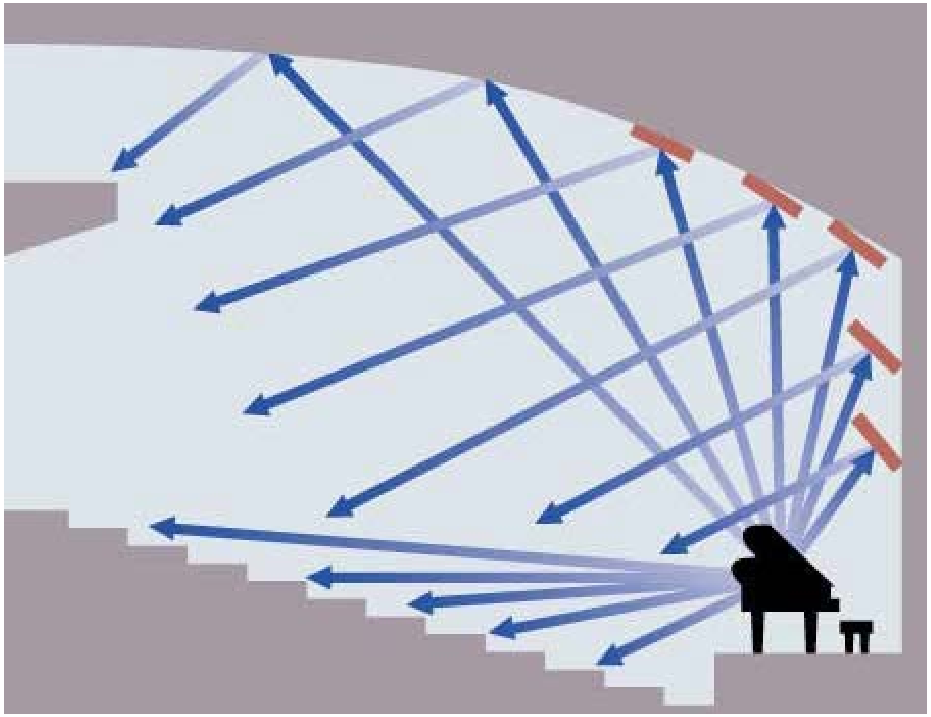
ACOUSTICS



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Acoustics

Derived from the Greek word **ἀκουστικός** (akoustikos), meaning "of or for hearing, ready to hear.

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:

The **decibel** (**dB**) is the unit used to measure the intensity of a sound in comparison to the environment.

On the **dB** scale, the smallest audible sound (near total silence) is 0 dB. A sound 10^p times more powerful is 10p dB.

If you have to raise your voice to be heard by somebody else then you are listening to an 85-dB sound. Eight hours of 90-dB sound can cause damage to your ears.

Any exposure to 140-dB sound causes immediate damage.

- 00: Near total silence
- 10: normal breathing
- 20: whispering at 5 feet
- 30: soft whisper

- 50: rainfall
- 60: normal conversation
- 110: shouting in ear, Car horn
- 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.

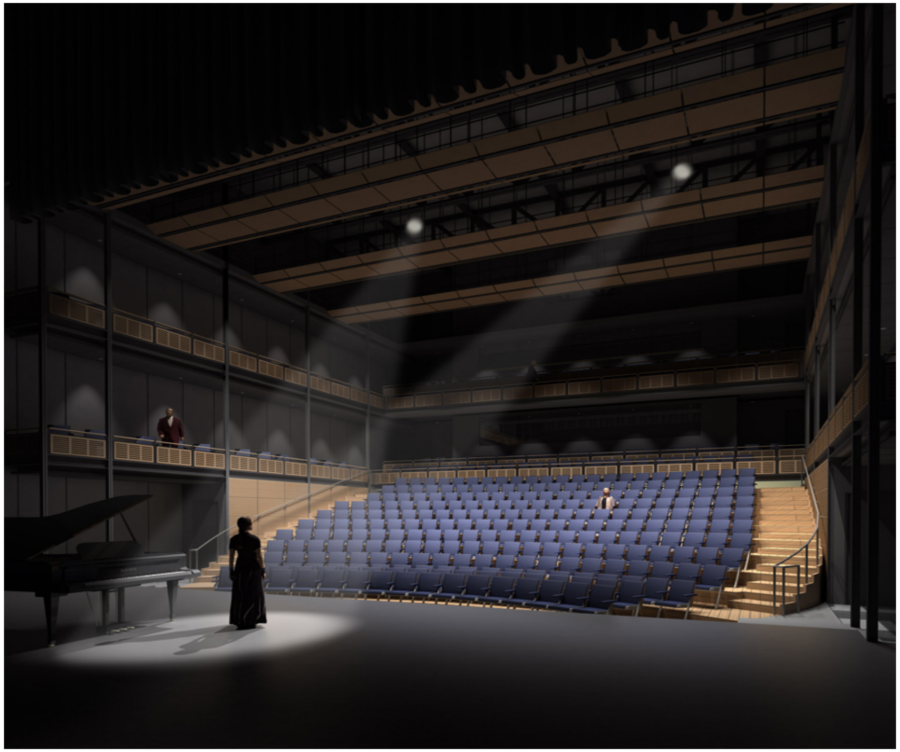
- Soft surfaces: textiles, and fiber materials, tend to absorb sound waves, preventing them from further motion.
- Hard surfaces: ceramic tile, gypsum board, or wood, tend to reflect sound waves, causing ‘echo’.
- Dense, massive, materials: concrete or brick, tend to transmit sound waves through the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

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

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

The surfaces absorb all sound, and reflect none.

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An anechoic chamber on the campus of Microsoft broke the world record with a measurement of – 20.6 db - officially the quietest place on the planet Earth

Acoustics of the buildings

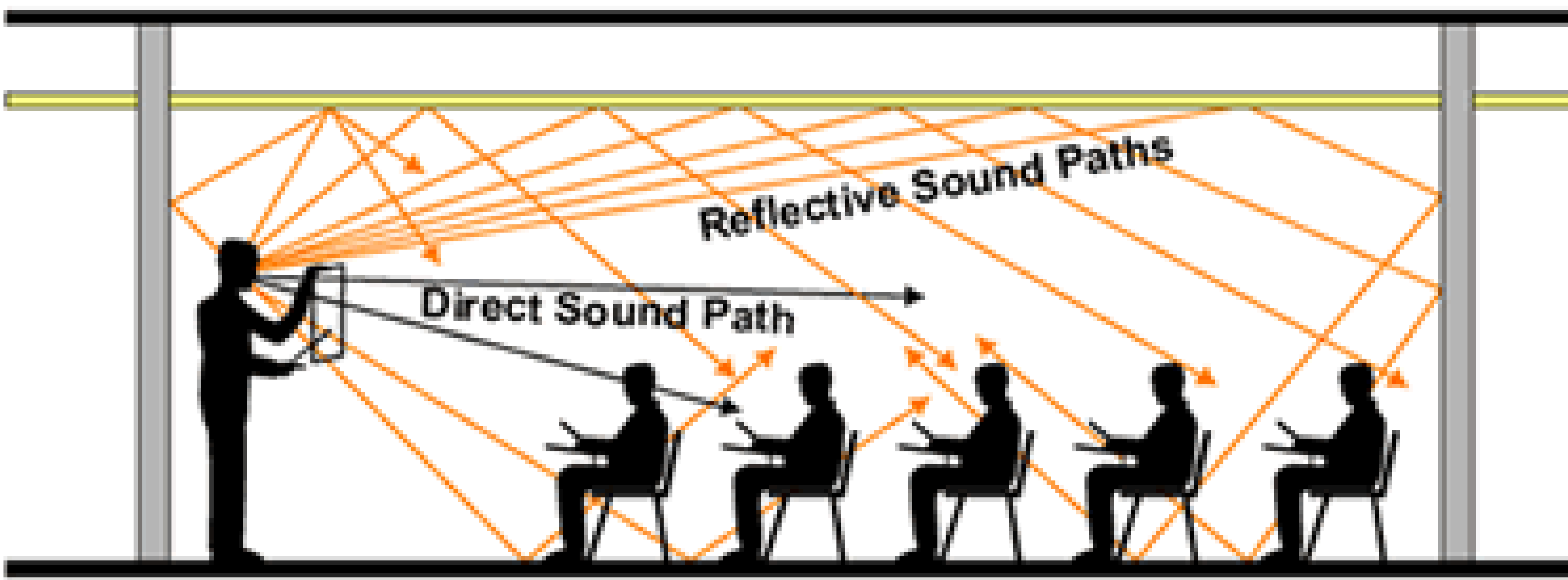
The branch of science which deals with the planning of a building to provide the best quality audible sound to audience.

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 receive a direct sound from the source followed by series of sounds reflected and traveling towards him with diminishing intensity.

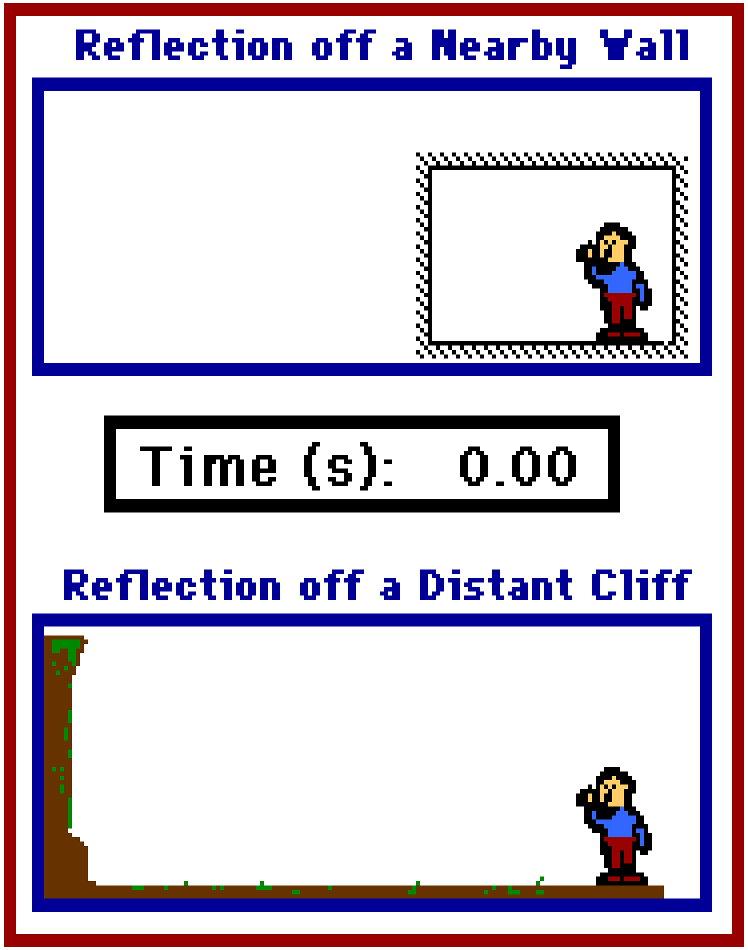


Reverberation

The perception of a sound usually endures in memory for only 0.1 seconds.

If the reflector is more than approximately 17 meters away from where you are standing, then the sound wave will take more than 0.1 seconds to reflect and return to you. This is called as **reverberation**.

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



Reverberation Time

The time taken by the sound wave

to fall below the minimum audibility level after the source is stopped.

Or

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

$$I = I_0/10^6$$

- 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, $T \propto \dfrac{V}{A}$

V= volume of hall
A= effective absorbing surface area

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

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 (Law)*** for reverberation time.

Effective absorbing surface area (A) is defined as:

total absorbing power = $\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots + \alpha_n S$

$$T = \frac{0.05V}{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots + \alpha_n S_n}$$

$$T = \frac{0.05V}{\sum_{1}^{N} \alpha_n S_n}$$

where S_n are different surfaces (sq. ft) 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.

Numerical

Find reverberation time for a hall of dimensions $40'$ x $30'$ x $20'$ having average absorption coefficient of 0.15. Also 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?

$$T = \frac{0.05V}{\sum_{1}^{N} \alpha_n \; S_n}$$

Volume = $40'$ x $30'$ x $20'$ = 24000 ft^3

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

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

Let area A is to be treated`

Total avg absorption = 0.15(5200-A) + 0.20A = 780 + 0.05A

T = (0.05 x 24000) / (780 + 0.05 A) = 1.2

A = 4400 ft^2

Numerical

Find reverberation time for a hall of dimensions $40' \times 100' \times 20'$ and having following particulars

i) 7500 sq ft of plaster, with $\alpha_1 = 0.03$

ii) 6000 sq ft of wood and floor, with $\alpha_2 = 0.06$

iii) 400 sq ft of glass, with $\alpha_3 = 0.025$

iv) 600 seats, with $\alpha_4 = 0.3$

v) audience of 500 persons, with $\alpha_3 = 4.3$ OWU ft^2 per person

And also find reverberation time of empty hall

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 finds $T = kV/A$, 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 is 1120 ft s^{-1})

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

(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

Numerical

The university lecture hall of dimensions 15m x 8m x 3m is heavily damped with average absorption coefficient of 0.3. Calculate its reverberation time with both approximations, and comment on results.

$$T = \frac{0.161V}{\sum_{1}^{N} \alpha_n \; S_n} \qquad \mathrm{T} = \frac{0.161\ V}{-S \log_e (1-\alpha)}$$

Volume = 15m x 8m x 3m = 360 m^3

Surface area of hall = 378 m^2

So, T (Sabin) = (0.161 x 360) / (378 x 0.3) = 0.51 sec

T (Eyring) = (0.161 x 360) / (-378 x ln (1-0.3) = 0.43 sec

Sabin's formula gives higher value than actual value for higher absorption. It is higher by an amount = 0.51-0.43/0.43 = 0.19 ~ 19%

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.

1ft^2 sabin is the amount of sound absorbed by one square feet 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:

Method-1: Using concept of open window

Step 1: Reverberation time of room with cushions or other absorbent materials presented in hall is first measured.

Step 2: 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.

Step 3: The ratio of the area of window opened to the total area of cushions or other absorbent materials is then determined and consider as absorption coefficient of the substance.

Method- 2 : Using concept of change of absorption

Reverberation time (T) of room is measured without absorbing material (T_1) and with absorbing materials (T_2).

T_1 is measured without absorbing materials $$T_1 = \frac{0.05V}{\alpha S}$$

T_2 is measured with absorbing materials $$T_2 = \frac{0.05V}{\alpha S + \alpha_m S_m}$$

Now, Absorption Coefficient of unknown material (α_m) is from; $$\frac{1}{T_2} - \frac{1}{T_1}$$

$$\alpha_m = \frac{0.05V}{S_m} \cdot \frac{T_1 - T_2}{T_1 T_2}$$

Thus knowing T_2, T_1, V, S_m , the absorption Coefficient α_m can be measured

Method- 3: Using concept of decay of intensity

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 = $\alpha Sv/4V$ [v=velocity of sound, V=volume of hall]

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 ($\boldsymbol{I_{Th}}$) of sound, then

$$\boldsymbol{I_{Th} = I_m e^{-CT_1}} \quad \text{(for source one)}$$

$$\boldsymbol{I_{Th} = I'_m e^{-CT_2}} \quad \text{(for source two)}$$

Hence,

$$\boldsymbol{I_m/I'_m = e^{C(T_1-T_2)}}$$

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

Numerical

A curtain of 4 ft x 4 ft is hanged at the center of the reverberation chamber whose dimensions are (10 x 20 x 30) ft^3. If the reverberation time is 1 s and 1.5 s, respectively for two different sources of sound of 50 mW and 80 mW, respectively, calculate the absorption coefficient of the curtain. Velocity of sound is 1126 ft/s.

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