UNIT II
SOUND WAVE AND ITSAPPLICATIONS

CHAPTER-05
Architectural Acoustics

What is acoustics?

Acoustics is a branch of physics that study the sound, acoustics concerned with the production, control, transmission, reception, and effects of sound.

The study of acoustics has been fundamental to many developments in the arts, science, technology, music, biology, etc

ARCHITECTURAL ACOUSTICS

- Architectural acoustics deals with the planning of a building, auditorium, music halls, recording room, etc., with a view to provide the best audible sound to the audience.

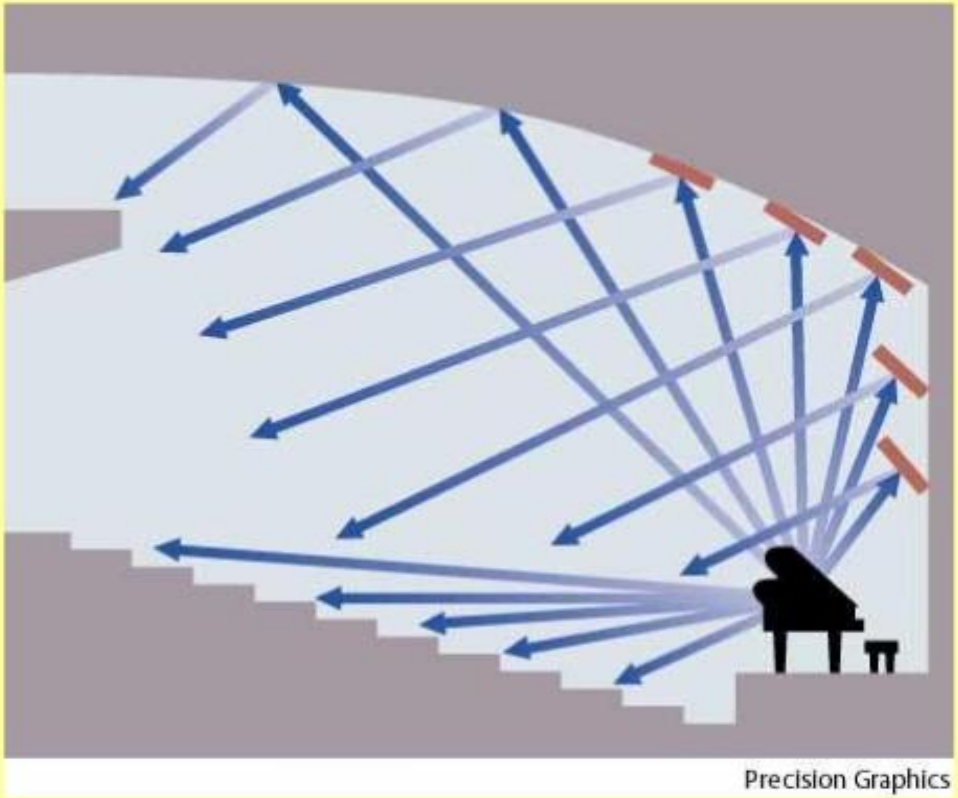
Classification of Sound Waves

- *Audible waves/sonics* : The frequency which stimulate the human ear and brain to the sensation of hearing having the frequency ranges from 20 Hz to 20 kHz.

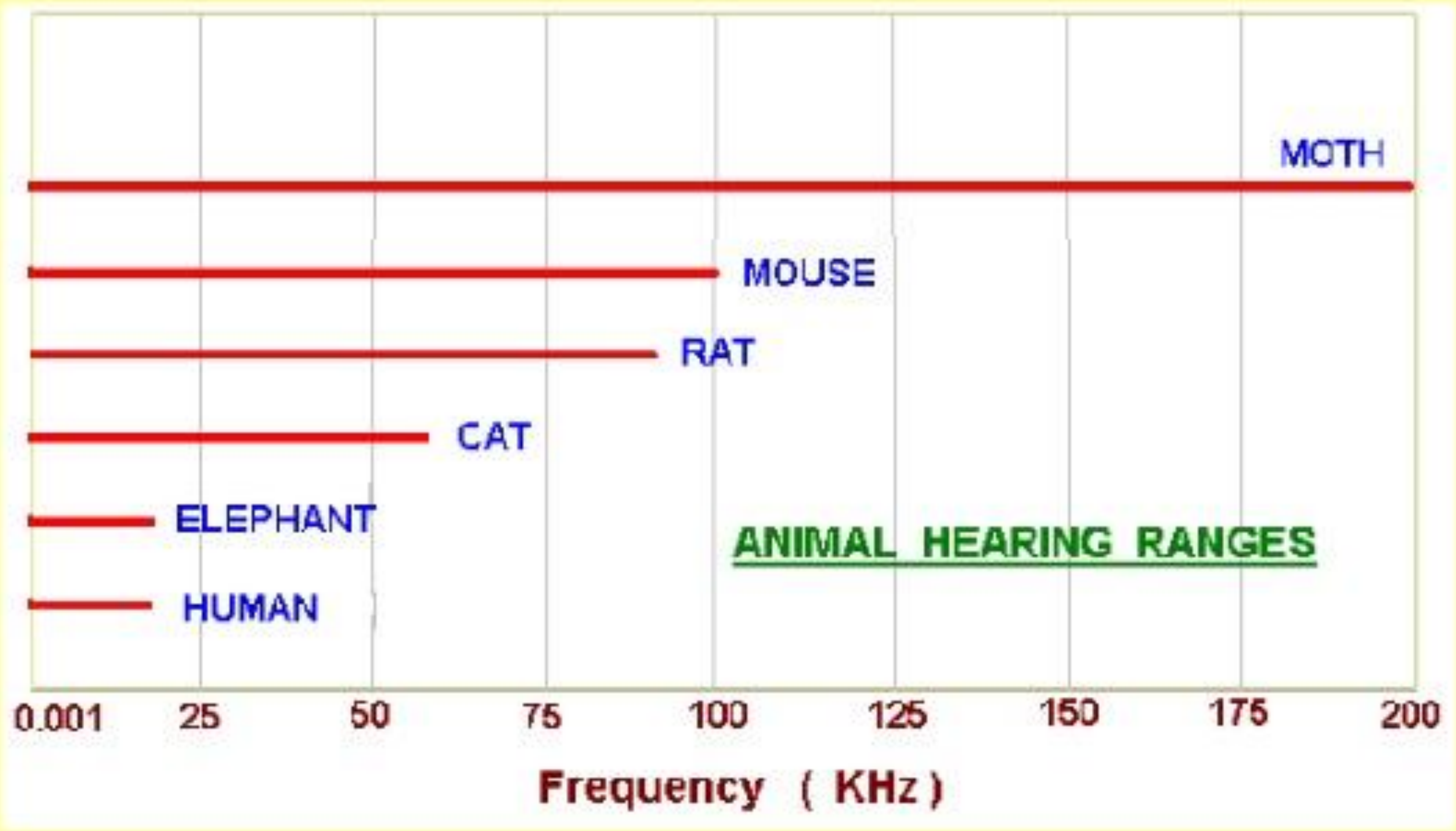
- *Infrasonic waves/ subsonics* : Infrasonic waves have their frequency less than the lower limit of audible range (i.e., below 20 Hz).

- *Ultrasonics or supersonics:* It is the range of sound waves having the frequencies above the limits of human audibility, i.e., frequencies greater than 20 kHz.

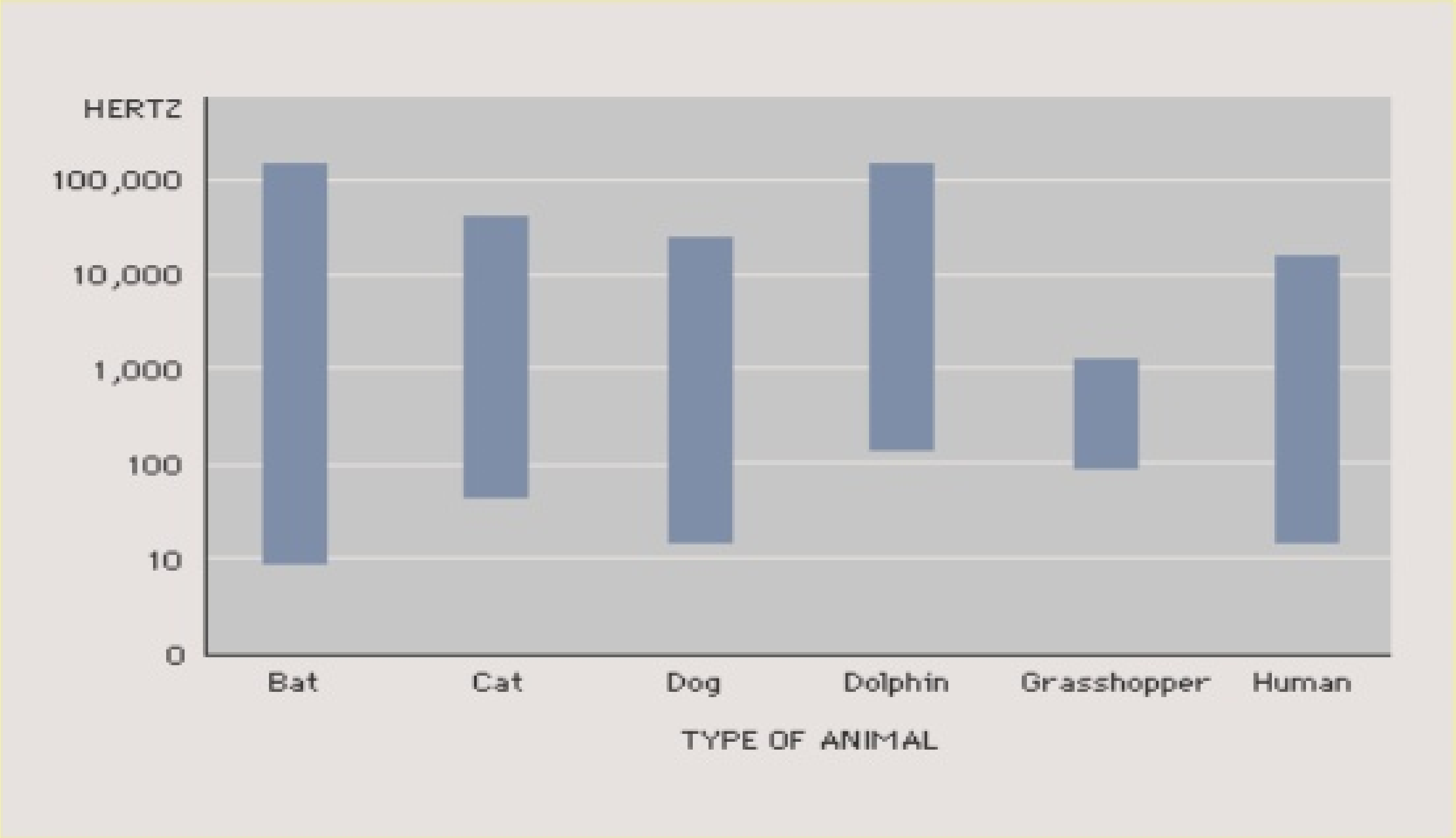
The human ear is capable of hearing sounds within a limited range.



Animals have varied hearing ranges



Hearing range of some animals



NOISE AND MUSICAL SOUND

➢ Musical sounds are characterised by their regularity and smoothness, while the noise is characterised by its irregularity and roughness.

❖ *Pitch: The pitch of sound wave is a general feature which depends only on the period or frequency* of vibration constituting the sound.

❖ *Intensity and loudness: The intensity of sound wave is* proportional to the square of the amplitude of sound wave. The loudness is measured as the degree of sensation.

❖ *Quality: It is an important property of sound wave with the help of which we can distinguish a* musical sound from others having same pitch and intensity.

WEBER—FECHNER LAW (SENSATION OF LOUDNESS)

- According to the Weber's law, the increase of stimulus to produce the minimum perceptible increase of sensation is proportional to the pre-existing stimulus.

✓Using Weber's law, Fechner derived the following relation between the magnitude of sensation and the intensity of stimulus:

$$\delta S = K \frac{\partial E}{E}$$

$$S = K \log E$$

where *S is the sensation magnitude, E the intensity of stimulus, and K is a constant.*

LOUDNESS LEVEL AND INTENSITY: BEL AND DECIBEL

- The usual unit of sound intensity in logarithmic scale is *bel.*
- Ten times of *bel* unit is known as *decibel*

❖In order to define bel or decibel, let us consider P_1 *and* P_2 *as the output powers of two sources of* sound. Now the gain regarding to these two sources in terms of *bel* and *decibel* is defined as:

$$\text{gain} = \log_{10}\left(\frac{P_2}{P_1}\right) \text{ bel}$$

$$\text{gain} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) \text{decibel}$$

✓ It is observed that 1 dB is equivalent to the power amplification of 1.26 or amplitude amplification of 1.12.

5.5 LOUDNESS LEVEL AND INTENSITY: BEL AND DECIBEL

The audible frequencies within which the ear can respond is very large, having range from 20 Hz to 20 kHz. In this range of frequency, our ears can distinguish a large gradation of intensity usually from 1 to 10^{12}. Since this range of sound is very wide so instead of using simple calculation to deal it, logarithmic scale is preferred. The usual unit of sound intensity in logarithmic scale is *bel*.

In order to define bel or decibel, let us consider P_1 and P_2 as the output powers of two sources of sound. Now the gain regarding to these two sources is defined as

$$\text{gain} = \log_{10}\left(\frac{P_2}{P_1}\right) \text{bel} \tag{5.2}$$

Bel is the large unit of sound intensity. It can be expressed in terms of smaller unit decibel (abbreviated as dB). As from its name, it is clear that decibel is 1/10th of the bel. In terms of decibel, Eq. (5.2) can be written as

$$\text{gain} = 10\log_{10}\left(\frac{P_2}{P_1}\right) \text{decibel} \tag{5.3}$$

As the output power is proportional to the square of amplitude, if A_1 and A_2 represent the corresponding amplitudes, then

$$\text{gain} = 10 \log_{10} \left(\frac{A_2}{A_1}\right)^2 \text{ decibel}$$

or

$$\text{gain} = 20 \log_{10} \left(\frac{A_2}{A_1}\right) \text{ decibel} \tag{5.4}$$

If we are selecting a system which has its gain as 1 dB, then Eq. (5.3) can be given as

$$10 \log_{10} \frac{P_2}{P_1} = 1$$

or

$$\log_{10} \frac{P_2}{P_1} = 0.1$$

or

$$\frac{P_2}{P_1} = 1.26 \tag{5.5}$$

According to Eq. (5.4),

$$20 \log_{10} \left(\frac{A_2}{A_1}\right) \text{dB} = 1$$

or

$$\log_{10} \left(\frac{A_2}{A_1}\right) = 0.05$$

or

$$\frac{A_2}{A_1} = 1.12 \tag{5.6}$$

Thus the gain of 1 dB is equivalent to the power amplification of 1.26 or amplitude amplification of 1.12.

Decibel levels

- 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

Decibel levels

- The human ear's response to sound level is roughly logarithmic (based on powers of 10), and the dB scale reflects that fact.
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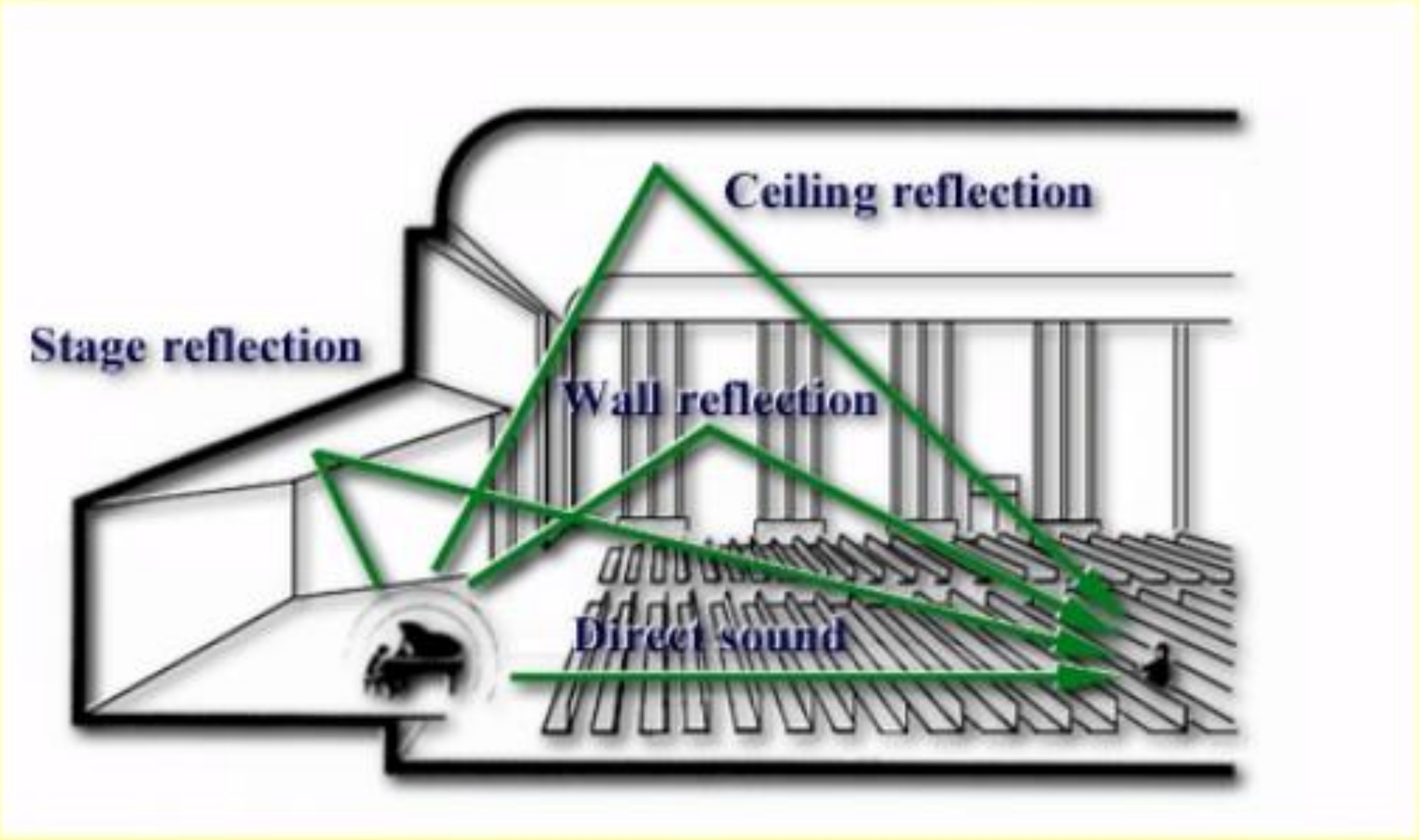
- An increase of 3dB doubles the sound intensity but a 10dB increase is required before a sound is perceived to be twice as loud.
- Therefore a small increase in decibels represents a large increase in intensity.
- For example - 10dB is 10 times more intense than 1dB, while 20dB is 100 times more intense than 1dB.
- The sound intensity multiplies by 10 with every 10dB increase.

BASIC REQUIREMENTS FOR THE ACOUSTICALLY GOOD HALLS

- ✓ The sound should be sufficiently loud and intelligible at every point in the hall.
- ✓ There should be no echoes.
- ✓ Relative intensities of several components of a complex sound must be maintained.
- ✓ For the sake of clarity the successive syllable spoken must be clear and distinct.
- ✓ There should be neither concentration of sound nor zone of silence in any part of the hall.
- ✓ Undue noise and effect of resonance should be avoided.
- ✓ The reverberation should neither be too large nor too small.
- ✓ There should be resonance within the building.

'Stradia': a sound simulation program



REVERBERATION

- Sound waves are produced in a big hall, they spread out, scatter, and strike the surfaces of the various objects in the hall such as ceiling, walls, and floor.
- Some of the sound energy is reflected and some absorbed and thus the distraction of sound energy in the hall continues to be affected.
- The reflected portions travel back into the hall and reunite to form objectionable echoes and affects good hearing.
- Thus, an audience in a hall receives the sound in two ways–directly from the source and after suffering reflections.
- The quality of the sound received by the audience is a combined effect of these two sets of waves.

- There is a time gap between the sound waves directly received from the source and the waves received by successive reflections.
- Due to this reason, sound received by audience does not cease immediately but it persists for some time even after the source is stopped.
- This persistence of audible sound after the source has ceased to emit sound is called reverberation.
- The time during which sound persists in the hall is called reverberation time of sound.
- It is measured from the time that the original sound is produced, or in the case of a continuous note from the time, that the source stopped sounding, to the time at which the sound becomes inaudible.

- The average growth and fall of sound density for a spoken syllable within an auditorium is exactly similar to the growth and decay curve of the electric current in an inductive circuit.

- Initially, when a source emits sound continuously, the listener receives an increasing sound intensity.

- After a few time, the energy emitted per second from the source becomes equal to the energy absorbed or dissipated by the room.

- At this stage, the resultant energy does not increase further with the time, i.e., it attains average steady value.

- Now if the original sound ceases, the sound heard does not stop instantaneously, because the listener continues to receive the successive reflections till the minimum audibility level.

❑ The time in which the energy density of sound falls to 10–6 times of its steady value, after the source is cut off, is known as the standard time of reverberation.

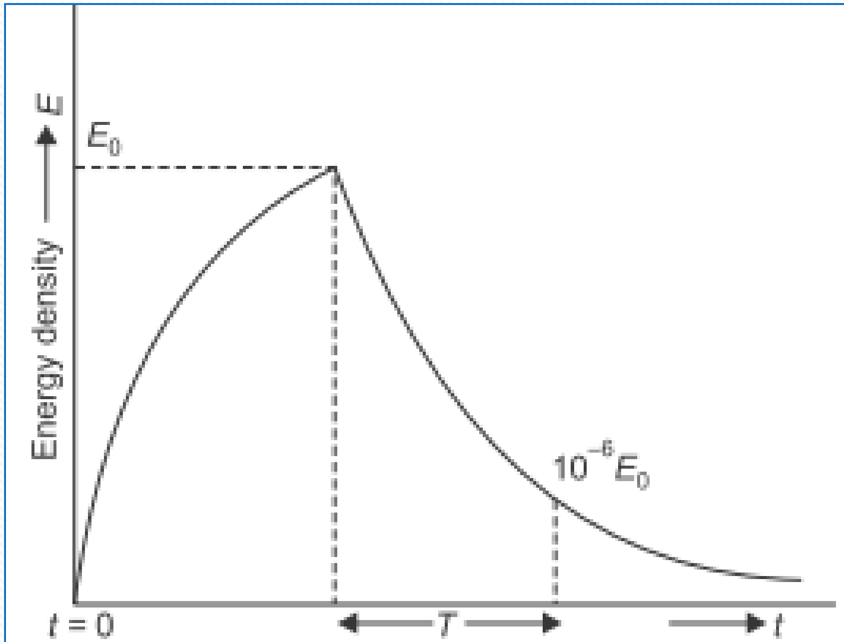


Fig. 5.1 Growth and delay of sound density

REVERBERATION

❖The persistence of audible sound after the source has ceased to emit sound is called *reverberation.*

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DETERMINATION OF THE TIME OF REVERBERATION: SABINE'S LAW

Sabin' s Law is based on his experimental findings for which he used

- Standard source of sound waves having initial intensity of 10^6 times that of the human audible intensity in a small hall and a stop watch.
- On the basis of his experimental findings he establish a relation as

$$T = \frac{0.05V}{\Sigma as}$$

a is the absorption coefficients a denotes a small area T is reverberation time and V is the volume of the room.

Deductions of Sabine

- The duration of reverberation is almost independent of the position of the source and of the absorber in the room.
- The effect of any given amount of absorbent is also independent of its position in the room.

ABSORPTION COEFFICIENT

Absorption coefficient for a surface area a is given as:

$$\alpha = \frac{\text{Sound energy absorbed by the surface}}{\text{Sound energy absorbed by an open window of same area}}$$

FACTORS AFFECTING THE ARCHITECTURAL ACOUSTICS AND THEIR REMEDIES

The factors affecting the architectural acoustics and their remedies are

- *Control of reverberation*
- *Adequate loudness*
- *Uniform distribution of sound*
- *Freedom from resonance*
- *Absence of echoes*
- *Absence of echelon effect*
- *Extraneous noise and sound insulation*