1 s after the original sound being prolonged. This prolonging of sound by reflection is called **reverberation**. Reverberation is also caused when a series of echoes are heard due to more than one reflecting surface.

An echo can be used for measuring the speed of sound. Exploration of underwater gas and oil is done by detecting the echoes of shock waves produced by explosions on the water surface. Echoes of ultrasonic waves are used for measuring the depth of sea-beds or locating submerged objects. An apparatus called **Sonar** (Sound Navigation Ranging) is used for this purpose.

Ultrasonic waves is also used for detecting flaws in the interiors of solids, destroying microorganisms, and mapping underground structures for oil and mineral deposits.

Bats emit ultrasonic waves of frequencies up to 80,000 Hz and use the reflection of these waves (echoes) to determine the presence and the distance of objects on their way and from them respectively.

Ultrasonics is applied widely in medical diagnosis and treatment. In sounding out the abdomen, as an example, the sound waves pass through the different tissues at speeds that depend on the elasticity and density of the tissue. As they collide with different structures, they send back echoes, which are picked up by sensitive microphones and turned into electrical signals on a television screen. From the pattern of the echoes, tumours, abscesses, lesions and other abnormalities can be picked up within the liver, pancreas, kidneys, heart and other organs. Medical Ultrasonography (commonly called Ultrasound) is ideal for use in human beings.

Refraction of Sound

When successive layers of air have different temperatures, the ability of sound to travel faster in warm air than in cold air causes bending of sound. This bending of sound is called refraction.

On a warm day, the air near the ground is warmer than the air above and so the speed of sound waves near the ground is higher. This causes bending of the sound away from the ground. On a cold day or at night, the reverse happens and the sound waves bend towards the earth. Thus on a cold day sounds can be heard over longer distances.

Sounds can be heard at abnormally long distances over water on quiet days. This happens because air next to water is cooler than air above and, therefore, sound waves bend toward the water and can travel long distances.

Resonance

Resonance is a phenomenon of forced vibrations due to which sound waves can be produced with a large amplitude or intensity. All bodies have their natural frequency of vibration. When we apply a small signal of the same frequency to the body, the signal is greatly amplified and this is called resonance.

For example a singer can shatter a glass by singing a certain note. The frequency of the note is the same as the natural frequency of the glass. The singer sings and the glass resonates. The amplitude of the vibrators increases and the glass shatters.

Soldiers crossing a suspension bridge always break step in case the frequency of vibration of their marching should coincide with that of the bridge. The cumulative effect of a considerable number of impulses applied at exactly the right instants might cause dangerously large oscillations of the bridge.

When we 'tune' a wireless receiver, we are actually adjusting its natural frequency (and therefore wavelength) to that of the incoming wireless carries waves, when it will be excited by resonance.

Doppler Effect

The Doppler Effect is the change in frequency of a wave (sound or light) due to the motion of the source or observer. The frequency (and hence pitch) of a sound appears to be higher when the source approaches the listener and lower when the source recedes from him.

It is due to the Doppler Effect that the whistle of a train appears shriller when if approaches a listener than when it moves away from him.

Speed guns (or radar sets), used by police to measure the speed of vehicles, use Doppler Effect. A radar set sends out a radio pulse and waits for the reflection. Then it measures the Doppler shift in the signal and uses the shift to determine the speed.

The Doppler Effect is very useful in astronomy. It can be used to find out whether a star is approaching us or receding away from us. When a star is receding from us the light emitted from the star appears more red (red light is of lower frequency than other colours). Thus the fact that the light emitted by the stars of distant galaxies suffers a red shift when observed from the earth means that the galaxies are receding from our galaxy. This is the principle evidence in favour of the hypothesis of expanding universe.

Doppler Effect can also be used to detect or even measure the rotation of a star, e.g. the sun.

The effect can be used to track a moving object, such as a satellite, from a reference point on the earth. The method is remarkably accurate; changes in the position of a satellite 108 m away can be determined to a fraction of a centimetre.

Sonic Boom

A supersonic (faster than sound) aircraft produces a cone of sound called a shock wave. When this shock wave reaches a listener, he hears a sort of loud explosion, called the sonic boom.

Musical Scale

A musical scale is a succession of notes, the frequencies of which are in simple rations to one another. Sa, re, ga, ma, pa, dha, ni is one such scale called the diatonic scale. The frequencies of these notes are: sa (256), re (288), ga (320), ma (341.3), pa (384), dha(426.7) and ni (480). The next note denoted by sa has a frequency 512, twice that of sa. The interval sa-sa is called an octave (8).

Noise Reduction in Recording Media

Dolby Laboratories Inc. is a music recording company, which has developed techniques to reduce noise levels in recorded music. Dolby noise reduction, employed during recording and during playback, works in tandem to improve the signal-to-noise ratio.

Dolby A was company's first noise reduction system, intended for use in professional recording studios. It provided about 10 dB of broadband noise reduction.

Dolby B was developed to achieve about 9 dB noise reduction primarily for cassettes. It was much simpler than Dolby A and therefore less expensive to implement in consumer products. From the mid 1970s, Dolby B became standard on commercially pre-recorded music cassettes.

Dolby C provides about 15 dB noise reduction. It first appeared on top-end cassette players in the 1980s.

Dolby SR (Spectral Recording) system is a much more aggressive noise reduction approach than Dolby A. Dolby SR is much more expensive to implement than Dolby B or C, but, it is capable of providing up to 25 dB noise reduction in the high frequency range.

Dolby S is found on some Hi-Fi and semi-professional recording equipment. It is capable of 10dB of noise reduction at low frequencies and up to 24 dB of noise reduction at high frequencies.