ABSORPTION COEFFICIENT

When a sound wave strikes a surface, a part of its energy is absorbed, a part of it is transmitted and the remaining part is reflected.

The property of the surface to convert sound energy into other forms of energy is known as absorption.

The effectiveness of absorption of sound energy by the surface is expressed as absorption coefficient.

Absorption coefficient (a) is defined as the ratio of sound energy absorbed by its surface to that of total sound energy incident on the surface.

$$a = \frac{\text{Sound energy absorbed by the surface}}{\text{Total sound energy incident on the surface}}$$

Practical definition of absorption coefficient

In order to compare the relative sound absorption of different materials the open window is taken as standard reference since it is a perfect sound absorber.

It is so because the whole of the sound energy passes through the open window and none is reflected.

Absorption coefficient of a surface is the ratio of sound energy absorbed by **1 m^2** of the surface to that absorbed by **1 m^2 of an open window**.

$$a = \frac{\text{Sound energy absorbed by } 1m^2 \text{ of the surface}}{\text{Sound energy absorbed by } 1m^2 \text{ of open window}}$$

DETERMINATION OF ABSORPTION COEFFICIENT

Let us consider a sample for which the absorption coefficient is to be measured. Initially without this material the reverberation time in a room is measured and let it be T_1.

Now the given sample is kept inside the room and again the reverberation time is measured and let it be T_2.

Then from sabine's formula

For case (i) (i.e) without the sample

$$T_1 = 0.167V/\Sigma as \text{ .... } (1)$$

Where Total absorption = $\Sigma as = a_1s_1+a_2s_2+$………

[for all the materials such as doors, windows, etc.]

For case (ii) (i.e.) Including the sample material

$$T_2 = 0.167V/ \Sigma as+a_ms_m \text{ .... } (2)$$

Where a_m = absorption coefficient of the material to be found

s_m = surface area of the material.

Therefore from equ. (1) we have

$$\Sigma as = 0.167V/T_1 \text{ .... } (3)$$

From equ. (2) we have $\Sigma as+a_ms_m = 0.167V/T_2$

Subtracting equ. (3) from equ. (4) we have

$$a_m s_m = 0.167V(1/T_2-1/T_1)$$

(or) $$a_m = 0.167V/s_m[T_1-T_2/T_1T_2]$$

Hence, by knowing the terms on the right hand side the absorption coefficient of the given sample can be determined.

2.1-Introduction

Sound waves are classified into three categories on the basis of frequency.

1. Infrasonics (below 20 Hz)
2. Audible sound (between 20 Hz to 20,000 Hz)
3. Ultra sound (above 20,000 Hz)

Audible sound is further classified as

a) **Musical sound** which produces pleasing effect on the ear.

b) **Noises** which produces unpleasant effect on the ear.

Characteristics of musical sound

a) **Pitch** – Pitch is the characteristic of sound that distinguishes between a shrill sound and a grave sound.

b) **Quality** – The quality of sound is that characteristic which enables us to distinguish between two notes of the same pitch and loudness produced by two different voices.

c) **Intensity of sound** – It is the energy of sound wave crossing per unit time through unit area at right angles to the direction of propagation.

d) **Loudness** – It is the degree of sensation produced in the ear.

Loudness

Loudness of the sound is defined as the degree of sensation produced on the ear. It varies from one listener to another. Loudness is different from intensity of sound.

Loudness is a physiological quantity. It is difficult to measure because it depends upon the individual listener. However, it is measured as the logarithmic value of intensity.

Weber-Fechner law

Loudness of sound is defined as the degree of sensation produced on the ear. This cannot be measured directly. So that it is measured in terms of intensity. Loudness is proportional to logarithmic
value of intensity.

$$L \propto \log I;$$

$$L = k \log I$$

Sound Intensity Level

It is the ratio of intensity of a sound (I) to the standard intensity of sound (I_o) .

$\beta = \log_{10} (I/I_o)$

Bel :

One bel is defined as the relative intensity between two sound notes if one is 10 times more intense than the other.

Decibel:

It is the smallest unit compared to Bel. It is the standard unit used to measure the loudness. One decibel is equal to one tenth of bel. An increase of sound intensity level by 1 dB would increase the intensity by 26 %.

Absorption coefficient

The absorption coefficient of a material is defined as the ratio of the sound energy absorbed by the surface to that of the total sound energy incident on the surface.

$$a = \frac{\text{Sound energy absorbed by the surface}}{\text{Total sound energy incident on the surface}}$$

The absorption coefficient can also be defined as the rate of sound energy absorbed by a certain area of surface to that of an open window of same area.

$$a = \frac{\text{Sound energy absorbed by } 1m^2 \text{ of surface}}{\text{Sound energy absorbed by } 1m^2 \text{ of open window}}$$

Reverberation time

The persistence of audible sound, even after the source has stopped to emit the sound is called reverberation. The time during which the sound persists in the hall is called as reverberation time.

Reverberation time is also defined as the time taken by the sound to fall to one millionth of its original intensity, after the source of sound is stopped.

When the reverberation time is lower than the critical value, sound becomes inaudible by the observer and the sound is said to be dead and if the reverberation time is too large, echoes are produced. Therefore, the reverberation time should have some optimum value.

2.5 Factors affecting acoustics of buildings and their remedies

The factors affecting acoustics of buildings and their remedies are as follows:

1. **Reverberation time:**

If the reverberation time is very small, the sound intensity decreases very fast and makes the sound appear dead. On the other hand, a large reverberation time causes mixing of different syllables and hence causes confusion.

For good quality sound, optimum reverberation time is required

Remedies:

i) Heavy curtains with folds are used to reduce reverberation time by increasing absorption of sound

ii) Floor is covered with carpets to absorb sound.

iii) Windows and openings are provided in the hall which can be opened or closed to control the reverberation time.

iv) Walls and ceilings are covered with sound absorbing materials.

v) If the hall is filled to its maximum capacity of audience, reverberation time is less.

2. **Loudness:**

There should be adequate loudness in all parts of the hall.

Remedies:

i) Large sounding boards are used behind the speaker facing the audience.

ii) Loudspeakers are used to increase the loudness.

iii) Low ceilings help to reflect the sound towards the audience.

iv) Sound absorbing materials are used in those parts of the hall where sound intensity is large.

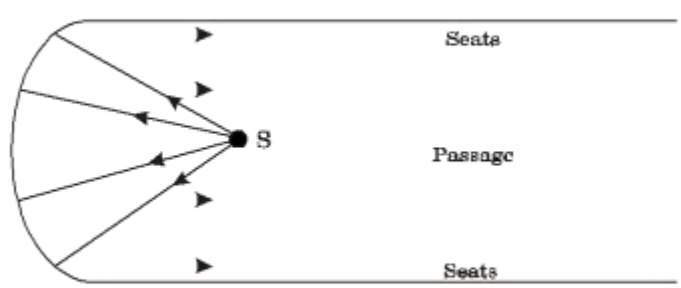

Fig:2.5.1- Reflection of sound

(3)Echo:

The reflection of sound from a distant reflecting surface is known as echo. If the echo reaches the listener about 1/15th of a second after the direct sound, the listener hears two sounds instead ofone which causes confusion. Such echoes mush be eliminated in halls.

Remedy:

High ceilings and distant walls are covered with second absorbing materials.

(4)Echelon effect:

Succession of echoes produced by a set of regularly spaced reflecting surfaces like staircase causes confusion in original sound. This effect is known as echelon effect.

Remedy:

The regularly spaced reflecting surfaces like stairs are covered with sound absorbing materials like carpets.

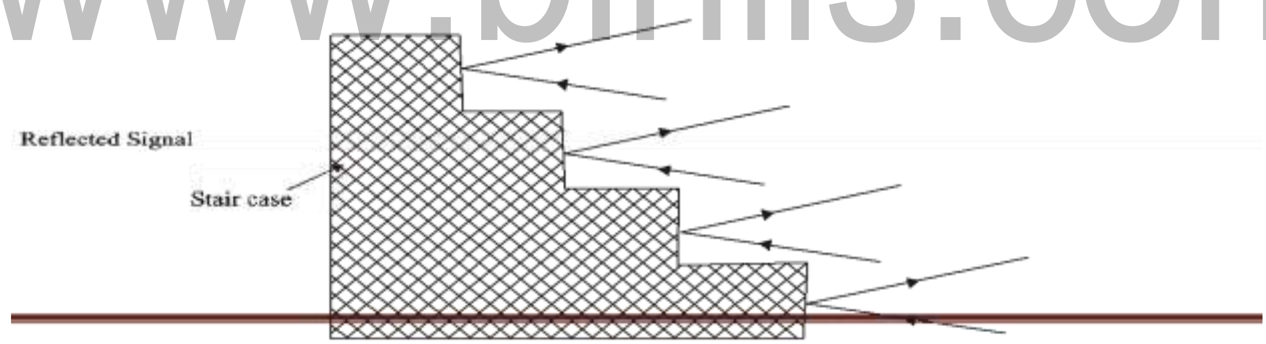

Fig:2.5.2- Stairs like reflecting surfaces

(5) Focusing:

Concave and parabolic surfaces in the hall focus sound. This causes concentration of sound in certain regions of the hall which is not desirable.

Remedies:

Curved surfaces are avoided, If there are curved surfaces, they are covered with sound absorbing materials.

(6) Resonance:

Loose fitting window panels and some other objects resonate at some audible frequencies creating more sound of these frequencies. This distorts the original sound.

Remedies:

Window panels are fixed properly, Vibrating objects are placed on sound absorbing materials.

(7)Noise:

Noise from different sources adversely affects the quality of sound in a hall. The noise can be **air borne, structure borne or inside noise.**

a)Air borne noise: the external noise, for example of traffic, which enters the halls throughdoors, windows and ventilators is known as external noise.

Remedies:

i) Openings for ventilators inside the hall are avoided.

ii) Doors and windows are provided with rubber covering on frames so that they shut without any gaps.

iii) Double doors and windows having separate frames enclosing sound absorbing materials are used.

b) Structure borne noise:

Noise produced by activities like drilling and hammering or the vibrations of heavy machinery is transmitted through the structure of the building. This is known as structure borne noise.

Remedies:

i) Heavy machinery is mounted on sound absorbing materials like wood or rubber.

ii) Double walls are used with space between them.

c) Inside noise:

It is the noise produced inside the hall by machinery, fans, air conditioners etc.

Remedies:

i) Sound absorbing materials and curtains are provided near the sources of noise.

ii) The sources of noise are mounted on sound absorbing materials.

2.4 IMPACT OF NOISE IN MULTI-STOREYED BUILDINGS

It is defined as the structure whose usage levels are regular in distribution and which correspond roughly to the required for human habitation. There are four main actions which causes impact of noise in multistoreyed buildings.

Impact of noise in multi-storeyed buidling

1. **Speech privacy**
2. **Background noise (e.g fan, a.c, generator, printer)**
3. **Sound masking**
4. **Orientation of buildings**

(i) Speech privacy: It is an issue in office building, including individual work space, inside conference halls and between offices. It mainly affects the quality of work in the adjacent office.

(ii) Back ground noise: It can adversely impact the work space too little background noise and speech privacy is reduced letting you to hear what is going on not only on work space but also away from that.

(iii) Sound masking: It can blend the building systems noise levels and exterior noise levels within electronic noise systems in the middle. Traditional sound masking systems are located in loud speakers above the ceiling.

(iv) Orientation of building: The noise impact may also be great for rooms perpendicular to road ways because

(a) a noise pattern can be more annoying in perpendicular rooms.

(b) windows on perpendicular walls do not reduce noise as effectively as those on parallel walls became at the angle of sound.

Apartment dwellers are often annoyed by noise in their homes, especially when the building is not well designed and constructed.

In this case, internal building noise from plumbing, boilers, generators, air conditioners and fans can be audible and annoying.

Improperly insulated walls and ceilings can reveal the sound of amplified music, voices, and noisy activities from neighbouring units.

External noise from emergency vehicles, traffic, refuse collection and other city noises can be a problem for urban residents, especially when windows are open or insufficiently glazed.

Even our classrooms or halls for indoor games are based on the principles stated above. The reverberation time is a key factor in designing a good acoustical structure. This knowledge is the backbone of civil engineering, structural and architectural engineering.

2.3 NOISE MEASUREMENT

Sound (Noise) Level

Sound and unwanted sound, called noise, is the result of fluctuations or oscillations in atmospheric pressure. These excite the ear mechanism and evoke the sensation of hearing.

The human ear responds to changes in sound pressure over a very wide range - the loudest sound pressure to which the human ear responds is ten million times greater than the softest. This large ratio is reduced to a more manageable size by the use of logarithms.

The logarithms scale provides a more convenient way of comparing the sound pressure of one sound with another. To avoid a scale which is too compressed, a factor of 10 is introduced, giving rise to the decibel unit.

It is a ratio, expressed in logarithmic scale relative to a reference sound pressure level.

1 decibel (dB) = 10 $\log_{10}$ (intensity measured/reference intensity)

The reference intensity used in the threshold of hearing which means sound which can be first heard at the sound pressure of 2×10^{-5} Newtons per sq. meter .

The level of sound pressure p is said to be L_p decibels greater than a reference sound pressure P_{ref} according to the following definition:

$$\text{Sound Pressure Level (Lp or SPL)} = 10 \log 10\left(\frac{P^2}{P_{ref}^2}\right)$$

$$= 20\log_{10} P - 20\log_{10} P_{\text{ref}}\ dB$$

where P is the sound pressure fluctuation (above or below atmospheric pressure) and P_{ref} is 20 micropascals (2×10^{-5} Pa), which is approximately the threshold of hearing.

Noise meters

These are the instruments specially designed for noise measurement from low to high frequencies, characteristics of human ear capacity. Noise meters record the dB scale for routine measurement of general noise levels.

Refined noise meters have been developed to take care of peak noise levels, duration of noise exposure and quality of noise which are aspects of specified noise situation.

Decibel scale is shown in **figure 2.3.1**

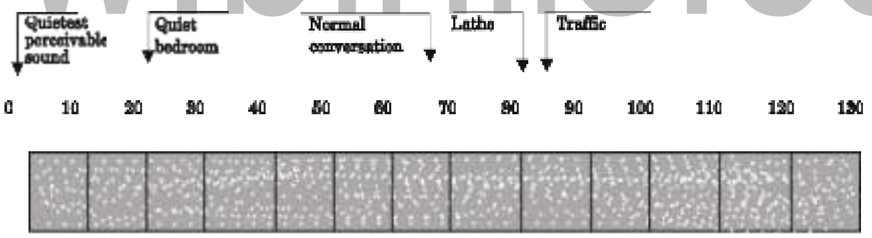

Fig. 2.3.1-The Decibel Scale

2.6 SOUND ABSORBING MATERIALS

The special materials used to increase the absorption of sound waves or to reduce the reflection of sound waves in a room or hall are known as sound absorbing materials.

The important facts in connection with sound absorbing materials are as follows:

- An ideal absorbing material should be economical in construction and maintenance,water-proof,fire-proof,sufficiently strong and good in appearance.
- In the hall treated with absorbing materials, the speech can be heard clearly and music can be fully enjoyed.
- All the absorbing materials are found to be soft and porous. They work on the principle that the sound waves penetrate into the pores and in this process, the sound waves are converted into other form of energy by friction.
- The absorbing capacity of the absorbing materials depends on the thickness of the material, its density and frequency of sound.
- The acoustic properties of the absorbing materials are considerably changed by their modes of fixing.
- Great care should be exercised while prescribing the covering for an absorbing material so as to improve its appearance. The improper covering destroys the absorbing properties of the material.
- It should be remembered that in a big hall, the audience is a major absorbing factor.

The requirements of a good acoustical material are as follows:

- It should be durable and should not be liable to the attacked by insects, termites, etc.

- It should be easily available at a reasonable cost.
- It should be efficient over a wide range of frequencies.
- It should be fire resistant.
- It should give pleasing appearance after fixing.
- It should have high coefficient of absorption.
- It should have sufficient structural strength.

Classification of sound absorbing materials

The sound absorbing materials are broadly classified into the following four categories:

(a) Porous absorbents

(b) Cavity resonators

(c) Resonant absorbing or panel absorbers

(d) Composite types of absorbents.

Have we shall discuss these materials one by one

(a) ***Porous absorbents.*** When sound waves strike the porous material, a part of waves is reflected while the other enters the porous material.

The part that enters the porous material is converted into heat energy while the reflected part is reduced in energy.

The examples are: fibre boards, soft plasters, rock wool, wood wool, mineral wools, glass silk, asbestos fibre spray, etc.

(b) ***Cavity resonators.*** A cavity resonator is a chamber or container having a small opening. When sound waves enter the resonator, the waves are absorbed due to multiple reflections.

(c) ***Resonant absorbents or Panel absorbers***. In this system, the absorbent materials is fixed on a framing (usually timber) with an air space between the framing and the wall. It acts as a panel absorber.

The common examples are: gypsum boards, wood and hard-board panels, suspended plaster ceilings, rigid plastic boards, windows, doors, etc.

(d) ***Composite absorbers***. When the functions of all the three types described above is combined in a single unit, then it is known as composite absorber.

The composite absorbers consist of a perforated panel fixed over an air space containing porous absorbent.

When sound waves strike the panel, they pass through it and damped by resonance of the air in the cavity.

Following are some of the common types of sound absorbing materials:

1. Hairfelt

The average value of coefficient of absorption of 25 mm thick hairfelt is 0.60.

2. Acoustic plaster

This is also known as the *fibrous plaster* and it includes granulated insulation material mixed with cement. The acoustic plaster boards are also available. They can be fixed on the wall and their coefficient of absorption varies from 0.15 to 0.30.

3. Acoustical tiles

These are made in factory and sold under different trade names. The absorption of sound is uniform from tile to tile and they can be fixed easily.

4. Strawboard

This material can be also used as absorbent material.

5. Pulp boards

These are the soft boards which are prepared from the compressed pulp. They are cheap and can be fixed by ordinary panelling. The average value of coefficient of absorption is 0.17.Compressed fiberboard

This material may be perforated or unperforated. The average coefficient of absorption for the perforated is 0.30.

6. Compressed wood particle board

This material is provided with perforations and it can be painted also. With a thickness of about 13 mm, the average coefficient of absorption is 0.40.

7. Perforated plywood

This material can be used by forming composite panels with mineral wool and cement asbestos or with mineral wool and hardboard. It is generally suspended from the trusses.

8. Wood wool board

This material is generally used with a thickness of 25 mm. The average value of coefficient of absorption is 0.20.

9. Quilts and mats

These are prepared from mineral wool or glass wool and are fixed in the form of acoustic blankets.

2.7 SOUND INSULATION AND ITS MEASUREMENT

The art of preventing the transmission of noise inside or outside the hall or rooms of a building is known as sound insulation.

It is also called sound proofing and it is a measure used to reduce the level of sound when it passes through the insulating building component. The basic principle of sound insulation is to suppress the noise.

Sound Insulation and Measurement

Sound is transmitted through most walls and floors by setting the entire structure into vibration. This vibration generates new sound waves of reduced intensity on the other side. The passage of sound into one room of a building from a source located in another room or outside the building is termed "sound transmission".

The **sound reduction index** is used to measure the level of **sound insulation** provided by a structure such as a wall, window, door, or ventilator.

Transmission loss or Sound Reduction Index, *R* dB, is a measure of the effectiveness of a wall, floor, door or other barrier in restricting the passage of sound. The transmission loss varies with frequency and the loss is usually greater at higher frequencies. The unit of measure of sound transmission loss is the decibel (dB). The higher the transmission loss of a wall, the better it functions as a barrier to the passage of unwanted noise.

There are two types of sound insulation in buildings: airborne and impact.

Airborne sound insulation is used when sound produced directly into the air is insulated and it is determined by the sound pressure level in the adjacent room.

1. Direct sound transmission
2. Flanking transmission
3. Overhearing
4. Leakage

Methods of sound insulation

The method of sound insulation will depend on the type of noise to be treated and the degree of sound insulation required. The methods of sound insulation can thus be classified into three main categories.

1. **When the source of noise is in the room itself**.
2. **When noise is air-borne**.
3. **When noise is structure-borne**.

1. When source of noise is in the room itself

Following are the methods of sound insulation which are commonly used when the source of noise is situated in the room to be treated for sound insulation.

(i) Improvement in working methods

(a) A working method creating less noise may be adopted. For instance, welding may be preferred to riveting.

(b) The machinery like type writers etc. should be placed on absorbent pads.

(c) The engine should be fitted on the floor with a layer of wood or felt between them.

(ii) Acoustical treatment

(a) The walls floors and ceilings should be provided with sound absorbing materials.

(b) The sound absorbing materials should be mounted on the surfaces near the source of noise.

(c) The acoustical treatment of the room considerably reduces the noise level in the room.

2. When noise is air-borne

Sound insulation for the reduction of air-borne noise can be achieved by the following methods.

1. By avoiding opening of pipes and ventilators.
2. By allotting proper places for doors and windows.

3. Using double doors and windows with separate frames and having insulating material in them.
4. Using heavy glass in doors, windows and ventilators.
5. By making arrangements for perfectly shutting the doors and windows.

3. When noise is structure-borne

Sound insulation for the reduction of structure-borne noise is done by the following ways.

1. Treatment of floors and ceilings with suitable sound absorbing material and anti-vibrations mounts.
   (i) By using floating floors and suspended ceilings.
   (ii) Soft floor finish (carpet, cork, vinyl, rubber, etc.)
   (iii) Resilient (anti vibrations) mounts help considerably in reducing structure-borne sound.

2. Using double walls with air space between them.
3. Insulation of machinery.

2.1 WEBER - FECHNER LAW

(Relation between loudness and intensity of sound)

According to Weber - Fechner law, the loudness of sound varies with intensity of sound.

Statement

The law states that the **loudness (L) produced is directly proportional to logarithm of intensity.**

i.e., $$L \propto k \log_{10} I$$

$$L = k \log_{10} I$$

where L – loudness

I – intensity

k – constant

$$\frac{dL}{dI} = \frac{k}{I}$$

SABINES FORMULA FOR REVERBERATION TIME

$$T = \frac{0.167\, V}{\Sigma\, as}$$

It is given by

$$T = \frac{0.167\, V}{a_1 s_1 + a_2 s_2 + \ldots}$$

where V – Volume of the room or hall in $\mathbf{m^3}$

a – Absorption coefficients of surface areas of different materials present in the hall in **O.W.U.**

s – Surface areas of the different surfaces in $\mathbf{m^2}$

$\Sigma\, as$ – Total absorption of sound i.e., sum of the product of absorption coefficients and surface areas of the different surfaces present in the hall in **O.W.U.** m^2 **or sabine**

It is popularly known as ***Sabine's formula for reverberation time***.

DERIVATION USING GROWTH AND DECAY METHOD

Let us assume that the sound energy is uniformly distributed throughout the hall. It does not depend on frequency.

We shall calculate the rate at which the sound energy is incident upon the walls and hence the rate at which the sound energy is being absorbed.

Consider a small element *ds* on a plane wall *AB* in the hall as shown in fig. 2.4.

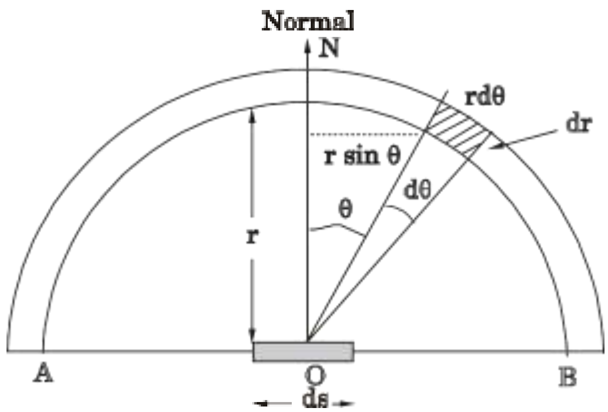

Fig. 2.1.1 Sound absorption on a plane wall

It is assumed that the element *ds* receives sound energy. Taking O as a mid point on *ds*, two semicircles are drawn with radii r and $r + dr$.

Now, consider a small shaded portion between the circles lying between two radii r and $r + dr$ drawn at angles θ and $\theta + d\theta$ with normal ON as shown in fig. 2.4.(a).

Radial length of the shaded portion $= dr$

Arc length of the shaded portion $= r\, d\theta$

Area of this shaded portion $= r\, d\theta\, dr$ ...(1)

Imagine, the whole figure is rotated about the normal through an angle $d\phi$ (radius of the rotating shaded portion being $r \sin\theta$).

The shaded portion travels through a small distance *dx* (circumferential length) and thus, traces out an elemental volume dV (Fig. 2.5).

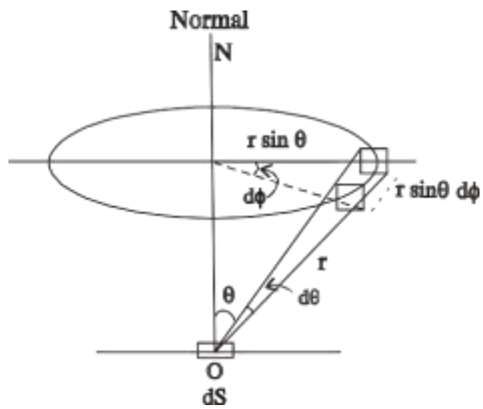

Fig. 2.1.2 - circumferential length

Distance travelled by this shaded portion,

$$dx = r \sin \theta \, d\phi$$

∴ Volume traced by the shaded portion,

$$dV = \text{area} \times \text{distance travelled}$$

$$dV = r \, d\theta \, dr \times r \sin\theta \, d\phi$$

$$dV = r^2 \sin\theta \, d\theta \, dr \, d\phi \quad ...(2)$$

If E is the sound energy density i.e., sound energy per unit volume, then,

Sound energy present within the elemental volume dV

$$= E \times dV$$

On substituting eqn (2), we have

$$= Er^2 \sin \theta \, dr \, d\theta \, d\phi \quad ...(3)$$

This sound energy from elemental volume is travelling equally in all directions in total solid angle of 4 π.

∴ Sound energy travels the volume dV per unit solid angle

$$= \frac{EdV}{4\pi} = \frac{Er^2 \sin\theta \, dr \, d\theta \, d\phi}{4\pi} \quad ...(4)$$

In this case, the solid angle subtended by the area ds at this elemental volume dV

$$= \frac{ds \cos\theta}{r^2}$$

Hence, sound energy from the elemental volume dV towards 'ds' is given by

$$\frac{Er^2 \sin\theta \, d\theta \, dr \, d\phi}{4\pi} \frac{ds \cos\theta}{r^2}$$

$$= \frac{Eds}{4\pi} \sin\theta \cos\theta \, d\theta \, d\phi \, dr \qquad ...(5)$$

Since sound energy is falling on *ds* from all directions,

θ changes from 0 to π/2 and ϕ changes from 0 to 2π.

Further, to get total sound energy received per second, *r* changes from 0 to *v*, where *v* is the velocity of sound (since sound existing within the distance of 0 to *v* metre from ds reaches *ds* in one second).

$$= \frac{Eds}{4\pi} \int_0^{\pi/2} \sin\theta \cos\theta \, d\theta \int_0^{2\pi} d\emptyset \int_0^{v} dr$$

$$= \frac{Eds}{4\pi} \int_0^{\pi/2} \sin\theta \cos\theta \, d\theta \times 2\pi \times v$$

$$= \frac{Eds}{4\pi} \times \frac{1}{2} \times 2\pi \times v$$

$$= \frac{Evds}{4\pi} \qquad \text{..............(6)}$$

The total sound energy falling on ds per second = E.v.ds/4, where v is the velocity of sound.

If a is the absorption coefficient of the wall AB of which ds is a part, then the sound energyabsorbed by ds in one second

$$= \frac{E.v.ds.a}{4}$$

Total energy absorbed per second by the whole enclosure $= \frac{E.v.£ads}{4}$

$= EvA/4$..............................(7)

Where $A = \Sigma$ a.ds is total absorption of sound in all the surfaces on which sound energy is incident.

Growth of sound decay

If P is the sound power output and V is the total volume of the hall, then total sound energy in the hall at a given instant 't' = EV.

Therefore, rate of growth per second = V.dE/dt...........................(8)

Rate of emission of sound energy = Rate of growth of sound energy in room + Rate of absorption of sound by the walls.

i.e. $P = V.dE/dt + EvA/4$.......................(9)

When steady state if reached, $dE/dt = 0$, and if steady state energy density is denoted as E_m,

$P = E_m vA/4$

Therefore, $E_m = 4P/vA$

Dividing equation (9) by V, we get

$(dE/dt) + (EvA/4V) = P/V$ …(10)

Putting $vA/4V = \alpha$,

$(dE/dt) + E\alpha = 4P\alpha /vA$

Multiplying with $e^{\alpha t}$ on both sides,

$(dE/dt + E\alpha) e^{\alpha t} = 4P\alpha e^{\alpha t}/vA$ $d/dt(Ee^{\alpha t}) = 4P\alpha e^{\alpha t}/vA$

Integrating on both sides,

$$\int \frac{d}{dt}(Ee^{\alpha t}) = \int \frac{4P\alpha e^{\alpha t}}{vA} = \frac{4P\alpha}{vA}\int e^{\alpha t} \quad \int e^{\alpha t} = e^{\alpha t}/\alpha$$

$Ee^{\alpha t} = (4P\alpha e^{\alpha t}/vA) + K$.......................... (11)

where K is a constant of integration. The value of K is determined by considering the boundary conditions.

Growth of Sound Energy

Sound energy grows from the instant the source begin to emit sound at $t = 0$ and $E = 0$

Applying this in equation (11), we get

$K = -4P/vA$..(12)

Therefore, using eq 11 and 12

$Ee^{\alpha t} = (4Pe^{\alpha t}/vA) – (4P/vA)$

$E= (4P/vA) – (4Pe^{-\alpha t}/vA)$

$E = 4P/vA\ (1- e^{-\alpha t})$

Therefore, $\mathbf{E=E_m(1- e^{-\alpha t})}$

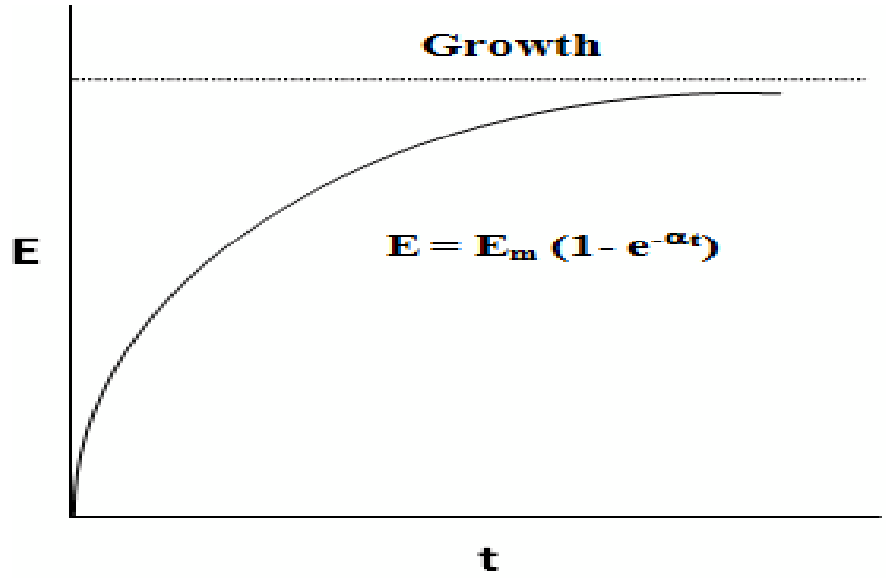

Fig:2.1.3- Growth of Sound Energy

This equation expresses the growth of sound energy density 'E' with time 't'. This indicated that E increases with t, and when $t \to \infty$, $E = E_m$.

Decay of sound energy

Assume that, when sound energy has reached its steady (maximum value) state Em, sound energy is cut off. Then the rate of emission of sound energy, P = 0.

Therefore, equation (11) can be written as $Ee^{\alpha t} = K$

Substituting the boundary conditions $E = E_m$ at $t = 0$ and $P = 0$, we get $E_m e^0 = 0 + K$

$K = E_m$ .... (14)
Therefore, from eq (11) & 14 we get

$Ee^{\alpha t} = E_m$

$E = E_m / e^{\alpha t}$

Therefore, $\mathbf{E = E_m . e^{-\alpha t}}$......(15)

This equation represents the decay of sound energy density with time after the source is cut off.

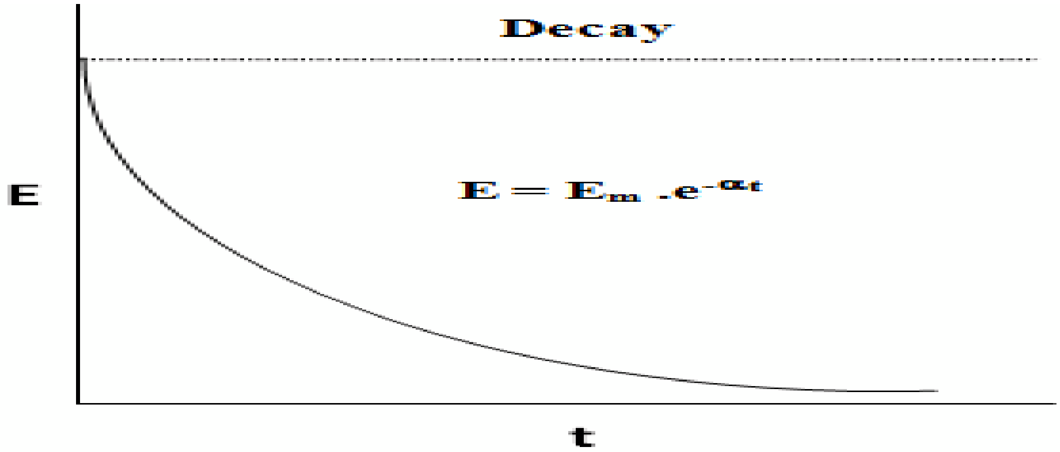

Fig:2.1.3- Decay of sound energy

Expression for reverberation time

The standard reverberation time is the time taken by thesound to fall of its intensity to one-millionth of its initial value after the source is cut off. Now, the value of sound energy density before cut off is E_m, at standard reverberation time, it reduces to$E= E_m/10^6$

To calculate T, we put $E = E_m.10^{-6}$ and $t = T$,

$E_m.10^{-6} = E_m.\ e^{-\alpha T}$

$e^{-\alpha T} = 10^{-6}$

$e^{\alpha T} = 10^6$

Taking log on both sides, we have

$\alpha T = 6\log_e 10$

$T = (6x2.3026x1)/\alpha$

$T = (6x2.3026x1) / (vA/4V)$

By using velocity of sound, v = 340 m/s

T = 0.165 V / A

or

T = 0.165 V / Σas

This equation is in agreement with the experimental values obtained by Sabine.