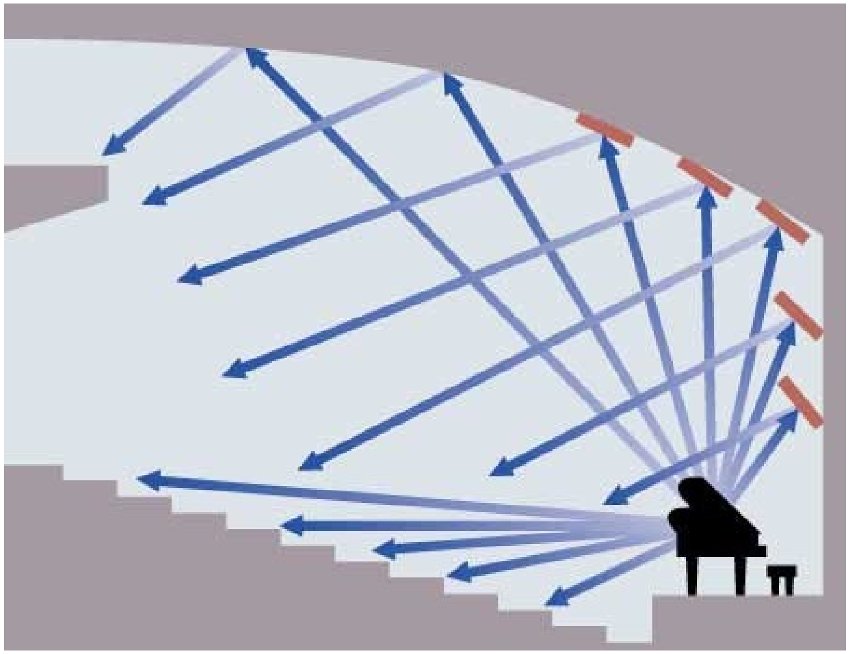
ACOUSTICS



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Contents in this topic

- Acoustics and its importance
- Reverberation time
- Absorption coefficient
- Method to measure absorption coefficient
- Sabine’s and Eyring’s formulae (Qualitative idea)
- Applications of acoustics- Designing of hall for speech, concert, and opera

Acoustics

Deals with the production, propagation, transmission, detection of sound waves is called acoustics.

Classification of sound:

(i) Infrasonic	20 Hz	(Inaudible)
(ii) Audible	20 to 20,000Hz	(Music and Noise)
(iii) Ultrasonic	20,000Hz	(Inaudible)

Decibel levels (db)

Threshold of audibility or Standard Intensity:

- 0: The softest sound a person can hear with normal hearing
- 10: normal breathing
- 20: whispering at 5 feet
- 30: soft whisper
- 50: rainfall
- 60: normal conversation
- 110: shouting in ear
- 120: thunder

Acoustics: Properties

Sound is a mechanical wave and therefore requires a medium to travel.
So, It is reflected, transmitted, or absorbed by the materials it encounters.

- Soft surfaces: textiles, and batt insulation, tend to absorb sound waves, preventing them from further motion.
- Hard surfaces: ceramic tile, gypsum board, or wood, tend to reflect sound waves, causing ‘echo’.
- Dense, massive, materials: concrete or brick, tend to transmit sound waves through the material.

Acoustics Consultants May Provide:

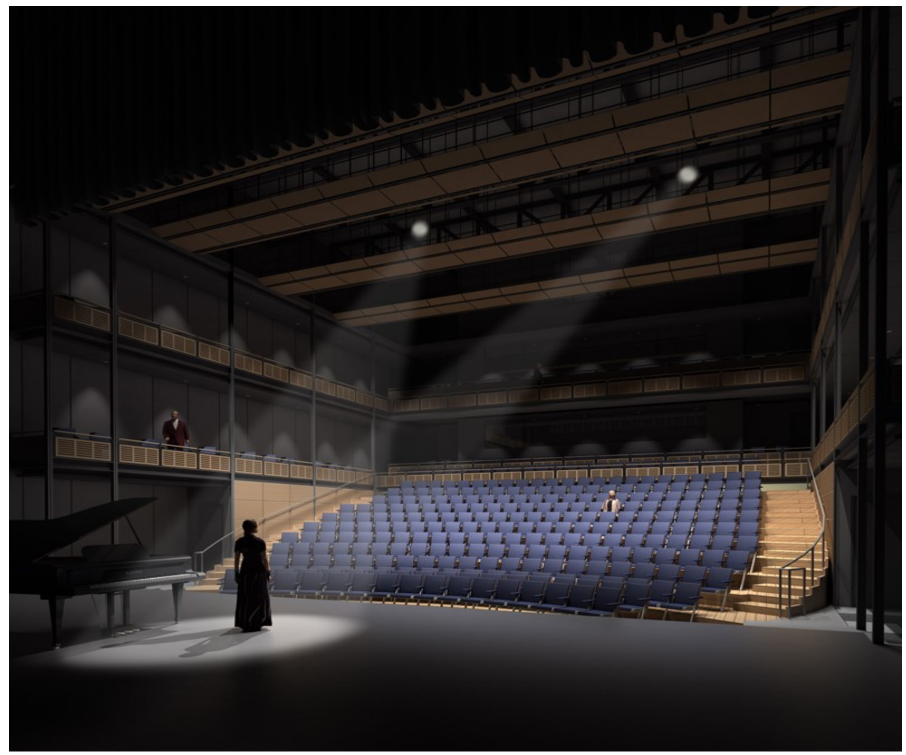
- Architectural Acoustics
- Sound Isolation Testing
- Impact Isolation Testing
- Mechanical (HVAC) System Noise and Vibration
- Environmental/Community Noise Assessment
- Computer & Physical Acoustical Modeling
- Field Testing
- Industrial Noise Control
- Sound Masking Systems Design

Architectural Acoustics (Acoustics of Buildings)

Deals with design and construction of hall or rooms

Hall or rooms are acoustically poor due to;

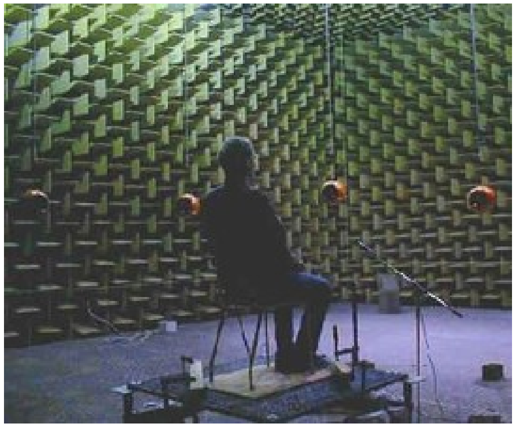
- distribution of intensity is not uniform
- different frequency of sound interfere and reduces the quality

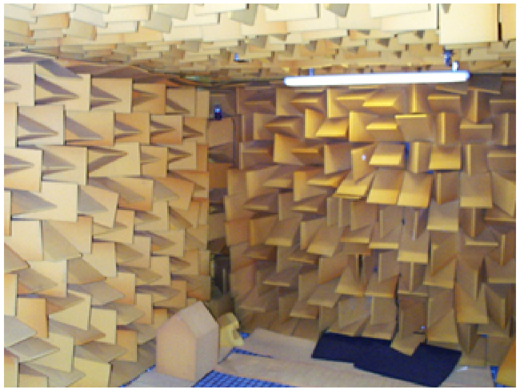


The Sydney Opera House concert hall building designed by Jorn Utzon

An anechoic chamber is a space in which there are no echoes or reverberations.

The surfaces absorb all sound, and reflect none.





Acoustics of the buildings

The branch of science which deals with the planning of a building to provide the best quality audible sound to audience.

Any hall having the good acoustics should have following features:

- ✓ The quality of the speech/ music remains unchanged in each and every portion of the Hall.
- ✓ The sound produced must be sufficiently loud.
- ✓ There shouldn't be any echo.
- ✓ The reverberation should be proper.
- ✓ There should not be any focusing of sound in any part of the hall.
- ✓ The walls should be sound proof to avoid the external noise in the hall

Reverberation

When a sound is produced inside a building, it expands and gets reflected from all the surfaces, viz; walls, ceiling and floor of the hall. Audience will receive a direct sound from the source followed by series of sounds reflected and traveling towards him. These successive sounds will be of diminishing intensity. Therefore listener will continue to receive the sound even after the source of sound has stopped emitting. This is called as reverberation.

Definition:

The persistence or prolongation of sound in a hall even though the sound source is stopped called Reverberation.

Echo	Reverberation
In Echo, the reflected sound is heard as a sound distinct from the original sound	In reverberation, the sound persists for some time
For distinct echo minimum distance of reflector should be 17.2 m	There is no condition of minimum or maximum size of room. It is present in every room.

An echo will be heard if the minimum distance between the source of sound and the obstacle is __ ?

As the sensation of sound persists in our brain for about 0.1 s, to hear a distinct echo.

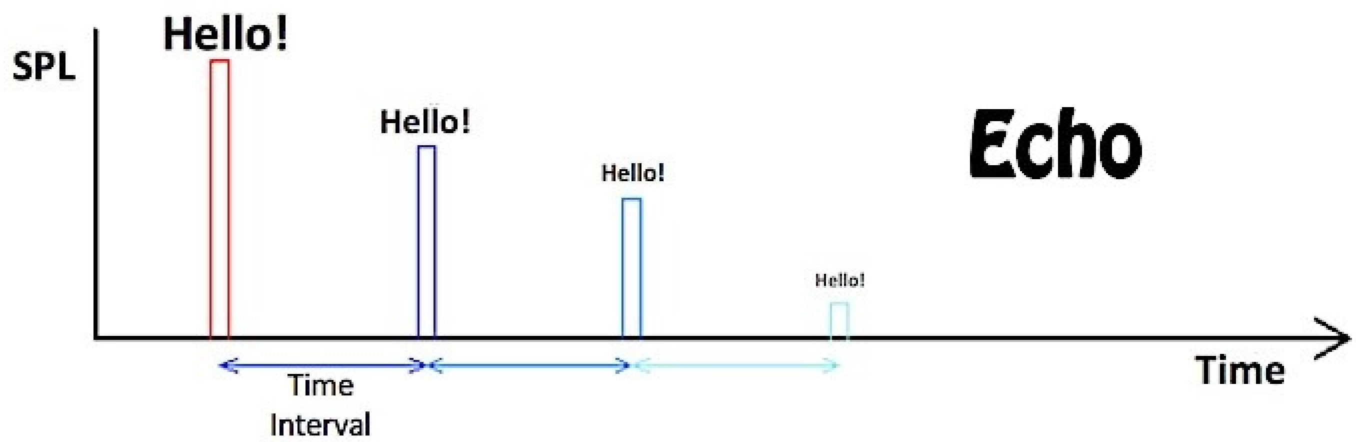
Thus the time interval between the original sound and the reflected one must be at least 0.1s.

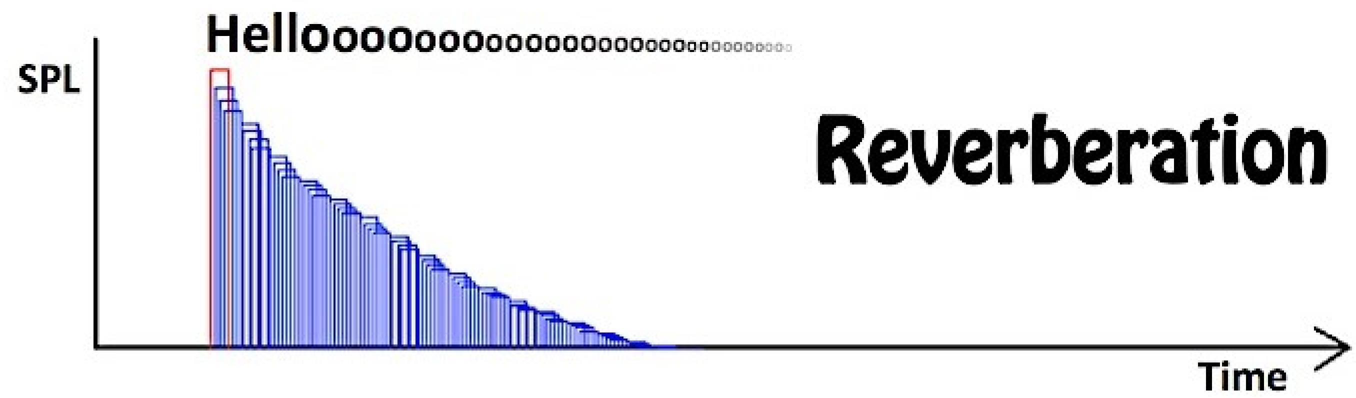
If we take the speed of sound to be 344 m/s at a given temperature, say at 22 ºC in air, sound must go to the obstacle and reach back the ear of the listener on reflection after 0.1s.

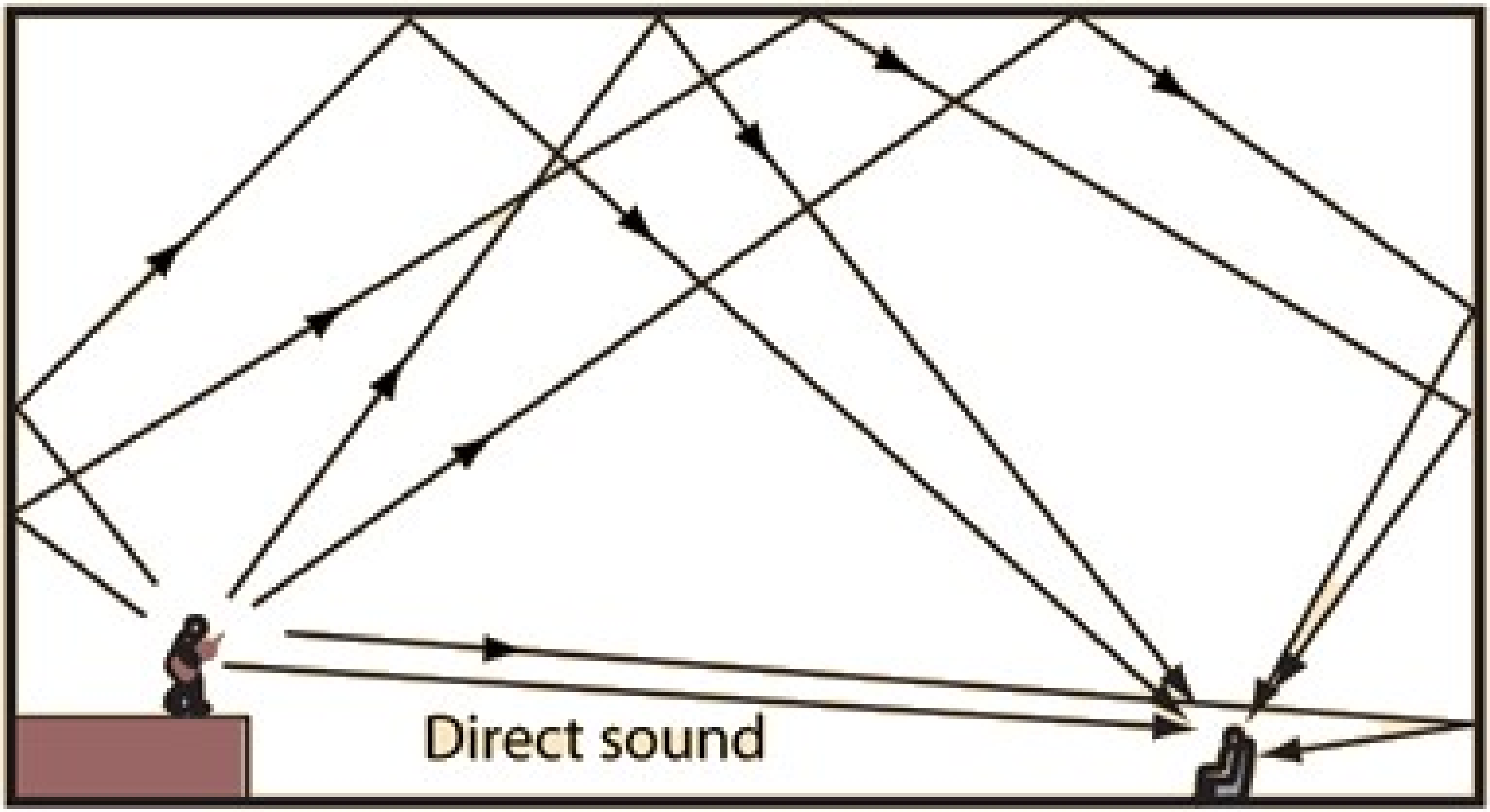
Hence, the total distance covered by the sound from the point of generation to the reflecting surface and back should be at least (344 m/s) ×0.1 s = 34.4 m.

Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance. I.e., 34.4/2 = 17.2 m.

Sound-Pressure Level (SPL) vs. Time






Direct sound

Reverberation Time

The time taken by the sound wave to fall below the minimum audibility level after the source is stopped.

Or

i.e. to fall to one millionth of its initial intensity, after the source is stopped.

$$I = (1/10^6) I_0$$

Here,

I and I_0 is the initial & final sound intensity level

- If Reverberation Time is too low: Sound disappear quickly and become inaudible.
- If Reverberation Time is too high: Sound exist for a long period of time - an overlapping of successive sounds results in unclear information.

Therefore, for the good audibility: Reverberation time should be optimum.

Optimum reverberation time

Activity in Hall	**Optimum Reverberation Time (Sec)**
Conference halls	1 to 1.5
Cinema theatre	1.3
Assembly halls	1 to 1.5
Public lecture halls	1.5 to 2
Music concert halls	1.5 to 2
Churches	1.8 to 3

Sabine's Formula for Reverberation Time

Prof. W. C. Sabine (1868-1919) determined the reverberation times of empty halls and furnished halls of different sizes and arrived at the following conclusions.

- The reverberation time depends on the reflecting properties of the walls, floor and ceiling of the hall.
- The reverberation time depends upon the volume of the hall.
- The reverberation time depends on the absorbing power of the various surfaces (carpets, cushions, curtains etc).
- The reverberation time depends on the frequency of the sound.
- The reverberation time is independent of the positions of the source and the listener and the shape of the room.

Sabine's Formula for Reverberation Time

Prof. Sabine summarized his results in the form of the following equation.

Reverberation Time, $$T \propto \frac{Volume\ of\ the\ Hall, V}{Absorption, A}$$

$$T = K\frac{V}{A}$$

where K is a proportionality constant, whose value depends upon the units in which the length is measured

If it is in feet then k = 0.05 and (velocity of sound 1120 ft s^{-1})

If it is in meter then k = 0.161 (velocity of sound 340 m s^{-1})

$$T = \frac{0.05\ V}{A} \quad \text{or} \quad \frac{0.161V}{A}$$

This Equation is known as ***Sabine's formula*** for reverberation time.

It may be rewritten as and also called as Sabine's Law

$$T = \frac{0.161V}{\sum_{1}^{N} \alpha_n \; S_n}$$

or $$T = \frac{0.161V}{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots + \alpha_n \; S_n}$$

where S_n are different surfaces (sq. meter) of absorption coefficients α_n

as V, S and α can be calculated from plans and specifications, so it is possible for an architect to design an auditorium with any desired time of reverberation.

Absorption of sound

The property of a surface by which sound energy is converted into other form of energy (heat) is known as absorption.

It is mainly due to two causes:

1. Porosity: In the process of absorption sound energy is converted into heat due to frictional resistance inside the pores of the material. The fibrous and porous materials absorb sound energy more, than other solid materials.

2. Flexural vibration: When sound waves fall on flexible materials not rigidly mounted, the material of course is set into vibration and the damping forces called into play dissipate the incident sound energy into heat.

Absorption Coefficient of Sound

The coefficient of absorption `α' of a materials is defined as the ratio of sound energy absorbed by its surface to that of the total sound energy incident on the surface.

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

A unit area of open window is selected as the standard. All the sound incident on an open window is fully transmitted and none is reflected. Therefore, it is considered as an ideal absorber of sound.

Thus the unit of absorption is the open window unit (O.W.U.), which is named a "sabin" after the scientist who established the unit.

1m^2 sabin is the amount of sound absorbed by one square meter area of fully open window.

Absorption Coefficient of Sound

- The value of `$\alpha$' depends on the nature of the material as well as the frequency of sound. It is a common practice to use the value of `α' at 500 Hz in acoustic designs.
- If a material has the value of "α" as 0.5, it means that 50% of the incident sound energy will be absorbed per unit area.
- If the material has a surface area of S sq.m., then the absorption provided by that material is

$$A = \alpha . S$$

Numerical

Find reverberation time for a hall of dimensions 40’ x 30’ x 20’ having average absorption coefficient of 0.15.

Volume = 40’ x 30’ x 20’ = 24000 ft3

Surface area of hall = 2[(40x30) + (30x20) + (20x40)] = 5200 ft2

Total avg absorption = 0.15 x 5200 ft^2 = 780 ft^2 OWU or sabin

So, T = (0.05 x 24000 ft^3) / 780 ft^2

T = 1.54 s

Numerical cont….

Find that how much area should treat with an absorbing material of absorption coefficient , 0.20, to reduce its reservation time to 1.2 s?

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Find that how much area should treat with an absorbing material of absorption coefficient , 0.20, to reduce its reservation time to 1.2 s?

Let area A is to be treated

Total avg absorption = $0.15(5200\text{-}A) + 0.20A = 780 + 0.05A$

$T = (0.05 \times 24000) / (780 + 0.05\ A) = 1.2$

$A = 4400\ ft^2$

Limitation of Sabine' s Formula

1. It is good for only small values of absorption coefficient ($\alpha < 0.2$)
2. It is not valid for higher values of α

   This is because for $\alpha = 1$, T should be zero, whereas Sabine's formula fines $T = kV/A$, a non zero value.
3. For higher values of absorption coefficient, the Sabine's formula gives higher value of reverberation time than its actual value.

Therefore, Eyring's Formula came in existence

Eyring's Formula

Under the same assumptions, as has been considered for Sabine's case

Fraction of energy absorbed = average absorption coefficient = α

and

Fraction of energy reflected = average reflection coefficient = $1-\alpha$

$$T = \frac{0.05\,V}{-S\log_e(1-\alpha)}$$

(when velocity of sound s 1120 ft s^{-1})

$$T = \frac{0.161V}{-S\log_e(1-\alpha)}$$

(when velocity of sound is 340 m s^{-1})

Note:

1. Both formulae gave identical value when α is small
2. However, for large value of α, two gave different values of T

Sabine's vs Eyring's Formulae

$$T = \frac{0.05\ V}{S\alpha}$$

$$T = \frac{0.05\ V}{-S\log_e(1-\alpha)}$$

1. Both formulae gave identical value when α is small
2. However, for large value of α (= 1), two gave different values

$$T = \frac{0.05\ V}{S}$$

$$T = 0$$

Since in this case there is no reflection of sound energy, there is no reverberation time, so Eyring's formula gives correct results

Absorption Coefficient of Sound

The coefficient of absorption `α' of a materials is defined as the ratio of sound energy absorbed by its surface to that of the total sound energy incident on the surface.

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A unit area of open window is selected as the standard. All the sound incident on an open window is fully transmitted and none is reflected. Therefore, it is considered as an ideal absorber of sound.

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$1 m^2$ sabin is the amount of sound absorbed by one square meter area of fully open window.

Methods to measure absorption Coefficient

Two important methods;

1. Reverberation chamber method
2. Stationary wave method

Reverberation chamber method

One can use three different ways to measure absorption coefficient of sound:

Reverberation chamber method-1

Reverberation period of room with cushions or other absorbent materials presented in hall is first measured

The cushions or other absorbent materials are then removed and the extent of the open window is gradually adjusted until the reverberation time is the same as before.

The ratio of the area of window opened to the total area of cushions or other absorbent materials is then determined and consider as absoprtion coefficient of the substance.

Reverberation chamber method- 2

T_1 is measured without absorbing materials

$$T_1 = \frac{0.167V}{\Sigma as}$$

T_2 is measured with absorbing materials

$$T_2 = \frac{0.167V}{\Sigma as + a_m s_m}$$

Now,
Absorption Coefficient α_m is from T_2-T_1

$$a_m = \frac{0.167V}{s_m} \cdot \frac{T_1 - T_2}{T_1 T_2}$$

Reverberation chamber method- 3

The average value of the absorption coefficient of a room may be calculated by the concept of decay of intensity.

According to which after the source of sound is switched off, the intensity I, at t is given by,

$$\boldsymbol{I = I_m e^{-Ct}}$$

Here, $C = \alpha Sv/4V$ and

I_m is the maximum intensity of sound

Let two different sources of sound are placed one by one in the hall and I_m and I'_m are the maximum intensities.

Now if T_1 and T_2 be, respectively, the times for these intensities to fall to the threshold intensities of sound, then

$$\alpha = \frac{0.05\ V(\ln I_m - \ln I'_m)}{S\,v(T_1 - T_2)}$$

Stationary wave method

A long cylinder chamber of about 30 cm in diameter made of low absorbing power material is taken. One end of the chamber is closed by a material whose absorption coefficient is to be determined. And through the other end, sound waves are let in being produced by a source of sound. These waves are reflected back by the closed end of the cylinder and form stationary waves on combing with the incident waves.

Stationary wave method cont..

The displacement at nodes and antinodes are determined by a hot wire microphone which can be moved to and fro by a sliding rod outside the enclosure. If the displacements of the interfering beams be

$$y_1 = a \sin(\omega t - kx)$$
$$y_2 = ma \sin(\omega t + kx)$$

Here,
a is the amplitude and
m is the coefficient of reflection

the resultant displacement is given by

$$y = y_1 + y_2 = a(1+m)\sin \omega t \cos kx - a(1-m)\cos \omega t \sin kx$$

$$\alpha = (1-R) = \frac{4a_1a_2}{(a_1 + a_2)^2}$$