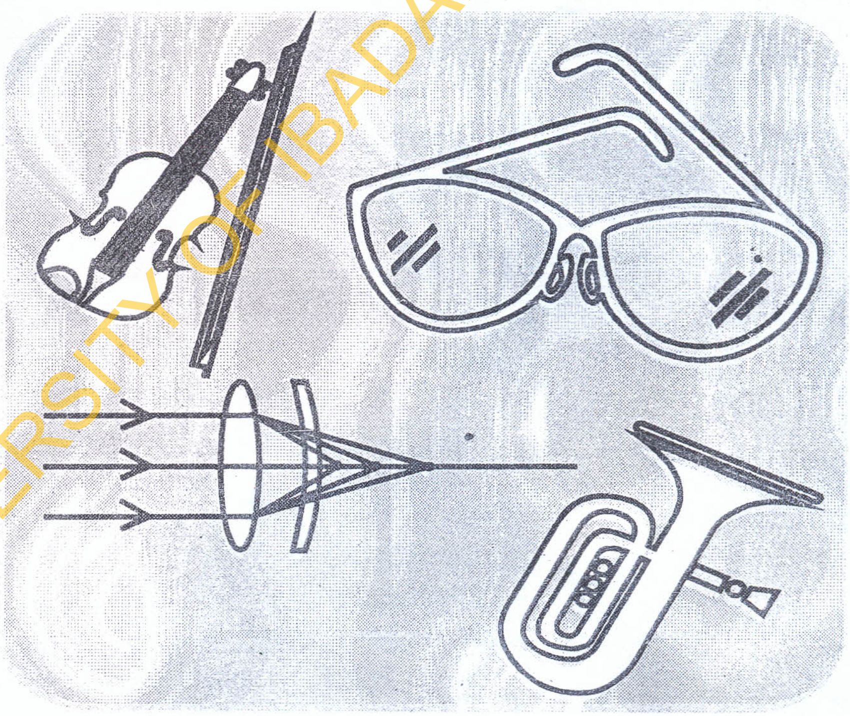
FUNDAMENTALS OF PHYSICS 2

Light And Soundwaves



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LIGHT AND SOUND WAVES

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CHAPTER TWELVE

APPLICATION OF SOUND WAVES

By Dr. B.A.J. Egede (Mrs.) and Dr. Farombi J. Gbenga

INTRODUCTION

Sound is produced by a vibrating body. The nature of the vibration determines the type of sound produced. There are some vibrations which are seen and some not seen but felt. For example, a plucked string as in violin or guitar, a struck bell etc. can be categorised as seen vibrations while vibrations as a result of thunderous noise, whistling, wind rushing through crack or small opening are said to be felt.

Sound can be classified into two. These are:

(i) Noises; and

(ii) Musical sounds

Before we distinguish between noises and musical sounds, it is good to state that a combination of two or more sounds produces the effect of a noise, but a combination of two or more noises can never produce the effect of a musical sound.

Noises are caused by disturbances of irregular frequency such as banging of things together, explosions etc. Musical sounds are caused by bodies performing regular vibrations.(i.e. of regular frequency).

In this chapter the application of sound waves in three major areas:- musical instruments, buildings and modern technology is discussed.

MUSICAL INSTRUMENTS

Musical instruments are classified into three:- (i) Wind, (ii) String and (iii) Percussion instruments. In all cases, the air around the instruments are set vibrating by some specific method and thus sound waves are produced.

Wind Instruments:

These are instruments which operate on the principle of vibration of sound waves in open and closed pipes. They include clarinets, saxophones, flutes, organ, trumpets, etc. Generally they produce musical notes when the air column in them are set into vibration.

They can further be divided into reed and flute pipes. The reed pipes include the saxophone and the clarinet while those with flute pipes include trumpets and all kinds of flutes. They can be metallic and wood wind instruments. In flute pipes, they are either open or closed. As stated in earlier theoretical considerations, the open instruments are richer in music because they produce more overtones.

Operation of Wind Instruments

To produce the musical notes in them, the player blows through it and varies the frequency by varying the length of the vibrating air column. This is achieved by manipulating the keys in the instruments. For the flute, when all the holes are closed, the lowest note is produced. Overtones are produced by opening the holes.

On the other hand the reed pipes contain springy metal called 'reed'. To produce sound, the player blows into it and the reed is set vibrating by the stream of air. The sound produced has the same frequency as the vibrating reed, as shown in *figure 12.1* below.

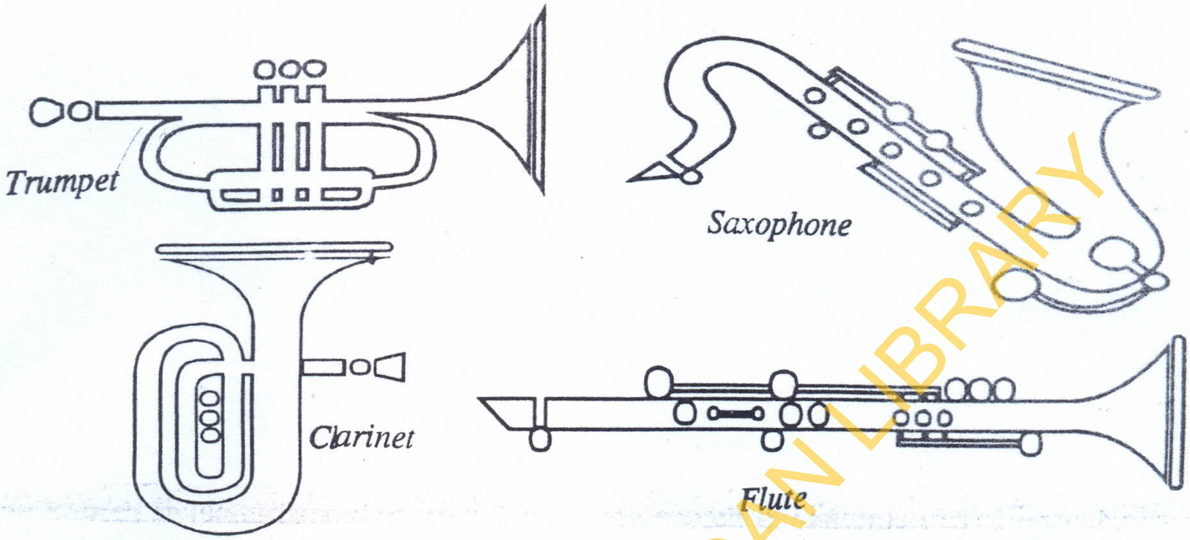

Fig.12.1 - *Wind Instruments:-Flute and Reed pipes, Trumpet, Clarinet and Saxophone*

String Instruments:

These are instruments which produce musical notes when tightly stretched lengths of wire or `string' are bowed or plucked so as to set them into vibration. The weak sound produced by the vibrating string is transmitted to a sounding board (as in the piano) and to a hollow body of instruments (as in the violin). This helps to magnify the sound by setting a larger mass of air into vibration.

Other stringed instruments are guitar, mandolin etc. The instruments can have a set of strings of varying thickness (or diameter) which are fixed at both ends. special screws are provided for varying the tension in them, so as to vary the frequency of the note produced. In some instruments, the tension in a set of strings are pre-fixed and varying notes are produced by varying the lengths according to laws of vibrations in a stretched string. The general principles/laws involves in making stringed instruments is that the frequency f, of a vibrating string depends on its length ℓ, mass per unit length m, (in terms of thickness and heaviness) and the tensional force T, applied to keep the string stretched (taut).

Mathematically,

$$F \; \alpha \; \frac{1}{\ell}\sqrt{\frac{T}{m}}$$

Where f	=	*frequency of a vibrating string*
ℓ	=	*length of the vibrating string*
T	=	*Tensional force to keep the vibrating string*
m	=	*Mass per unit length of the vibrating string*

It follows that a long, thick, loose string produces a note of low frequency while a short, thin, and taut vibrating string produces a high frequency note.

Three common stringed instruments are: Violin guitar and Piano. This grouping is done based on what a player does to these string instruments. There are other types of string instruments like harp and Sonometer. Harp and Sonometer are played the same way guitar and violin are played respectively.

The violin has only 4 strings, all of the same length, but of varying thickness. A player bows a violin. The guitar is a six-stringed instrument (there are some bass guitar of 4 strings), it has similar characteristics to that of violin, only that the string are plucked. The piano contains a number of strings of varying thickness and length which are kept under force. Each string is struck by small felt hammess activated by the keys on the key board.

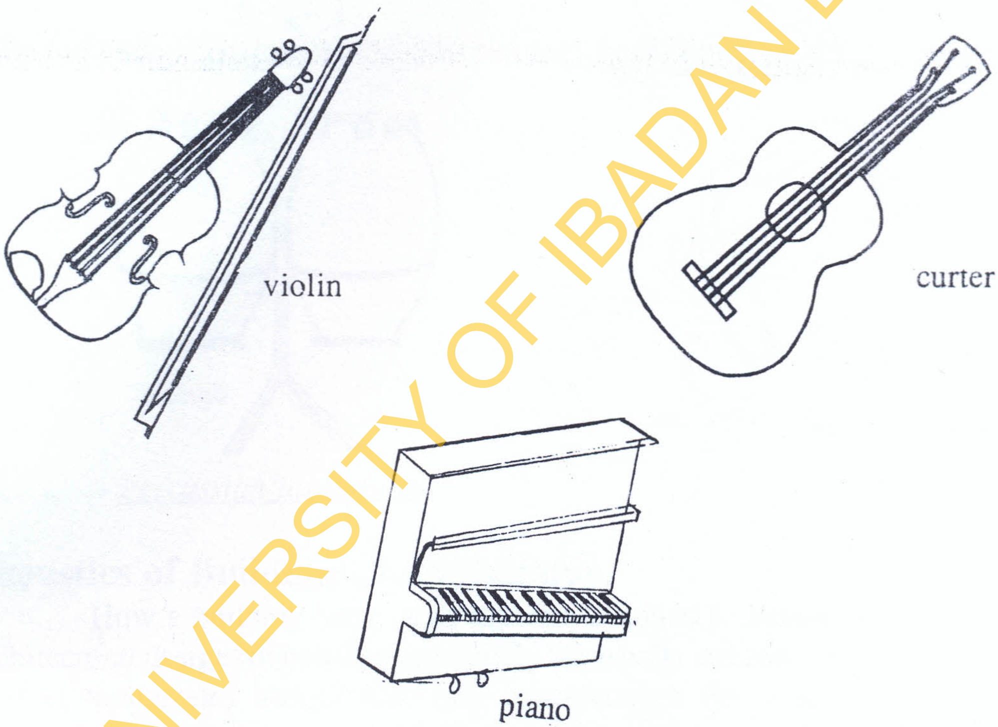

Fig.12.2 - Stringed Instruments

Percussion Instruments:

In these instruments, musical notes are produced by vibrating membranes which are part of the instruments. There are various types of these instruments depending on the society and culture in which they are produced and the types of membranes used, in the design.

Examples are, the Timpari, Bass drum (used by army band on the March), the side drum (or snare drum), the Tambourine, the cymbals, the Castanets, etc. Typical local ones to the Nigerian and African societies are the talking drums, bells, wooden gongs, tuning forks, etc.

Using the talking drum as an example, there exist many types such as wooden drum, pot drum, calabash drum, Hourglass drum, Tom-Tom drum, Skin Xylophone drum, etc. To describe how the tones are produced consider the Hourglass talking drum used mainly by the Yorubas. It is shaped like an hourglass, and covered with animal skin at both ends held firmly in place with leather strings, unlike other skin drums which are tuned with regs. A series of leather strings running from one of the drum to the other connects the two drum heads. Musical tones are produced as required by hitting one end with a small carved stick and tightening and releasing the leather string connecting the two drum heads.

Frequency of the notes are varied by the tightening (or otherwise) of the leather strings. Loudness of the musical note is varied by varying the size of the drums.

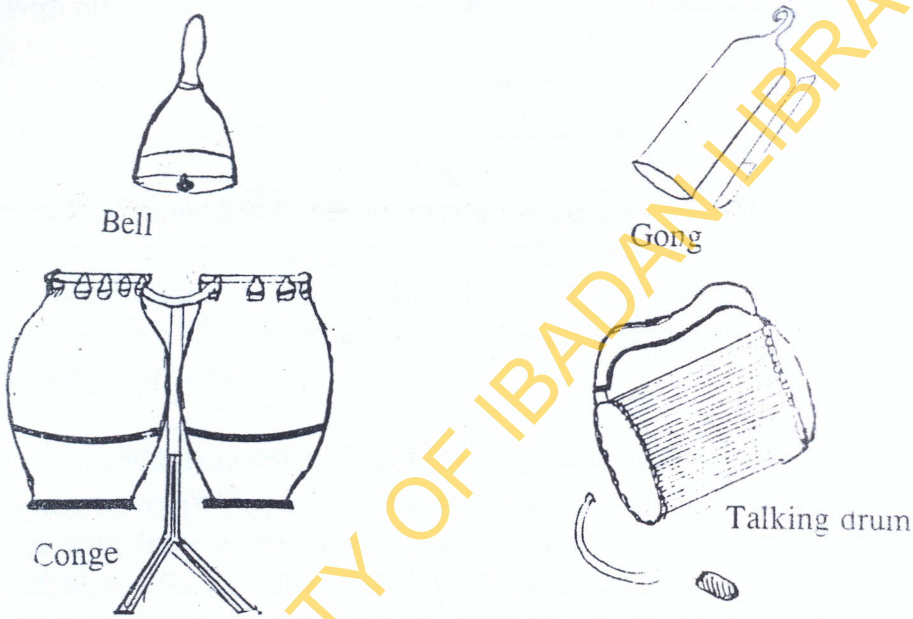

Fig.12.3 - *Percussion Instruments*

Acoustics of Buildings, Reverberation

How a building behaves in relation to sound is known as its acoustics. Hence the architectural designs of buildings especially large halls and concert halls (like church buildings, cinema rooms etc) should take into consideration the acoustics of the buildings. This consideration is done mainly to eliminate some problems associated with sound waves in such places such as caused by echo and reverberation.

Reverberation is particularly noticeable in cathedrals and other large buildings where multiple reflection of sound can occur from walls, roofs and ceilings. Its effect is undesirable in such places because it causes speech and music heard by the audience to be confused and indistinct. Although it can have an advantage of reinforcing weak voices, it needs to be minimized to make for clarity in understanding the information passed.

The most important characteristics of a concert hall or an arts theater (for musical and drama performances) is their reverberation time. This is the time taken for the sound waves of specified standard intensity to die away until it just becomes inaudible. The reduction of this time is desirable in the acoustic design of buildings. The reduction is achieved generally by fixing sound absorbent materials or obstructors of reflection of sound in the building walls roofs and floors.

It has been found that soft clothing of audience absorb sound instead of reflecting it, so as to make speech and music appear weaker. This principle is employed in minimising the problem of reverberation. In this case, walls, floors and ceilings of auditorium or large art theater halls are covered with absorbent materials such as rugs, felt materials, padded leather panels, curtains etc. Hence it is common to find such halls with thick curtains running from ceiling to the floor and rugged wall-to-wall. In addition the walls may not be continuous, it can be iaminated with pillars leaving openings so that the sound waves will leave the walls directly without being reflected.

Halls and rooms should also be made free from the phenomenon of echoes. Rooms without the occurrence of echo when speech or music is going on are known as anechoic ones. This can be obtained by lining the walls, ceiling and floor wiuh anechoic wedges made of glass fibres or plastic foam encased in muslin.

At times the shapes of halls offer poor acoustic designs. A dome-shaped portions of the hall gives a greater chance for the occurrence of echoes and reverberation. However these can be reduced by carving a lot of openings in the dome-shaped portions of the hall in addition to the use of sound absorbents.

Ultrasonics: Generation and Practical Applications

Ultrasonic waves (which are also known as ultrasound in its technological application) are sound waves with frequencies in the range of *20KHZ* to *100 KHZ,* which is above the audible range *(20 Hz to 20 KHz)*. Due to their high and corresponding short wave-lengths it has a wide practical application in the medical field for producing images of tissues and its production is thus important.

Generation of Ultrasonic Waves by Piezoelectric effect:

When needed for clinical use ultrasonic waves are produced from crystals such a quartz or strontium titanate in the following way.

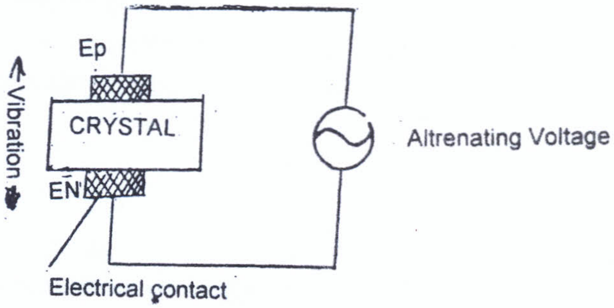

Fig.12.4 - Production of Ultrasonic Waves.

Electrical contacts E_p and E_n are made to the opposite faces of the crystals. Then a high frequency alternating voltage is applied to the contact. The crystal starts vibrating at the frequency of the applied voltage and emits a beam of ultrasonic waves. The process of converting electrical energy into mechanical energy is known as the Piezo-electric effect. This phenomenon is reversible. Hence if an external force makes the crystal vibrate an alternating voltage is also produced across the crystal. The crystal therefore acts as both transmitter and receive of ultrasonic waves.

Practical applications of Ultrasonic Waves

In the field of medicine, ultrasound is used for both diagnostic and curative purposes. This is due to the advantage that it can be used to produce images of small objects because of its high frequency and small wavelengths. The ultra-sonic waves are far safer than the x-rays. Certain organs such as the liver and the spleen which are invisible to x-rays can be diagnosed with ultrasonic waves. However the ultrasonic images do not always provide as much details as x-ray images. Some specific practical application of ultra-sound are as follows.

They are used in a medical instrument known as ultrasonic flow meter to measure the speed of blood flow in the body. This technique works on the principle of the Doppler effect. The frequency of wave scattered by blood vessels are compared with the incident frequency and used to obtain the speed of the blood flow. Ultrasonic waves are being used in medicine by a technique which has its root in the fact that different types of body tissue for example, muscle, bone and fat have varying reflective characteristics for very high frequency waves.

A very common use of ultrasound at the present, is that of the observation of the foetus in the womb. In recent times, clinics, hospitals and maternity homes would refer pregnant women to go for ultrasound scanning, when a problem is being anticipated with the foetus for routine purpose to obtain more accurate information about the development of the fetus. As stated earlier the popularity of this method rests on the relatively less risk associated with using ultrasound imaging to that of x-rays. Ultra sound is found to be genetically safe for the fetus and produces no birth defects. The scanning of the foetus using ultrasound can detect difficulties in pregnancy such as likelihood of an abortion, breach presentation, and foetal abnormalities such as water on the brain.

In photographic process a device known as ultrasonic ranging unit has been designed by the polaroid corporation and is used in some of their brand of cameras to provide an almost instantaneous measurement of the distance between the camera and the object being photographed. In this device a pulse of ultrasonic waves is transmitted from the transducer to the object being photographed. The object reflects part of the signal producing an echo which is detected by the device. The time interval between the outgoing pulse and the detected echo is then electronically converted to a distance value using the speed of sound.

WORKED EXAMPLES

1. Ade standing some distance away from large building claps his hands. He hears the echoe after *1.5sec*. If the speed of sound in air is *330m/s*, calculate how far Ade is from the large building.

Solution:

Velocity of sound, $V = 330m/s$

Time taken for the echo to be received $= 1.5sec.$

The time taken for sound of clap to travel from the man to the large building

$$= \frac{t}{2} = \frac{1.5}{2} = 0.75sec.$$

So the distance between Ade and the building

$$= \frac{Vt}{2}$$

$$= 330 \times 0.75$$

$$= 247.5m$$

2. Calculate the resonance length of a closed pipe for a tuning fork of fundamental frequency of $256Hz$. Take the speed of sound in air to be $330ms^{-1}$

Solution:

In a closed pipe, the fundamental frequency is given by

$$f = \frac{v}{\lambda} \quad but \ \lambda = 4\ell$$

$$F = \frac{v}{\lambda} \quad but \ \lambda = 4\ell$$

$$F = \frac{V}{4\ell}$$

$$Where \ V = 330ms^{1}$$

$$F = 256H_z$$

$$\therefore \ell = \frac{V}{4F}$$

$$= \frac{330}{4 \times 256}$$

$$= 0.32m$$

3. A sonometer wire of length $0.75m$ and mass per unit length $1.5x10^{-4}kgms^{-1}$ is stretched by a load of $6.0kg$. If it is plucked at its mid-point what will be

(i) the wavelength

(ii) the frequency of the note emitted.

If $g = 10ms^{-2}$.

Solution:

(a) The wire vibrates as shown above and emits its fundamental frequency F of wavelength λ. If ℓ is the length of the wire then

$$\ell = \frac{\lambda}{2}$$

$$\therefore \lambda = 2\ell = 2x0.75m = 1.5m$$

(b) The fundamental frequency F emitted by a wire of length ℓ, mass per unit length m, and under tension T is given by

$$F = \frac{\ell}{2\ell}\sqrt{\frac{T}{m}}$$

$$T = (6.0 \, x \, 10)N$$

$$F = \frac{1}{2x0.75}\sqrt{\frac{60}{1.5x10^{-4}}}$$

$$= \frac{1}{1.5} \, x \, 200 \, H_z$$

$$= \frac{2000}{15} H_z$$

$$= 133.33 H_z$$

Summary

Sound waves have wide applications in musical instruments, the laws of vibration in pipes and strings are used to design various types of wind and string instruments. Production of sound by the vibration of membranes such as tightened animal skins (or leather) is used to design a wide variety of percussion musical instruments.

In the acoustics of buildings some properties of sound waves such as reflection result in undesirable phenomena such as echoes and reverberations. These hinder the clarity and audibility of sound. Hence their effects are minimised by various designs aimed at reducing the reflection of sound within buildings.

Sound waves are made use of in modern technology and medicine in the form of ultra-sound scanning and in some polaroid cameras. Ultrasonic sound waves with frequencies above the audible range have been found very useful in this area of application.

Exercises

1. Explain the three classes of musical instruments, stating the principle of sound wave which is applied in each class. What is the common phenomenon in all the instruments?
2. Wind musical instruments can be open or closed pipes. What is the advantage of the open ones over the closed pipes and on what principle of the sound wave does this advantage depend
3. Distinguish between noise and a musical note.
4. How are the laws of vibration in a stretched string applied in a guitar?
5. Percussion instruments such as the talking drum are widely used for local and traditional purposes. Describe any form of the talking drum known to you explaining how its frequency can be varied.
6. What is reverberation? How can it be controlled in an auditorium?
7. "A dome shaped cafeteria in a University was found to present noticeable reverberation due to a poor acoustic" design. Explain the practical and theoretical implication of this problem stated above.
8. List various possible ways a good acoustic design can be achieved in buildings of all kinds.
9. Explain the term "ultrasonic waves" How are they produced for practical use?
10. What advantages does ultrasound imaging have over x-rays in their clinical uses?
11. Explain the term "Piezoelectric effect". Explain its characteristics with respect to the production of ultrasonic waves.
12. What characteristics of the ultrasonic waves made its use in the medical field possible?
13. What are the practical applications of ultrasonic waves in modern technology?

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