Applied Physics For CIVIL Stream

BPHYC102/202

Module 3

Acoustics, Radiometry and Photometry

Introduction

In day today life sound engineering plays a vital role in film industries, broadcasting of television signals and even in television signals. So a new field of science is developed which deals with the planning of a building or a hall with a view to provide best audible sound to the audience and is called Acoustics of building.

Reverberation and Reverberation time

The persistence or prolongation of audible sound even after the source has ceased to produce sound is called reverberation.

The time interval, after the source of sound is cut off, in which the intensity of a sustained note falls to one millionth $(10^-6\ )$ of its original value is called reverberation time.

Importance of Reverberation time

Reverberation time T should be neither too large nor too small. If T is too large the resulting sound persists for a long time and results into confusion due to overlapping of sounds of two syllables uttered in succession. On the other hand, if T is too small; the sound produced ends abruptly and becomes unpleasant to hear. Total absence of reverberation produces an unpleasant effect called dead effect. A room with zero reverberation time is called dead room.

Obtaining Optimum value for Reverberation time

The optimum reverberation time of a room or space is defined as the time it takes for sound to decay by 60 dB.

Example 1:If the sound in a room took 10 seconds to decay from 100 dB to 40 dB, the reverberation time would be 10 seconds. This can also be written as the $T60$ time.

Example 2: The Symphony Hall in Boston which is one of the finest concert halls in the world has reverberation time of 1.8 seconds when it is fully occupied.

The optimum value of the reverberation time depends on the size of hall, surface area and nature of reflecting surfaces inside the hall.

The reverberation time can be suitably adjusted by keeping the following points in mind:

1. Few windows are kept open.

2. Walls and ceilings are covered with perforated asbestos, card boards or felt.

3. Heavy curtains, calendars and charts are hung at various places. 4. Seats are provided with cushions.

5. The reverberation time also depends on the number of audience. Hence a specific number of audiences are required for a hall.

Absorption co-efficient

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

A unit area of open window is selected as the standard. The entire sound incident on an open window is fully transmitted and none is reflected. It is considered as an ideal absorber of sound. This unit of absorption is the open window unit which is named as Sabin.

If there are different materials having absorption coefficients $a_1, a_2, a_3....$ and surface areas $S_1, S_2, S_3....$ in a hall, then the total absorption of the hall is given as,

$A = a_1S_1 + a_2S_2 + a_3S_3....$

$A = \sum_{i=1} a_iS_i$

FACTORS AFFECTING THE ACOUSTICS OF BUILDING

When sound waves are produced in a hall, it reaches the observer directly as well as after reflections from walls, floors, ceilings, etc. Thus there is a possibility for causing interference between these waves, which in turn affects the originality of the sound produced.

The factors affecting the acoustics (sound) of building are as follows.

i. Unoptimised reverberation time.

ii. Very low or very high loudness.

iii.Improper focusing of sound to a particular area, which may cause interference.

iv.Echoes or echelon effects produced inside the buildings.

v. Resonance caused due to matching of sound waves.

vi.Unwanted sound outside or inside the building may also affect the acoustics o buildings.

Requisites for Good Acoustics

To produce sound of optimum quality in a hall, one has to satisfy the following conditions.

1. Each syllable should be of adequate energy so that sound will be sufficiently loud and intelligible at every part of the hall. This can be done by using loud speakers.

2. The hall should be designed suitably such that reverberation time must be of optimum value i.e., nearly 2s for music and nearly 1s for speech.

3. The sound energy produced should be uniformly distributed throughout the hall. This echelon effect can be reduced by carpeting the floor and making unequal steps.

4. Sound from outside may enter the hall through the windows and doors. This can be minimized by using double shutters.

5. Curved walls and corners can be avoided to prevent undesirable focusing of sound at some parts and zones of silence.

Expression for Sabines Formula For Reverberation Time

The relation connecting the reverberation time with the volume of the hall, the area and the absorption coefficient is known as Sabine's Formula.

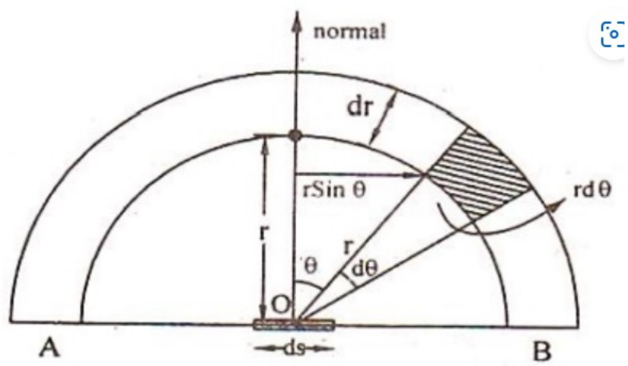
Sabine's developed the formula to express the rise and fall of sound intensity by the following assumptions.

I. Distribution of sound energy is uniform throughout the hall.

II. There is Interference between the sound waves.

III.The Absorption coefficient is independent of sound intensity.

IV.The Rate of emission of sound energy from the source is constant. Let us



consider a small element 'ds' on a plane wall AB. Assume that the element ds receive the sound energy 'E'.

Let us draw two concentric circles of radii 'r' and r + dr from the center point 'O' of ds.

Consider a small shaded portion lying in between the two semi circles drawn at an angle θ and $\theta + d\theta$, with the normal to ds as shown in the figure.

Let 'dr' be the radial length and $r\ d\theta$ be the arc length

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

If the whole figure is rotated about the normal through an angle '$d\phi$' as shown in the figure, then it is evident that the area of the shaped portion travels through a small distance dx.

$$dx = r\sin\theta . d\phi \longrightarrow 2$$

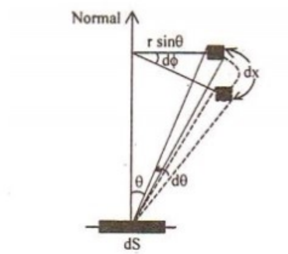
Therefore Volume of the shaded portion is

$$dV = \text{Area} \times \text{ distance}$$

Substituting from equation 1 and 2 we have

$$dV = rd\theta dr . r\sin\theta d\phi$$

$$dV = r^2 \sin\theta dr . d\theta d\phi$$

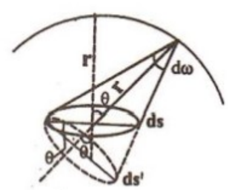


∴ The sound energy present in this volume

$$dV = E \times volume$$

$$dV = Er^2 \sin\theta dr . d\theta d\phi$$

This sound energy will travel through the element in all directions.



∴ The sound energy present in this volume dV per unit solid angle is

$$dV = \frac{Er^2 \sin\theta dr . d\theta d\phi}{4\pi}$$

∴ In this case the solid angle subtended by the area 'ds' at this element of volume 'dV' is

$$d\omega = \frac{ds'}{r^2}$$

From figure we can write

$$\cos\vartheta = \frac{ds'}{ds}$$

$$ds' = ds\cos\theta$$

Therefore we can write solid angle subtended by the area 'ds' as

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

Hence, the sound energy travelling from the element (i.e., from dw to 'ds')

$$= \frac{Er^2 \sin\theta dr . d\theta d\phi}{4\pi} \frac{ds\cos\theta}{r^2} \longrightarrow 3$$

To find total energy received by the element 'ds' per second, we have to integrate the equation (3) for the whole volume lying within a distance 'v' is the Velocity of sound.It is obvious from the geometry of the figure that, It is obvious from the geometry of the figure that,

ϕ Changes from 0 to 2π

θ Changes from 0 to $\pi/2$

r Changes from 0 to v

$\therefore$ Integrating equation 3 with respect to these lines, we can write

Energy received per second by ds = $\dfrac{Eds}{4\pi}\int_0^v dr \int_0^{\frac{\pi}{2}} \sin\theta.\cos\theta.d\theta \int_0^{2\pi} d\phi$

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

$$= \frac{Eds}{2} \int_0^v dr \int_0^{\frac{\pi}{2}} \sin\theta.\cos\theta.d\theta$$

Multiply both numerator and denominator by 2 we get

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

$$= \frac{Eds}{4} \int_0^v dr \int_0^{\frac{\pi}{2}} Sin2\theta.d\theta$$

$$= \frac{Eds}{4} \int_0^v dr \qquad \because \int_0^{\pi/2} Sin2\theta = 1$$

$$= \frac{Eds}{4} v \longrightarrow 4$$

Let 'a' be the absorption coefficient of the area 'ds'.

$\therefore$ The energy absorbed by ds in unit time = $\dfrac{Evads}{4}$

$\therefore$ The total absorption at all the surfaces of the wall is $\dfrac{1}{4} Ev \sum a.ds$

$\therefore$ Total rate of Energy absorption = $\dfrac{1}{4} EvA \longrightarrow 5$

Where 'E' is the energy from sources and 'A' is the total absorption on all surfaces on which the sound falls $A = \sum a.ds$

If 'P' is the Power Output (i.e., the rate of emission of sound energy from the source) then we can write

Rate of Emission of Sound energy i.e., Power Output $P = \frac{1}{4} E_m vA$

Here E_m is the maximum energy from the source (which has been emitted) that is maximum energy which is incident on the wall

$$\therefore E_m = \frac{4P}{vA} \longrightarrow \quad 6$$

If V is the volume of the hall we can write the total energy at any instant't' = EV

$\therefore$ Rate of Growth or Increase in energy = $\frac{d}{dt}(EV) = V\frac{dE}{dt} \longrightarrow \quad 7$

At any instant

Rate of Growth of Energy	=	Rate of Supply of Energy from the source	-	Rate of absorption of energy by walls

$\therefore$ From equation 5 and 7 we can write

$$V.\frac{dE}{dt} = P - \frac{1}{4}EvA$$

$$\frac{dE}{dt} = \frac{P}{V} - \frac{EvA}{4V}$$

Let $\alpha = \frac{vA}{4V}$

$$\frac{dE}{dt} = \frac{4P}{vA}\alpha - \alpha E$$

$$\frac{dE}{dt} + \alpha E = \frac{4P}{vA}\alpha$$

Multiplying by $e^{\alpha t}$ on both sides, we have

$$\left(\frac{dE}{dt} + \alpha E\right)e^{\alpha t} = \left(\frac{4P}{vA}\alpha\right)e^{\alpha t}$$

$$\frac{d}{dt}\left(Ee^{\alpha t}\right) = \frac{4P}{vA}\alpha e^{\alpha t}$$

Integrating an solving we get

$$Ee^{\alpha t} = \frac{4P}{vA}.e^{\alpha t} + k \longrightarrow \quad 8$$

Where k is the constant of integration

Initially the sound increases from E to E_m and now it is going to decay from Em. Therefore time is considered as '0' for E=Em. At E=E_{mv} the sound energy from the source is cut off. Therefore rate of emission of sound energy from the source=0 i.e., P=0

Therefore from equation 8 we can write

$$E_m e^0 = 0 + k$$

$$k = E_m$$

Therefore substituting the value of k for decay in equation 8 , we get

$$Ee^{\alpha t} = \frac{4P}{vA}e^{\alpha t} + E_m$$

Since P = 0 Energy from the source is cutoff for decay of sound.

We can write

$$Ee^{\alpha t} = E_m$$

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

According to Sabine, the reverberation time is defined as the time taken by a sound to fall to one millionth of its initial value, when the source of sound is cut off.

Time taken for E to be equal to $E = \frac{E_m}{10^6}$

Therefore condition is at t = T; $E = \frac{E_m}{10^6}$ …………..(9)

Therefore equation 9 becomes $E = \frac{E_m}{10^6} = E_m e^{-\alpha t}$

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

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

$$\alpha t = \log_e 10_6$$

$$\alpha t = 6 \log_e 10$$

$$\alpha t = 6 \times 2.3026 \log_{10} 10$$

$$\alpha t = 6 \times 2.3026 \times 1 \longrightarrow 10$$

We know $\alpha = \frac{vA}{4V} \longrightarrow 11$

Substituting equation 11 in 10 ,we get

$$\frac{vA}{4V}T = 6 \times 2.3026$$

$$T = \frac{4V \times 6 \times 2.3026}{vA}$$

We know the velocity of sound in air at room temperature v = 330m/s

$$\therefore T = \frac{4 \times 6 \times 2.3026}{330} \times \frac{V}{A}$$

$$T = \frac{0.167V}{A}$$

$$T = \frac{0.167V}{\sum as} \longrightarrow 12$$

Where $\sum as = a_1 s_1 + a_2 s_2 + \ldots\ldots\ldots$.

Equation 12 represents the expression for reverberation time.

Types of Acoustics

There are some important types of acoustics:

Archaeoacoustics- Archaeoacoustics is a field of archaeology and acoustics that studies the relationship between people and sound throughout history. A discipline that combines archaeology and computer simulations to research and understand ancient music.

Aeroacoustics- Aeroacoustics is the study of noise generated by air movements, such as turbulence and the movement of sound through the fluid air.

To study how to quieten aircraft, acoustical engineers apply knowledge in the field of acoustics. Aeroacoustics is important for understanding how wind musical instruments work.

Environmental noise and soundscapes- Environmental acoustics is about noise and vibration that comes from different sources. It's aimed at reducing noise and vibrations from many different sources. Soundscape research is starting to investigate how sound can have a positive impact on people's mental and physical well-being in the context of the urban environment.

Ultrasounds- A sound with a Frequency greater than the audible limit is called ultrasound. There isn't a difference in the physical properties when compared to normal sound. In a lot of fields, it is used with sputum. Ultrasonic devices can be used for measuring distances and detecting objects. In physics, it's used to image the insides of the body.

Psychoacoustics- Many studies have been conducted to understand the relationship between acoustics and cognitive, or more commonly known as psychoacoustics, in which what one hears is a combination of perception and biological aspects.

Reflection and Refraction of Sound in Acoustics

Reflection-If a sound is not absorbed or transmitted when it strikes a surface, it will be reflected. The law for reflection is the same as that for light, i.e. the angle of incidence of a sound wave equals the angle of reflection, just as if it were produced by a 'mirror image' of the stimulus on the opposite side of the surface. However, this law of reflection holds only when the wavelength of the sound is small compared to the dimensions of the reflecting surface.

Refraction-The speed of sound in air is affected by the temperature of the medium, the wave moving faster at higher temperatures and slower at cool temperatures. When parts of a sound wave are in layers of a medium at different temperatures, and therefore are travelling at different velocities, the direction of propagation of the wave changes. This effect is called refraction. A similar effect happens when the wave changes media.

Loudness

The uniform distribution of loudness in a hall or a room is an important factor for satisfactory hearing. Sometimes, the loudness may get reduced due to excess sound-absorbing materials used inside a hall or room.

Echo and absence of Echo

An echo is heard due to the reflection of sound from a distant sound-reflecting object.If the time interval between the direct sound and reflected sound is less than 1/15th of a second, the reflected sound is helpful in increasing the loudness. But, those sounds arriving later than this cause confusion.

Remedy: An echo can be avoided by covering long-distance walls and high ceilings with suitable sound-absorbing material. This prevents the reflection of sound.

Echelon Effect

It refers to the generation of a new separate sound due to multiple echoes. A set of railings or any regular reflecting surface is said to produce the echelon effect. This echelon effect affects the quality of the original sound.

Remedy: The remedy to avoid the echelon effect is to cover such surfaces with sound-absorbing materials.

Transport of Sound Energy in a Hall

When sound energy is incident on any surface, one part is reflected from the surface, another part is absorbed while the remaining part is transmitted. The property of a surface by which sound energy is converted into other form of energy is called as absorption. Sound energy is converted into heat due to frictional resistance inside the pores of the material.

Then the amount of sound energy in a given volume in a hall is $= \frac{E}{4\pi}(\frac{dScos\theta}{r^2})$

Requirement of Sound Insulation

The aim of acoustic insulation is to reduce noise transmission from one room to another. As a result, the noise is reduced and comfort improved.

The acoustic performance expected from a room, in relationship to its neighbouring rooms, is achieved through insulation.

The measurement index of sound insulation:

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.

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.

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

2. Acoustical treatment.

3. By avoiding opening of pipes and ventilators.

4. By allotting proper places for doors and windows.

5. Using double doors and windows with separate frames and having insulating material in them.

6. Using heavy glass in doors, windows and ventilators.

7. By making arrangements for perfectly shutting the doors and windows.

8. Treatment of floors and ceilings with suitable sound absorbing material and anti-vibrations mounts.

9. Using double walls with air space between them.

10. Insulation of machinery.

Noise

Noise is an unwanted sound produced due to heavy traffic outside the hall which leads to displeasing effect on the ear. There are three types of noises.

i. Air Borne noise

ii. Structure Born Noise

iii. Inside Noise

All these three noises pollute the area at which it has been produced and create harmful effects to the human beings. Fortunately human beings have the capability to reject the sound within certain limits with conscious efforts and to carry on his normal work.

EFFECTS PRODUCED DUE TO NOISE POLLUTION

. It produces mental fatigue and irritation.

· It diverts the concentration on work and hence reduces the efficiency of the work.

·It sometimes affects the nervous system and lowers the restorative quality of sleep.

·strong noises leads to damage the eardrum and make the worker hearing impaired.

·The noises which are produced regularly will even retard the normal growth of infants and young children.

Air Borne Noise

The noise which reaches the hall through open windows, doors, and ventilations are called as air borne noise. This type of noise is produced both in rural areas [natural sound of wind and animals] and in urban areas] noise that arises from factories, aircrafts, automobile, trains, Flights etc.

REMEDIES:

i. By making the hall air conditioned, this noise may be eliminated.

ii.By allotting proper places or doors and windows, this noise can be reduced.

iii. It can be further by using double doors and windows with separate rames and by pacing the absorbents in-between them.

STRUCTURE BORNE NOISE

The noise that reaches the hall through the structure of the building is termed as Structure Borne noise. Those types of noise produced inside the building, which may be due to the machinery operation, movement of furniture's footsteps etc and these sounds will produce structural vibration giving rise to the Structure Borne Noise.

REMEDIES:

i. By properly breaking the continuity of the interposing layers by some acoustical insulators this type of noise can be avoided.

ii. By providing carpets, resilent, antivibration mounts etc., this type of noise can be reduced.

INSIDE NOISE

The noises that are produced inside the halls is known as inside noise. Or example in some offices the sound produced by machinery, type writers ect produces this type of noise.

REMEDIES:

i. By placing the machineries and type writers over the absorbing materials or pads this type of noise can be reduced.

ii. It can be reduced by covering the floors with carpet.

iii. By fitting the engine on the floor with a layer of wood or elt between them this type of noise can be avoided.

Noise Measuring Instruments

1. Sound Level Meter (SLM)
2. Noise Dosimeter
3. Octave Band Analyzer
4. Data Logging Sound Level Meters
5. Integrating Sound Level Meters

Radiometry and Photometry

RADIOMETRY- Radiometry deals with the measurement of the energy transferred by a source through a medium (or media) to a receiver. Radiometry uses the laws of geometrical optics in order to treat the propagation of energy from a source to the surrounding space.

PHOTOMETRY- Radiometry is divided according to various regions of the electromagnetic spectrum like ultraviolet radiometry, intermediate-infrared radiometry, far-infrared radiometry and microwave radiometry, however in all these division similar measurement techniques are applied and are distinguished in the visible and near-visible region of the electromagnetic spectrum.

This subdivision of radiometry that deals with the measurement of the electromagnetic radiation in the visible range and near-visible part of the electromagnetic spectrum, is called Photometry.

Radiometric and Photometric Quantities

An important part of the design of an optical system is its efficiency in transferring light.One must be able to specify the amount of energy emitted or received. Many similar quantities are used to specify the amount of light (electromagnetic radiation in general) leaving a source or arriving at a receiver, and many different systems of units are used.

Radiometric. Spectral and Photometric Quantities

Table 1. Quantities and units used in photometry and radiometry.

Photometric quantity	Unit	relationship with lumen	Radiometric Quantity	Unit
Luminous flux	lm (lumen)		Radiant flux	W (watt)
Luminous intensity	cd (candela)	lm sr^{-1}	Radiant intensity	W sr^{-1}
Illuminance	lx (lux)	lm m^{-2}	Irradiance	W m^{-2}
Luminance	cd m^{-2}	lm sr^{-1} m^{-2}	Radiance	W sr^{-1} m^{-2}
Luminous exitance	lm m^{-2}		Radiant exitance	W m^{-2}
Luminous exposure	lx s		Radiant exposure	W m^{-2} s
Luminous energy	lm s		Radiant energy	J (joule)
Total luminous flux	lm (lumen)		Total radiant flux	W (watt)
Color temperature	K (kelvin)		Radiance temperature	K (kelvin)

Quantity	Symbol	Units	Remarks
spectral flux	$\Phi_{e,\nu}$ $\Phi_{e,\lambda}$	W/Hz W/nm	radiant flux per unit frequency or wavelength
spectral intensity	$I_{e,\Omega,\nu}$ $I_{e,\Omega,\lambda}$	W sr^{-1} Hz^{-1} W sr^{-1} nm^{-1}	radiant intensity per unit frequency or wavelength
spectral radiance	$L_{e,\Omega,\nu}$ $L_{e,\Omega,\lambda}$	W sr^{-1} m^{-2} Hz^{-1} W sr^{-1} m^{-2} nm^{-1}	radiance per unit frequency or wavelength
spectral irradiance	$E_{e,\nu}$ $E_{e,\lambda}$	W m^{-2} Hz^{-1} W m^{-2} nm^{-1}	irradiance per unit frequency or wavelength
spectral radiosity	$J_{e,\nu}$ $J_{e,\lambda}$	W m^{-2} Hz^{-1} W m^{-2} nm^{-1}	radiosity per unit frequency or wavelength
spectral exitance	$M_{e,\nu}$ $M_{e,\lambda;}$	W m^{-2} Hz^{-1} W m^{-2} nm^{-1}	radiant exitance per unit frequency or wavelength
spectral exposure	$H_{e,\nu}$ $H_{e,\lambda}$	J m^{-2} Hz^{-1} J m^{-2} nm^{-1}	radiant exposure per unit frequency or wavelength
spectral luminous flux	$\Phi_{v,\nu}$ $\Phi_{v,\lambda}$	lm Hz^{-1} lm nm^{-1}	luminous flux per unit frequency or wavelength
spectral luminous intensity	$I_{v,\nu}$ $I_{v,\lambda}$	cd Hz^{-1} cd nm^{-1}	luminous intensity per unit frequency or wavelength
spectral illuminance	$E_{v,\nu}$ $E_{v,\lambda}$	lx Hz^{-1} lx nm^{-1}	illuminance per unit frequency or wavelength

Reflectance And Transmittance

Reflectance ρ is the amount of flux reflected by a surface, normalized by the amount of flux incident on it.

Transmittance τ is the amount of flux transmitted by a surface, normalized by the amount of flux incident on it. Any flux not reflected or transmitted is absorbed (α). Conservation of energy requires that, $\rho + \tau + \alpha = 1$

Relation Between Radiometric and Photometric Quantities

1. Radiant Flux and Luminous Flux-

Radiant flux (also called optical power or radiant power) is the energy Q (in Joules) radiated by a source per unit of time, expressed as,

$\phi = \frac{dQ}{dt}$. The unit of radiant flux is the watt (W= J/s).

Luminous flux (ϕ_v) is the time rate of flow of light as weighted by $V(\lambda)$. The unit of luminous flux is the lumen (lm). It is defined as.

$\phi_v = \int_\lambda \phi_{e,\lambda} V(\lambda) d\lambda$

where $\phi_{e,\lambda}$ is the spectral concentration of radiant flux as a function of wavelength .The term, luminous flux, is often used in the meaning of total luminous flux in photometry.

2.Radiant Intensity and Luminous Intensity-

Radiant intensity (I_e) or luminous intensity (I_v) is the radiant flux (luminous flux) from a point source emitted per unit solid angle in a given direction, as defined by,$I = \frac{d\phi}{d\omega}$

where 'd' is the radiant flux (luminous flux) leaving the source and propagating in an element of solid angle d containing the given direction. The unit of radiant intensity is W/sr, and that of luminous intensity is the candela (cd = lm/sr).

3.Irradiance and Illuminance-

Irradiance (E_e) or illuminance (E_v) is the density of incident radiant flux or luminous flux at a point on a surface, and is defined as radiant flux (luminous flux) per unit area, as given by, $E = \frac{d\phi}{dA}$

where $d\phi$ is the radiant flux (luminous flux) incident on an element dA of the surface containing the point. The unit of irradiance is W/m^2, and that of illuminance is lux ($lx = lm/m^2$).

4.Radiance and Luminance-

Radiance (L_e) or luminance (L_v) is the radiant flux (luminous flux) per unit solid angle emitted from a surface element in a given direction, per unit projected area of the surface element perpendicular to the direction. The unit of radiance is $Wsr^{-1}m^-2$, and that of luminance is cd/m^2. These quantities are defined by, $L = \frac{d^2\phi}{d\omega.dA.cos\theta}$

where $d\phi$ is the radiant flux (luminous flux) emitted (reflected or transmitted) from the surface element and propagating in the solid angle d containing the given direction. dA is the area of the surface element, and θ is the angle between the normal to the surface element and the direction of the beam.

5.Radiant Exitance and Luminous Exitance-

Radiant exitance (M_e) or luminous exitance (M_v) is defined to be the density of radiant flux (luminous flux) leaving a surface at a point. The unit of radiant exitance is W/m^2 and that of luminous exitance is lm/m^2 (but it is not lux). These quantities are defined by, $E = \frac{d\phi}{dA}$

where $d\phi$ is the radiant flux (luminous flux) leaving the surface element. Luminous exitance is rarely used in the general practice of photometry.

6.Radiant Exposure and Luminous Exposure-

Radiant exposure (H_e) or luminous exposure (H_v) is the time integral of irradiance $E_e(t)$ or illuminance $E_v(t)$ over a given duration $\triangle t$, as defined by, $H = \int_{\triangle t} E(t).dt$.

The unit of radiant exposure is Jm^-2, and that of luminous exposure is lux·second ($lx.s$).

7.Radiant Energy and Luminous Energy-

Radiant energy (Q_e) or luminous energy (Q_v) is the time integral of the radiant flux or luminous flux (ϕ) over a given duration $\triangle t$, as defined by,

$Q = \int_{\triangle t} \phi t \; dt$

The unit of radiant energy is Joule (J), and that of luminous energy is lumen·second (lms).

8.Total Radiant Flux and Total Luminous Flux-

Total radiant flux or total luminous flux (ϕ_v) is the geometrically total radiant(luminous) flux of a light source. It is defined as

$$\phi = \int_{\Omega} I d\Omega$$
$$\phi = \int_{A} E dA$$

where I is the radiant (luminous) intensity distribution of the light source and E is the irradiance (illuminance) distribution over a given closed surface surrounding the light source. If the radiant (luminous) intensity distribution or the irradiance (illuminance) distribution is given in polar coordinates (θ, ϕ), the total radiant (luminous) flux of the source ϕ is given by,

$$\phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I(\theta, \phi)\ sin\theta\ d\theta\ d\phi$$
$$\phi = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E(\theta, \phi)\ sin\theta\ d\theta\ d\phi$$

8.Radiance temperature and Color Temperature-

Radiance temperature (unit: kelvin) is the temperature of the Planckian radiator for which the radiance at the specified wavelength has the same spectral concentration as for the thermal radiator considered.

Color temperature (unit: kelvin) is the temperature of a Planckian radiator with radiation of the same chromaticity as that of the light source in question. This term is commonly used to specify the colors of incandescent lamps even though the chromaticity coordinates of real incandescent lamps are not exactly on the blackbody locus. The next two terms are also important in photometry.

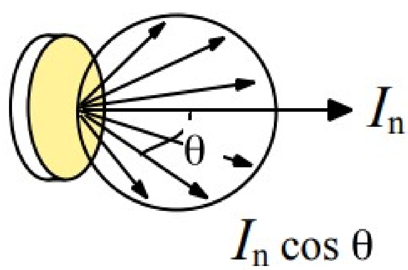
Principles in Radiometry and Photometry

Inverse Square Law-

Illuminance E [lx] at a distance d [m] from a point source having luminous intensity I[cd] is given by $E = \frac{I}{d^2}$,

For example-if the luminous intensity of a lamp in a given direction is 1000 cd, theilluminance at 2 m from the lamp in this direction is 250 lx. Note that the inverse square law is valid only when the light source is regarded as a point source. Sufficient distances relative to the size of the source are needed to assume this relationship.

Lambert's Cosine Law-



The luminous intensity of a Lambertian surface element is given by,

$I(\theta) = I_n cos\theta.$

Lambertian surface: A surface whose luminance is the same in all directions of the hemisphere above the surface.

Perfect (reflecting/transmitting) diffuser: A Lambertian diffuser with a reflectance (transmittance) equal to 1.