MODULE 3

ACOUSTICS, RADIOMETRY and PHOTOMETRY

The branch of physics which deals with generation, reception, propagation and analysis of sound is called acoustics.

The acoustical properties of a room or hall have considerable effect on the clarity and intelligibility of speech or music produced in the hall. Thus, the study of sound waves plays an important role in many engineering and non - engineering applications.

Types of Acoustics

The areas of acoustical studies and their applications include:

Architectural acoustics - Study of sound waves in closed halls and buildings.

Musical acoustics - Physics of musical instruments.

Engineering acoustics - Technology of sound production and recording, study of vibrations of solids and their control (including noise control).

Bio-acoustics / Medical acoustics - Use of sound in medical diagnosis and therapy.

Basic Terminologies

The different musical sounds are distinguished from each other by the following characteristics:

(i) Pitch (or) frequency

Pitch is the characteristic of a sound which distinguishes between a shrill sound and a grave sound.

The pitch of a musical note is the sensation conveyed to our brain by the sound waves falling on our ears.

Pitch depends directly on the frequency of the sound waves. Pitch is measured in Hertz (Hz).

Example

- The voice of women and children has high pitch because the frequency of sound is high.
- The voice of an old man has low pitch because the frequency of sound is low.
- In guitars, thicker wires give a lower frequency and thinner wires give a length frequency.

(ii) Quality (or) Timbre

Quality or timbre of the sound wave is a characteristic which enables us to distinguish between musical notes emitted by different instruments or voices even though they have the same pitch and loudness.

(iii) Intensity of sound (I)

Intensity of a sound wave (I) at a point is defined as the amount of sound energy Q flowing per second per unit area held normally at the point to the direction of the propagation of sound wave.

Intensity of sound wave $I = \frac{Q}{tA}$ where Q - Amount of sound energy flowing, t - Time of flow, and

A - Area normal to the propagation of sound.

Intensity, $I = \frac{P}{A}$ where Power, $P = \frac{Q}{t}$

Intensity is a measurable physical quantity. It is expressed in joule second^{--1} metre^{--2} or watt metre^{-2} (Wm^{-2}).

(iv) Sound intensity level or relative intensity of sound

- The logarithmic ratio of intensity of a sound to standard intensity ($I_o=10^{-12}\ Wm^{-2}$) is known as sound intensity level or relative intensity of sound.
- Standard intensity of sound is the minimum audible sound intensity heard by our ears.

- Sound intensity level, $\beta=\log_{10}\left(\frac{I}{I_0}\right)$ bel
- The unit for sound intensity level is bel named in honour of Alexander Graham Bell,

Note: Consider sound intensity, $I=10I_o$

Then Sound intensity level is $\beta=\log_{10}\left(\frac{10I_o}{I_0}\right)$ bel

Then we get $\boldsymbol{\beta=\log_{10} 10=1\text{bel}}$

Similarly, if $I=100I_o$

Then Sound intensity level is $\beta=\log_{10}\left(\frac{100I_o}{I_0}\right)$ bel

Then we get $\boldsymbol{\beta=\log_{10} 100=2\text{bel}}$

- Bel is the sound intensity level of a sound whose intensity is ten times the standard intensity.
- In practice, bel is a larger unit. Hence, another unit known as decibel (dB) is more often used.

1bel=10 decibel

- Hence, sound intensity level is measured in decibel is $\boldsymbol{\beta} = 10\ \mathbf{log_{10}}\ \left(\frac{I}{\mathbf{I_0}}\right)\ \mathbf{dB}$

Reflection and Refraction of Sound Waves

Reflection and refraction are two important phenomena that occur with sound waves as they travel through different mediums.

Reflection of sound waves: Reflection occurs when sound waves encounter a boundary between two different mediums and bounce back. The angle of incidence (the angle at which the sound wave strikes the boundary) is equal to the angle of reflection (the angle at which the sound wave bounces off the boundary).

The reflection of sound wave produces echoes and reverberation.

Refraction of Sound Waves: Refraction takes place when sound waves travel through mediums with varying densities, causing the waves to change direction. The change in direction is due to the difference in the speed of sound in the two mediums. When a sound wave passes through a medium where the speed of sound is different, one side of the wave front moves faster than the other, causing the wave to bend.

Reverberant sound (Reverberation): The existence or prolongation or persistence of sound in a room (due to multiple reflections from surfaces) even after the source of sound has stopped to emit the sound is called reverberant sound or reverberation.

Reverberation time: The time duration upto which a sound persists even after the source of sound has stopped to emit the sound is called reverberation time. It is measured as the time taken by the sound to fall below the minimum audibility after source of sound has stopped to emit the sound.

Importance of Reverberation Time

a) **Noise Effect:**

- Any unpleasant sound to our ears is called noise.

- Noise causes irritation and strain to our ear. Noise of high intensity may cause permanent or temporary deafness.
- Noise can be caused by various sources, such as machinery, traffic, ventilation systems, or other environmental factors.
- High reverberation time can lead to the creation of noise.

b) Dead Effect:

- The dead effect in the room is due to an extremely short reverberation time, typically less than 0.1 seconds.
- The dead effect, also known as a "dead room" or "anechoic chamber," is the opposite of a reverberant room.
- In a dead room, the surfaces are designed to absorb sound energy entirely rather than reflect it.
- Dead rooms are used for various purposes, such as audio testing and measurements, to eliminate reflections and achieve accurate and controlled acoustic condition.

Optimum Reverberation Time Values for Good Auditoriums

For a good auditorium, the reverberation time generally falls within the following ranges:

1. **Concert Halls:** Reverberation time of approximately 1.8 to 2.2 seconds is considered ideal for classical music performances. This allows the sound to blend and enrich the musical experience.

2. **Opera Houses:** Reverberation time of around 1.6 to 1.9 seconds is often preferred for opera performances. A slightly shorter reverberation time helps maintain clarity in vocal performances.

3. **Theaters**: Theater spaces can have a slightly shorter reverberation time, typically between 1.2 to 1.6 seconds. This allows for good speech intelligibility and helps the audience hear the dialogue clearly.

4. **Multi-purpose Halls:** These venues may have adjustable acoustics to accommodate various events. Reverberation time can vary from 1.2 to 2.0 seconds depending on the configuration.

Absorption of Sound

- When a sound wave strikes a surface there are three possibilities:

(a) Part of energy is absorbed

(b) Part of it is transmitted

(c) Remaining energy is reflected

- The property of the surface to convert sound energy into other forms of energy is known as absorption.
- The effectiveness of surface in absorbing sound energy is expressed by absorption coefficient denoted by α (alpha).

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

Open Window Concept

- An open window allows sound incident on it to completely pass through without any reflection and hence behaves as a perfect absorber of sound.
- An unit area of an open window is taken as the standard unit of absorption.
- Absorption coefficient is defined as the reciprocal of the area of the sound absorbing surface that absorbs the same quantity of sound as that of a 1 m^2 of an open window.

  Ex: If 5 m^2 of a material absorbs the same quantity of sound as 1 m^2 of an open window, then the absorption coefficient of the material is 1/5 = 0.2.
- The unit of absorption coefficient is sabin or open window unit (O. W. U.).

Average Value of Absorption Coefficient

- Let the α_1, α_2, α_3, …. , α_n be the absorption coefficients of the different materials in a hall whose surfaces exposed to sound are S_1, S_2, S_3, …. S_n respectively, measured in m^2.
- The total absorption is given by, A = $\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_2 + - - + \alpha_n S_n = \sum_{i=1}^{n} \alpha_i S_i$
- The average value of absorption co − efficient, $\bar{\alpha} = \frac{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_2 + - - - + \alpha_n S_n}{S_1 + S_2 + S_3 + - - - + S_n} = \frac{\sum_{i=1}^{n} \alpha_i S_i}{\sum_{i=1}^{n} S_i}$
- The value of absorption coefficient varies between 0 and 1.

Absorptive power

The absorptive power of a surface is defined as the ratio of sound energy absorbed over a certain time to the radiant sound energy incident on it at the same time.

Requisites for Acoustics in Auditoriums

1. The sound heard must be sufficiently loud in every part of the hall and no echoes should be present.
2. The total quality of speech and music must remain unchanged.
3. The reverberation time must neither be too large or too small.
4. There should be no concentration of sound in any part of the hall.
5. There should be no extraneous noise.
6. There should be no Echelon effect.
7. There should be no resonance within the auditorium.

Factors Affecting the Acoustics and their Remedial Measures

1. **Reverberation time**

If reverberation time in a hall is too large, there is an overlapping of successive sounds which results in a loss of clarity and echo. On the other hand, if reverberation time is very small, loudness is not sufficient. The speaker may find no response from the audience. Such a hall is considered as dead by the speaker. Thus, it is very important that reverberation time in a hall should not be too long or short. A satisfactory or preferred value of the reverberation time is called optimum reverberation time.

Optimum reverberation time is obtained by the following ways:

- Providing many windows and ventilators.
- Covering a part of the ceiling, walls and even the back of chairs with suitable sound absorbing materials like felt, fibre board, glass, wool etc.
- Using curtains with folds.
- Covering the floor with carpets and having graded ceiling tops.
- Having a good-size of audience.
- Decorating the walls with pictures and maps.

2. Loudness

- Loudness is the degree of sensation produced in the ear.
- If the intensity of sound is weak, loudness may go below the level of audibility.
- Sufficient loudness in every part of the hall is important for satisfactory hearing.

The loudness of sound is increased by the following ways:

- To achieve good loudness, maximum reflection of sound from the stage is desirable so that there is no loss of sound energy. This can be done by using a large sounding board behind the speaker.
- Large polished wooden reflecting surfaces above the speakers are helpful.
- Use of good quality loudspeakers is essential.
- Low ceilings are helpful for better reflection of sound.

3. Focusing

Sound waves that reflect from the concave surfaces of a building get focused to a point. The intensity of sound will be maximum at such points and zero at other places. This is called focusing effect.

Uniform distribution of sound in a hall can be achieved in the following ways:

- There should not be any curved surfaces in the hall. If such surfaces are present, they should be covered with suitable sound absorbing materials.
- Ceiling should be as low as possible.

4. Echoes

- When a sound wave falls on a reflecting surface (more than 17 meter away), it is reflected as a distinct repetition of direct sound. This reflected sound is called an echo**.**
- Echoes occur due to the reflected sound waves. They reach the listener a little later than the direct sound, which causes confusion. This defect is common particularly when the reflecting surface is curved.

Remedies to reduce echoes are:

- Providing low ceiling.
- Covering walls and ceiling with suitable sound absorbing materials.

5. Echelon effect

Sound produced in front of regular structures like a set of railing or staircase or any regular spacing of reflecting surfaces may produce sound notes due to regular repetition of echoes of the original sound. This effect is called as Echelon effect.

Remedies to reduce the echelon effect are:

- Regular structure like a stair case or a set of railings in the hall should be avoided.
- The stair cases may be covered with carpets to avoid reflection.

6. Resonance

- If the frequencies of the original sound and that of the newly created sound are the same, it may result in resonance. Such vibrations are called ***resonant vibrations.***
- Due to the interference between original sound and the newly created sound, the original sound is distorted. Hence, it leads to an unpleasant effect. Such resonant vibrations should be suitably damped.
- Resonance effect can be rectified by hanging large number of curtains in the hall.

7. Noise

Unpleasant sound which creates harsh or jarring effect to the human ear is called noise.

There are three types of noises.

(i) Inside noise, (ii) Air - borne noise, and (iii) Structure - borne noise

(i) Inside noise

Noise produced inside the room is known as inside noise.

Examples:

- The sound created by the movement of people, crying babies, movement of furniture.
- The sound produced from machines, typewriters, etc.

Remedies to reduce inside noise:

- Machines and typewriters can be placed over sound absorbing materials.
- The walls, floors and ceilings can be covered with suitable sound absorbing materials

- The engines that create noise may be fitted on the floor with a layer of wood or felt between them.

(ii) Air-borne noise

Noises coming through open windows, doors and ventilators are known as air-borne noises and are common in a densely populated area.

Remedies to reduce inside noise:

- Using double doors and windows with separate frames and placing sound absorbing material in between them.
- By allotting proper places for doors and windows.
- Using heavy glasses in doors, windows and ventilators.
- By making the hall air-conditioned.

(iii) Structure-borne noise

Noises conveyed through the structures of a building are called structure-borne noises.

Examples:

The operation of machinery, movement of furniture, footsteps etc. produce structural vibrations giving rise to structure-borne noise.

Remedies to reduce structure-borne noises:

- Noises from water pipe can be controlled by using rubber couplings at junctions.
- Using double walls with an air space between them.
- Covering the floors and ceilings with suitable sound absorbing materials and anti-vibration mounts.

Concept of Noise

- Noises are generally measured by sound pressure level (SPL).
- The reference intensity for the threshold of hearing of sound pressure is 2×10^{-5} Nm^{-2} or sound intensity of 10^{-12} Wm^{-2}.

- The level of sound pressure P is said to be L_p decibels greater than a reference sound pressure P_o according to the following definition:

$$\text{Sound Pressure Level } (L_p \text{ or SPL}) = 10\log_{10}\left(\frac{P^2}{P_o^2}\right) \text{ dB}$$

Sound Measurement (Intensities, Pressures and Decibels) in Air at Room Temperature and Sea Level Pressure

Intensity (W/m^2)	Pressure (Nm^2)	dB	Sound source
100	2,00,000	200	Rocket take off
1.0	20	120	Boiler shop
10^{-2}	2.0	100	Siren at 5 meters
10^{-4}	0.2	80	Heavy machinery
10^{-6}	0.02	60	Normal conversation at 1 meter
10^{-8}	0.002	40	Public library
10^{-12}	2×10^{-5}	0	Threshold of hearing

Noise Meters

- Noise meters are the instruments specially designed for noise measurement from low to high frequencies that are within the human ear capacity.
- Noise meters use dB scales 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 a specified noise situation.
- The commonly used noise meters are Sound Level Meter (SLM) and Noise Dosimeter.

Impact of Noise

Noise has the following four impact on multistoried buildings:

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

1. Speech privacy:

- It is an issue within office building, including individual work space, inside conference halls and between offices.
- It mainly affects the quality of work in the adjacent office.

2. Background noise:

Excessive background noise can adversely affect the work space. At the same time, too little background noise can reduce speech privacy, allowing one to hear not only what's happening in their workspace but also elsewhere.

3. Sound masking:

It blends the noise levels from building systems and exterior sources by utilizing electronic noise systems. Traditional sound masking setup typically involve loudspeakers positioned above the ceiling.

4. Orientation of buildings:

The orientation of a building can significantly affect noise impact, particularly for rooms perpendicular to roadways. This is because:

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

(b) windows on perpendicular walls don't reduce noise as effectively as those on parallel walls because of the angle of sound.

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

Sound Insulation

- 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
- Sound insulation is 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 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".

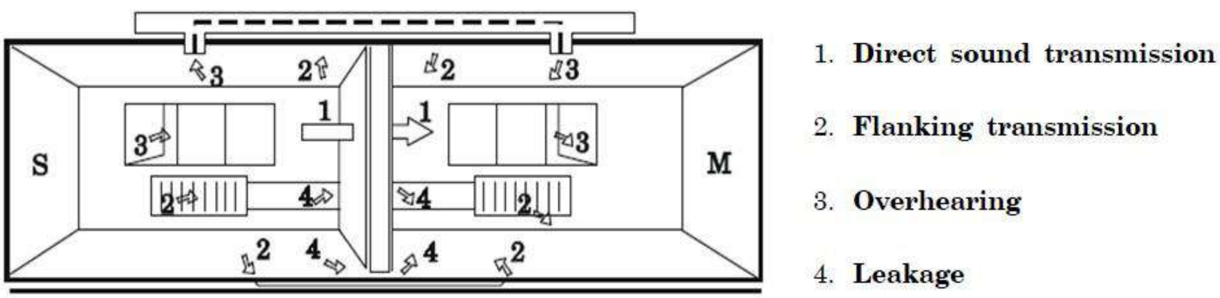


Fig. Sound insulation and its measurement

- The sound reduction index R is used to measure the level of sound insulation provided by a structure such as a wall, window, door, or ventilator. It is expressed in dB.

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 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.

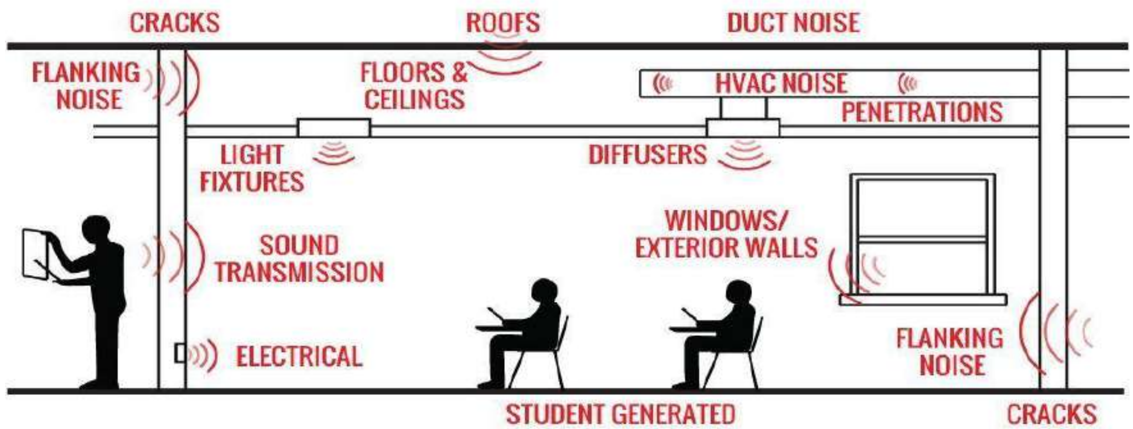
(c) The engine should be fitted on the floor with a layer of wood or felt between them.

(ii) Acoustical treatment

(a) The wall 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:

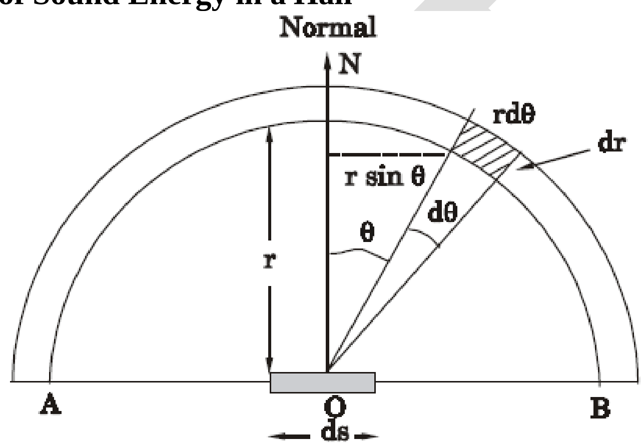
1. By avoiding opening of pipes and ventilators.
2. By allotting proper places for doors and windows.
3. Using double doors and windows with separate frames and having insulating material in them.
4. Using heavy glass in doors, windows and ventilators.
5. By making arrangements for perfectly shutting the doors and windows.

3. When noise is structure-borne

Sound insulation for the reduction of structure-borne noise is done in the following ways:

1. Treatment of floors and ceilings with suitable sound absorbing material and antivibration 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.

Expression for Transport of Sound Energy in a Hall



Assuming that the sound energy is uniformly distributed throughout the hall, the expression for transport of sound energy in a hall is given by,

$$E_T = \frac{E\ dS \cos\theta}{4\pi r^2}$$

Where, ds is the small element on a plane wall AB, r is the radius, E is the sound energy and Ө is angle between the normal to the area ds and r.

Sabine's Formula:

Prof. W.C. Sabine observed the concept of reverberation time for varieties of conditions like empty room, furnished room, small room, auditorium etc. and concluded the following:

(a) Reverberation time depends upon reflectivity of sound form various surfaces available inside the hall. If the reflection is good, reverberation time of the hall will be longer as sound take more time to die out.

(b) Reverberation time depends upon volume of the hall. i.e. $T \propto V$

(c) Reverberation time depends upon the absorption coefficient of various surfaces present in the hall. For shorter reverberation, absorption should be more. i.e. $T \propto 1/A$

Hence, $T \propto \frac{V}{A}$ i.e. $T = K\frac{V}{A}$, where K is a constant of proportionality.

(d) It has been further observed that is all the parameters are taken in SI units then, proportionality constant (K) is found to be 0.161.

Hence, $\mathbf{T = 0.161\frac{V}{A}}$, where Absorption 'A' in the equation represents overall absorption which is given as

$$A = \sum_{i=1}^{n} \alpha_i S_i = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_2 + - - + \alpha_n S_n$$

(e) As absorption coefficient is found to increase with increase in frequency, reverberation time decreases with frequency.

Sabine's Formula for Reverberation Time

According to Sabine, the standard reverberation time T is the time taken by sound wave to fall to one millionth of its original intensity even after the source of sound is cut-off. If E_m is the sound energy of the source before cut-off and during the standard reverberation time, it reduces to $E_m/10^6$.

Therefore, $E = \frac{E_m}{10^6} = E_m\, 10^{-6}$ ----- (1)

W. K. T. $E = E_m e^{-\alpha t}$ -------- (2)

From eq. 1 and eq. 2 we get,

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

i.e, $10^{-6} = e^{-\alpha t}$

or, $10^6 = e^{\alpha t}$

For optimum reverberation, t=T

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

Taking $\log_e$ on both sides,

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

$$2.303 \times 6 \times \log_{10} 10 = \alpha T \times \log_e e$$

$$\text{Or } T = \frac{6\times2.303\times1}{\alpha} \text{-------------} (3)$$

However, $\alpha = \frac{vA}{4V}$ ------------ (4) where v is the velocity of sound (344 ms^{-1}) and V is the volume of the hall.

Substituting eq. (4) in eq. (3), we get, reverberation time, $T = \frac{6\times2.303\times4\times V}{v\times A} = \frac{6\times2.303\times4\times V}{344\times A}$

$$T = \frac{0.161V}{A} \qquad (5)$$

Eq. 5 is known as Sabine's formula for reverberation time.

Measurement of Absorption Coefficient 'α' using Sabine's Formula

Let T_1 be the reverberation time in an empty room. Then,

$T_1 = \frac{0.161V}{A}$ ----- (1), where $A = \sum_{i=1}^{n} \alpha_i S_i$ represents the total absorption.

Let a certain amount of absorbing material of area S and absorption coefficient α' be placed in the room.

The reverberation time will now be,

$T_2 = \frac{0.161V}{A+\alpha'S}$ ----- (2)

Using eq. 1 and 2 we get,

$$\frac{1}{T_1} - \frac{1}{T_2} = \frac{1}{\frac{0.161V}{A}} - \frac{1}{\frac{0.161V}{A+\alpha^F S}}$$

$$= \frac{A}{0.161\,V} - \frac{A+\alpha^F S}{0.161\,V}$$

$$= \frac{A}{0.161\,V} - \frac{A}{0.161\,V} + \frac{\alpha^F S}{0.161\,V}$$

Therefore, $\frac{1}{T_1} - \frac{1}{T_2} = \frac{\alpha^F S}{0.161\,V}$

$$\Rightarrow \alpha' = \frac{0.161V}{S}\left[\frac{1}{T_1} - \frac{1}{T_2}\right] \text{------} (3)$$

Knowing the quantities on the right-hand side of eq. 3, the absorption coefficient α' of the absorbing material can be calculated.

Absorption Coefficients of Some Materials

Material	**Absorption coefficient per m^2 at 500 Hz**
Open window	1.00
Ventilators	0.10 to 0.50
Curtains with heavy folds	0.40 to 0.75
Audience (One adult in an upholstered seat)	0.46
Concrete	0.17
Marble	0.01

RADIOMETRY

Definition of radiometry

Radiometry is the scientific field that deals with the measurement and study of electromagnetic radiation, including visible light, infrared, ultraviolet, and other forms of electromagnetic waves.

It encompasses various principles and techniques used to quantify and describe the characteristics of radiation, such as its intensity, flux, spectral distribution, and energy.

Review of Electromagnetic (EM) spectrum

The electromagnetic (EM) spectrum is a continuum of all electromagnetic waves arranged by their frequencies and wavelengths. It encompasses a vast range of electromagnetic radiation, from extremely low frequencies with long wavelengths, such as radio waves, to extremely high frequencies with short wavelengths, like gamma rays.

The review of the different regions of the EM spectrum:

Radio Waves:

Frequency range: $< 3 \times 10^{11}$

Wavelength range: > 1 mm

Applications: Broadcasting, telecommunications, radar, and radio astronomy.

Microwaves:

Frequency range: $3 \times 10^{11} – 10^{13}$ Hz

Wavelength range: 1 mm – 25 μm

Applications: Cooking, wireless communications, satellite communications, and radar.

Infrared Radiation:

Frequency range: $10^{13} – 10^{14}$Hz

Wavelength range: 25 μm – 2.5 μm

Applications: Thermal imaging, remote controls, night vision, and some medical applications.

Visible Light:

Frequency range: $4 \times 10^{14} – 7.5 \times 10^{14}$Hz

Wavelength range: 750 nm to 400 nm

Applications: Human vision, photography, and optical communications.

Ultraviolet (UV) Radiation:

Frequency range: $10^{15} – 10^{17}$ Hz

Wavelength range: 400 nm – 1 nm

Applications: Sterilization, fluorescent lighting, and some medical treatments.

X-rays:

Frequency range: $10^{17} – 10^{20}$ (approximately)

Wavelength range: 1 nm – 1 pm (approximately)

Applications: Medical imaging (X-ray radiography), security scanning, and industrial applications.

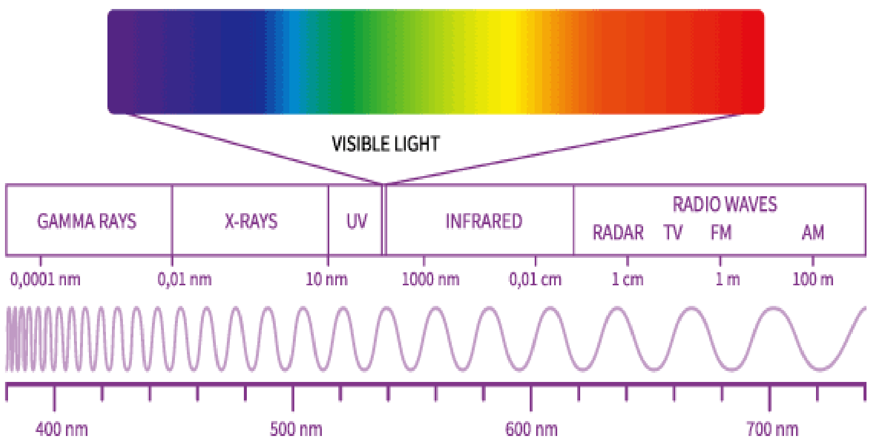
Gamma Rays:

Frequency range: $10^{20} – 10^{24}$ (approximately)

Wavelength range: < 10^{-12} m (approximately)

Applications: Cancer treatment (radiation therapy), nuclear medicine, and scientific research.

Each region of the EM spectrum interacts with matter in different ways, leading to a wide range of applications in various scientific, industrial, and everyday contexts. The study and understanding of the EM spectrum are crucial for many fields, including astronomy, telecommunications, medicine, and environmental monitoring.



Radiant Energy

Radiant energy is the amount of heat radiated (E) emitted by a black body for a second per unit area which is directly related to the fourth power of its absolute temperature (T).

The Radiant heat energy (E) formula is articulated as, $\mathbf{E \propto T^4}$ **or** $\mathbf{E = \sigma T^4}$

Where, Stefan's constant $\sigma = 5.67 \times 10^{-8}$ W/m^2/K^4 , T is absolute temperature of the body (K)

Radiant Power

Radiant power also known as radiant flux or radiant energy flux.

It is the amount of radiant energy emitted, transmitted, or received per unit of time.

The unit of radiant power is the watt (W), which represents joules per second (J/s).

Mathematically, radiant power (P) can be expressed as:

$$P = dE / dt$$

Where: P = Radiant power (in watts, W) , dE = Change in radiant energy (in joules, J), dt = Change in time (in seconds, s)

Radiant intensity

Radiant intensity (I) is a measure of the radiant power emitted, transmitted, or received by a point source in a particular direction.

- It represents the amount of radiant power per unit solid angle.
- The unit of radiant intensity is watts per steradian (W/sr).

Mathematically, radiant intensity (I) can be expressed as:

$$I = dP / d\Omega$$

Where: I = Radiant intensity (in watts per steradian, W/sr) dP = Change in radiant power (in watts, W) dΩ = Change in solid angle (in steradians, sr)

Radiance

Radiance (L) is a fundamental radiometric quantity that describes the amount of radiant power emitted by a surface per unit area, per unit solid angle, and per unit wavelength interval.

- It characterizes the directional distribution of radiant flux at a specific point on a surface.
- The unit of radiance is watts per square meter per steradian per square meter ($W/(m^2 \cdot sr \cdot m^2)$).
- Mathematically, Radiance (L) at a given wavelength (λ) in a particular direction,

$$L = d^2\Phi / (dA \cdot d\Omega \cdot d\lambda \cdot \cos(\theta))$$

Where:

- $d^2\Phi$ = Change in radiant flux (in watts, W) incident on or emitted by an infinitesimal area (dA) of the surface within a small solid angle (dΩ) and wavelength interval (dλ).
- dA = Infinitesimal area (in square meters, m^2)
- dΩ = Infinitesimal solid angle (in steradians, sr)
- dλ = Infinitesimal wavelength interval (in nanometers, nm)
- θ = Angle between the surface normal and the direction of the radiance (in degrees)

Radiant Exitance (radiosity or radiant emittance)

Radiant Exitance is a radiometric quantity that describes the total radiant power emitted or radiated by a surface per unit area.

- It represents the amount of radiant energy leaving a surface in all directions.
- The unit of radiant exitance is watts per square meter (W/m^2).

Mathematically, radiant exitance (M) can be expressed as: $M = d\Phi / dA$

Where: M = Radiant exitance (in watts per square meter, W/m^2) $d\Phi$ = Change in radiant flux (in watts, W) leaving the surface within a small change in time (dt). dA = Infinitesimal area (in square meters, m^2)

Definition of spectral quantities

Spectral radiant power: Spectral radiant power is the amount of radiant power emitted, transmitted, or received per unit wavelength interval at a specific wavelength.

Spectral radiant intensity: Spectral radiant intensity is the amount of radiant power emitted per unit solid angle and per unit wavelength interval.

Spectral radiance: Spectral radiance is the amount of radiant power emitted, transmitted, or received by a surface per unit projected area, per unit solid angle, and per unit wavelength interval.

Spectral irradiance: Spectral irradiance is the amount of radiant power incident on a surface per unit projected area and per unit wavelength interval.

Reflectance and transmittance

Reflectance: Reflectance is the proportion of incident radiation that is reflected by a surface or material.

It is a measure of how much light or radiation is "bounced off" a surface rather than being absorbed or transmitted through it.

Reflectance is often expressed as a percentage or a decimal value between 0 and 1.

Transmittance: Transmittance is the proportion of incident radiation that passes through a material without being absorbed or reflected. It is a measure of how much light or radiation is able to "transmit" through a material. Like reflectance, transmittance is often expressed as a percentage or a decimal value between 0 and 1.

It can shown that, $T + R + A = 1$, where T=transmittance, R=reflectance, and A=absorptance.

PHOTOMETRY

Photometry is a branch of science that deals with the measurement of light and its properties, particularly in terms of human visual perception. It focuses on quantifying the intensity of light, its distribution, and its various attributes as perceived by the human eye. Photometry plays a crucial role in fields such as lighting design, optics, astronomy, and vision science.

Luminous energy

Luminous energy is the amount of energy emitted over a specific time period by a light source that is perceived by the human eye.

Luminous energy is typically measured in a unit called the "lumen-second" (lm-s) or "talbot" (T).

It takes into account the spectral sensitivity of the human eye, which is most sensitive to light in the green-yellow region of the spectrum.

Luminous Flux: Luminous flux is the total amount of visible light emitted by a light source per unit time in all directions.

Luminous flux is measured in lumens (lm).

Luminous intensity:

Luminous intensity is a photometric quantity that measures the amount of visible light emitted from a source in a particular direction.

The SI unit of luminous intensity is the candela (cd).

Luminance:

Luminance is the amount of visible light emitted by a surface per unit area and per unit solid angle in that direction.

The SI unit of Luminance is candelas per square meter (cd/m^2), which is equivalent to nits.

One nit is equal to one candela per square meter.

Luminous Exitance (luminous emittance):

Luminous exitance is a photometric quantity that measures the total visible light emitted or reflected by a surface per unit area.

It is a fundamental concept in photometry and is used to describe the light output of a surface.

Luminous exitance (M) is given by $M = d\Phi/dA$

Where: M is the luminous exitance (in lumens per square meter or lux), $d\Phi$ is the total luminous flux emitted or reflected by the surface (in lumens), dA is the differential area of the surface (in square meters)

Relationship between lumen and watt

Lumen (lm) and watt (W) are both units of measurement, but they represent different characteristics of light sources.

Lumen (lm): Lumen is a unit of measurement that quantifies the total amount of visible light emitted by a light source. It measures the brightness or luminous flux of the light.

Watt (W): Watt is a unit of measurement for power consumption or energy consumption. It indicates the rate at which energy is used or produced.

Candela

A light has a luminous intensity of 1 candela if it emits 1 lumen (1 lm per steradian.)

Illumination or Intensity of illumination (E)

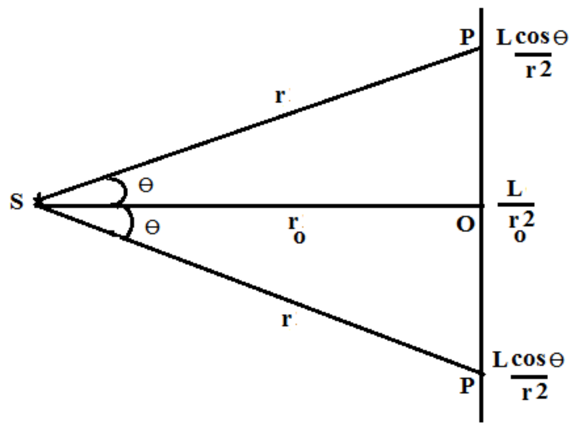
The luminous flux incident normally per unit area of the surface is called illumination or intensity of illumination.

Lambert's Cosine Law (Cosine Law)

It states that the Intensity of the illumination is directly proportional to the cosine of angle of incidence and inversely proportional to the square of the distance between surface and the source.

For any ϴ, $I = \frac{L\cos\theta}{r^2}$ where, L is the luminous intensity ($L = \frac{\emptyset}{4\pi}$)

ϴ=0, Then intensity of illumination, $I = \frac{L}{r_o^2}$



Inverse Square Law

It states that the illumination of surface is inversely proportional to the square of distance between source and light surface (d).

$$E = \frac{I}{d^2}$$

Questions

1. Define Photometry and explain photometric quantities.

2. Elucidate the Impact of Noise in Multi-storied buildings.

3. For an empty assembly hall of size 20 x15 x 10 cubic meter with absorption coefficient 0.106. Calculate reverberation time.

4. Define reverberation and reverberation time and hence derive Sabines Formula.

5. Mention the conditions for good acoustics.

6. Define the five spectral quantities.

7. Give the qualitative explanation of radiometric quantities such as Radiant energy, radiant power, radiant intensity, radiance, radiant existence etc along with respective equations.
8. Describe Reflectance and transmittance.
9. Explain the impact of noise in Multi-storied buildings.
10. Discuss the Factors affecting acoustics of buildings and remedial measures.
11. Explain Cosine law and inverse square law.
12. The reverberation time is found to be 1.5 second for an empty hall and it is found to be 1 second when a curtain cloth of $20m^2$ is suspended at the center of the hall. If the dimensions of the hall are 10 x 8 x 6 m3 calculate the coefficient of absorption of the curtain cloth.

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