SPH244 : Acoustics and Lighting

Administration.

Set text book

Introduction to Architectural Science:, S.Szokolay (4th edition) Elsevier 2004.

Assessment

- 10% Practice Examination, week 12
- 20% Major project
- 30% Tutorial exercises.
- 40% Final examination. The examination will be open book. You can take copy of the textbook with no annotations into the examination. Also one handwritten A4 piece of paper (both sides) can be taken into the examination (i.e. you have to write it yourself and not photocopy someone else's sheet).

It is *not* necessary to pass the examination to obtain an overall pass in the unit.

Unit composition

60%	Lighting
30%	Acoustics
10%	Energy usage

Interior Lighting: History

“Let there be light”

Homo erectus (400,000 BC): Fire and embers, the blazing torch (sticks wrapped together)

Homo Sapiens (20,000 BC): First lamps, shells, horns and rocks with fibre wick and filled with animal or vegetable grease. First reflectors (niches carved into cave walls)

Fuel Lamps (5000 BC) Oils derived from animals and plants used. Olive Oil, Sesame Oil (in Asia). Olive Oil traded.

Oil Reservoir Lamps (500 BC) The oil was enclosed in a cover. Keeps rats and cockroaches from consuming oil.

Candles (400 AD) Best candles made of beewax, others from tallow (smelly and smokey). Widespread home usage around 1400.

Renaissance theatre (1600) Indoor theatre, chandeliers with lamps or candles.

Gas Lighting (1814) By 1823 40,000 lamps in 200 miles of London streets. Used in theatres since flow is adjustable. 500-1000 theatres burn down in Europe and the USA in 19th century.

Kerosene Lamps (1853) Originally distilled from oil shale. Development of petroleum industry (Pennsylvania). Becomes preferred method of indoor lighting. Prior to kerosene lamp the best quality lamps were fuelled by sperm whale oil. Development of oil industry saves whales from extinction.

Incandescent Light (1879). The first usable light bulb powered by electricity developed. Major trigger for development of electrification. In 1881 300 power stations in existence to power 70,000 light bulbs. Tesla and Westinghouse develop AC generators.

Light Pipes (1880). Tube with interior reflective surfaces. Development crippled by light bulb.

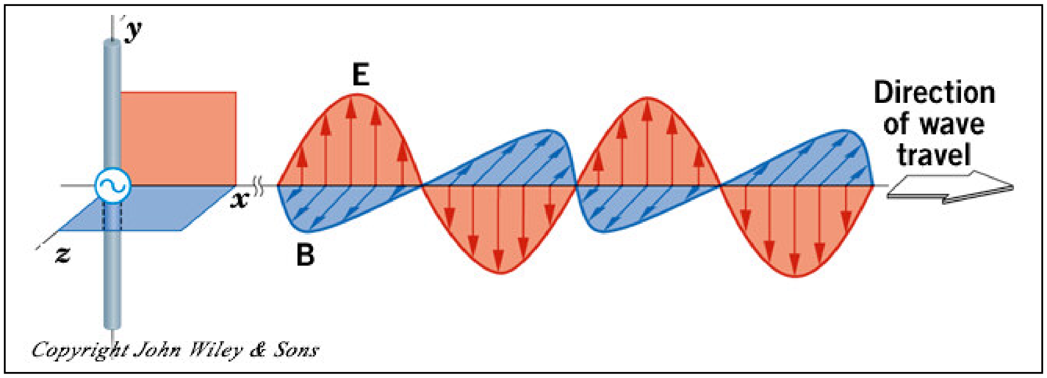
Fluorescent Lamps (1937). Introduced in New York World fair. Light emitted from phosphor on surface. More light, less heat.

Light bulb jokes, (1960).

Q: How many Psychiatrists does it take to change a light bulb?
A: Only one, but the bulb has got to really WANT to change.

The nature of light

Light is an electromagnetic wave



It consists of electrical disturbances and magnetic disturbances travelling through space.

Waves are characterized by three quantities, the speed (c), wave length (λ given in m) and frequency (f given in Hz) obeying

$$speed = (frequency)(wavelength)$$

or

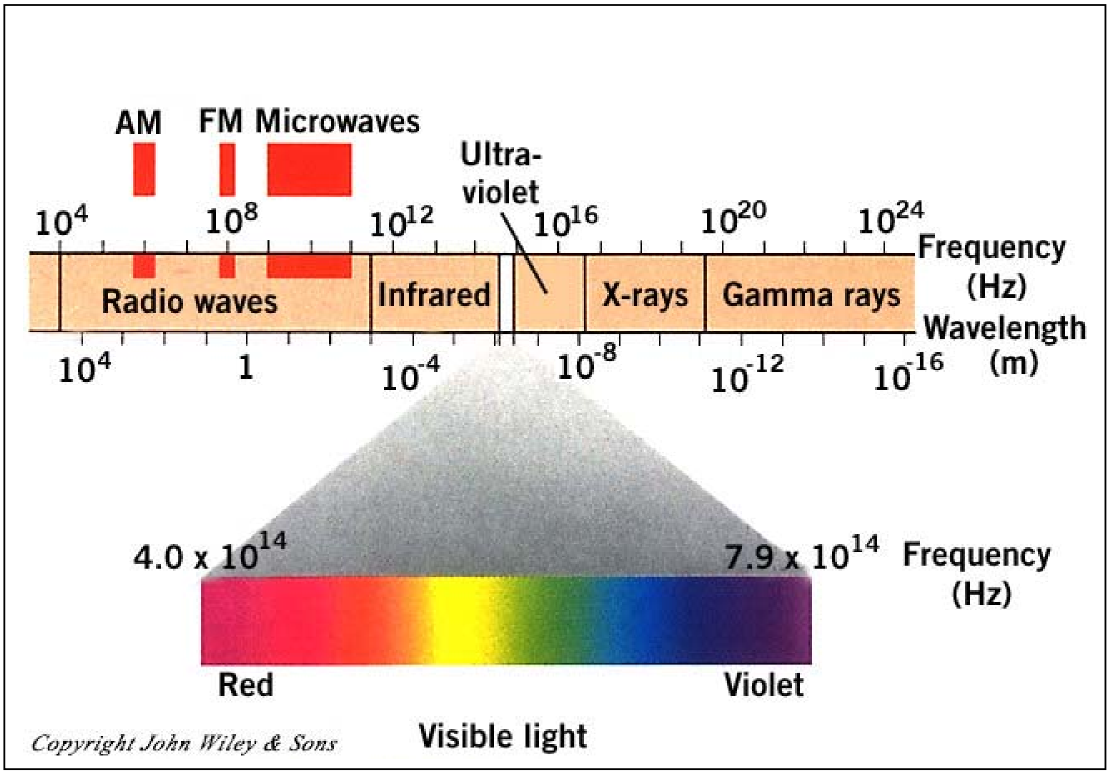
$$c = f\lambda$$

For light, the speed is

$$c \approx 3\times10^{8} m/s$$

The speed of light decreases in transparent media. This causes light to bend when going through glass and water.

Visible light

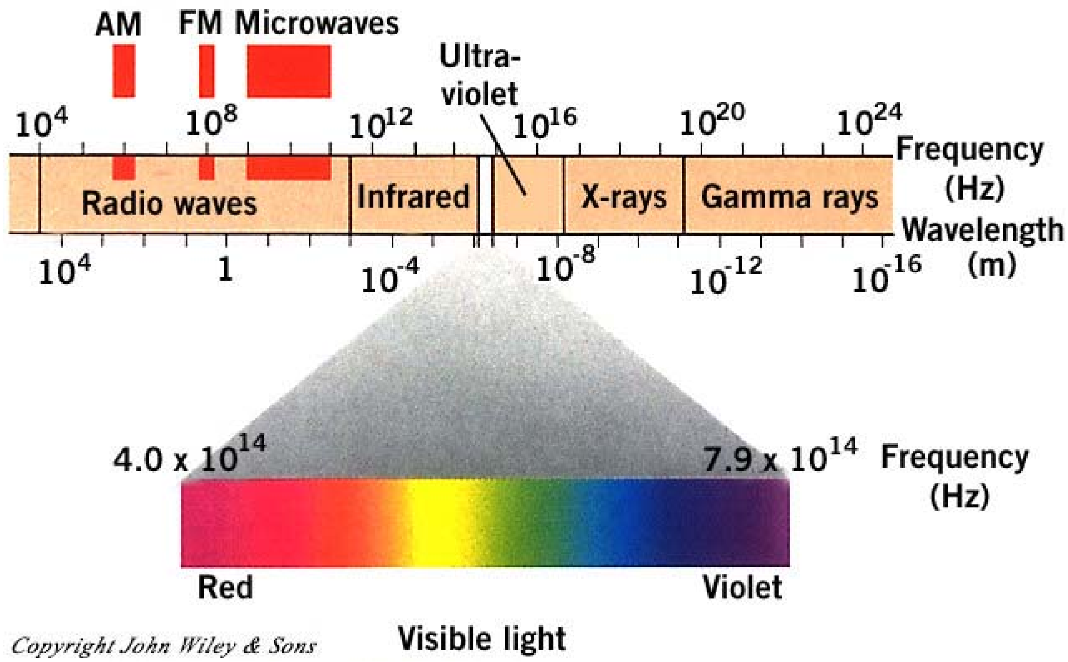


Visible light consists of a very short wavelength EM radiation with wavelengths ranging between 760×10^{-9} and 380×10^{-9} m.

One of the properties of waves is that it can bend around obstructions (called diffraction). The ability to bend depends on the relative size of the wavelength and obstruction. Only if the wavelength is comparable to the obstruction does diffraction become noticeable.

Diffraction is only noticeable for visible light when the obstruction is smaller than 1000×10^{-9} m.

The colours of the visible spectrum

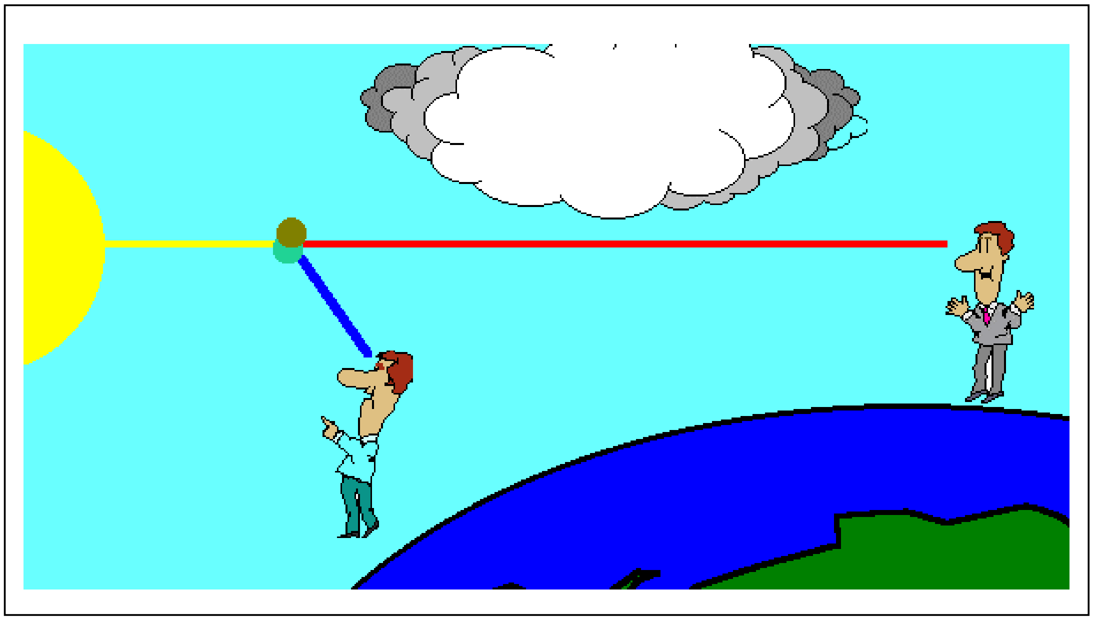


Isaac Newton was the first to demonstrate that visible light consisted of a blend of different colours. He identified 7 colours which are now understood to correspond to light of different wave lengths. In units of nanometer (1.0 nm = 1.0×10^{-9} m).

Colour	Wavelength (nm)
Violet	380-410
Indigo	410-450
Blue	450-510
Green	510-560
Yellow	560-600
Orange	600-630
Red	630-760

Why is the sky blue?

The white light from the sun is a mixture of all colours. A clear day-time sky is blue because molecules in the air scatter blue light from the sun more than they scatter red light.



Why are sunsets red?

When we look towards the sun at sunset, we see red and orange colours because the blue light has been scattered out and away from the line of sight.

Photometry (Units and Concepts)

The physically measurable quantities used in specifying lighting standards and codes of practice form the basis of photometry. This gives a quantitative measure of what is meant by bright or dim light.

Photometry is concerned with that part of EM radiation that is perceived by the human eye as light.

There are 4 fundamental quantities.

Concept	Usual Symbol	Unit	Abbreviation
Luminous Intensity	I	candela	cd
Luminous Flux	F, Φ	lumen	lm
Illuminance	E	lux	lx
Luminance	L	candela/m^2	nit = cd/m^2

Luminous Intensity (I in cd)

Luminous intensity is used to describe the amount of light emitted from a light source. It describes the ability of an object to emit light.

Originally, the basic unit of light was the candela, derived from the light emitted from 1 candle.

Formally, from National Institute of Standards and Technology (Washington)

> **The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.**

Source	Intensity
Candle	1.0 cd
100 Watt Incandescent bulb	150
Automobile headlamp (high beam)	100,000
Lighthouse	300,000
Flashtube (at peak)	1,000,000

Note, the luminous intensity can depend on the direction at which the source is viewed.

Luminous Flux (F in lm)

Luminous flux measures the intensity of light as it is emitted. It is a measure of the flow (or flux) of a light emitted through a given angular spread.

The luminous flux from a light source is equal to the intensity in candela multiplied by the solid angle over which the light is emitted, taking account of the varying intensity in different directions.

If the light is not being absorbed, then the luminous flux from a point source of light is the same at different distances from the source.

The International System unit of luminous flux, is equal to the light emitted in a unit solid angle by a uniform point source of one candela.

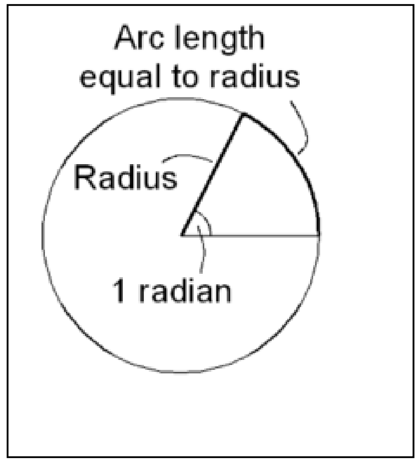
Solid angle and steradian definition

The steradian is the unit of 2-D angle just like the radian gives a measure of a 1-D angle.

The circumference of a circle is $2\pi r$ where r is the radius.

There are 2π radians in a circle.

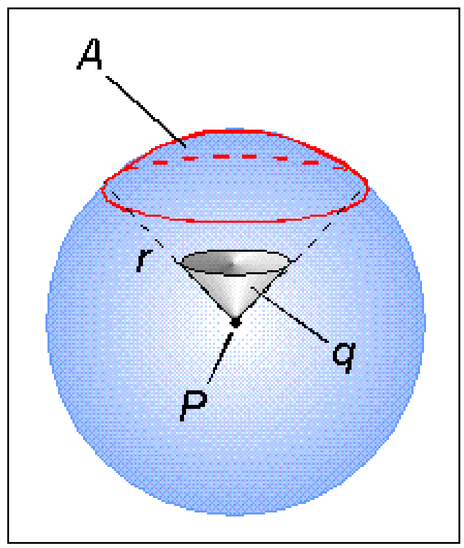
The distance of an arc subtending an angle of θ is θr.



The surface area of a sphere is $4\pi r^2$ where r is the radius.

The total solid angle of a sphere is 4π steradian. This is 12.566 steradian.

So 1 steradian corresponds to about 7.96% of the area of a sphere.



The solid angle of a hemi-sphere (i.e. half a sphere) is 2π.

Luminous Flux (F in lm) (continued)

The luminous flux emitted by a candle with a luminous intensity of 1.2 cd is

$F = 4\pi\ 1.2 = 15.1$ lm.

Source	Luminous Flux (lm)
Candle	12 cd
100 Watt incandescent bulb	1,800
40 W fluorescent lamp	28,000

Example: Suppose a light source of intensity 60 cd only emits light in one hemisphere. What is the luminous flux coming out from the source?

In this case, one multiples 60 by 2π since the source only emits light through a solid angle of 2π.

Illuminance (E in = lux = lm^2/m)

This gives a measure of the illumination of a surface and is derived from the luminous flux. If a surface of area *A* receives a flux of *F* lumens, then the average illuminance is the luminous flux per square metre.

$$E = \frac{F}{A}$$

This assumes the surface is oriented perpendicular to the light source. If the surface is not perpendicular one must include an angle dependent factor.

Note, illuminance is the product while illumination is the process.

This is a measure of the amount of visible light striking a surface.

Object/Source	Illuminance (lux)
Sunny day (outdoors)	100,000
Cloudy day	2,000
Well lit desk	500
Public area in buildings	300
Moonlight	0.20
Starlight	0.0020

Illuminance (E in = lux = lm^2/m)

Example: Suppose an inspection shop is 20 m long and 10 m wide. According to regulations the illuminance on the floor has to be 450 lux. What is the absolute minimum luminous flux required at the work place?

- The surface area is $20\times10 = 200$ m^2.

- With a regulated illuminance of 450 lux, each square meter of the surface must receive a flux of 450 lm.

- So the total luminous flux must be $450\times200 =$ 90,000 lm.

This is a very simple sample calculation of the kind you will be expected to do. What is involved in a lighting design is the need to go from lux $\rightarrow$ lumen.

Luminance (L in = cd^2/m = 1 nit)

This is a measure of the brightness of a surface when it is looked at from a *specific direction*.

$$\text{Luminance} = \frac{\text{Luminous intensity (cd) in some direction}}{\text{Projected area (m}^2\text{) of object as viewed}}$$

An object that is small and emits 1.0 cd of light will appear brighter than an object than a big object emitting 1.0 cd of light. The luminance can refer to self-luminous objects (light-bulbs) or objects that reflect light.

If a 100 candela source is enclosed in spherical opaque diffuser of radius 0.050 m, its luminance is

$$L = \frac{100}{\pi(0.050^2)} = \frac{100.0}{0.00786} = 12{,}700 nit$$

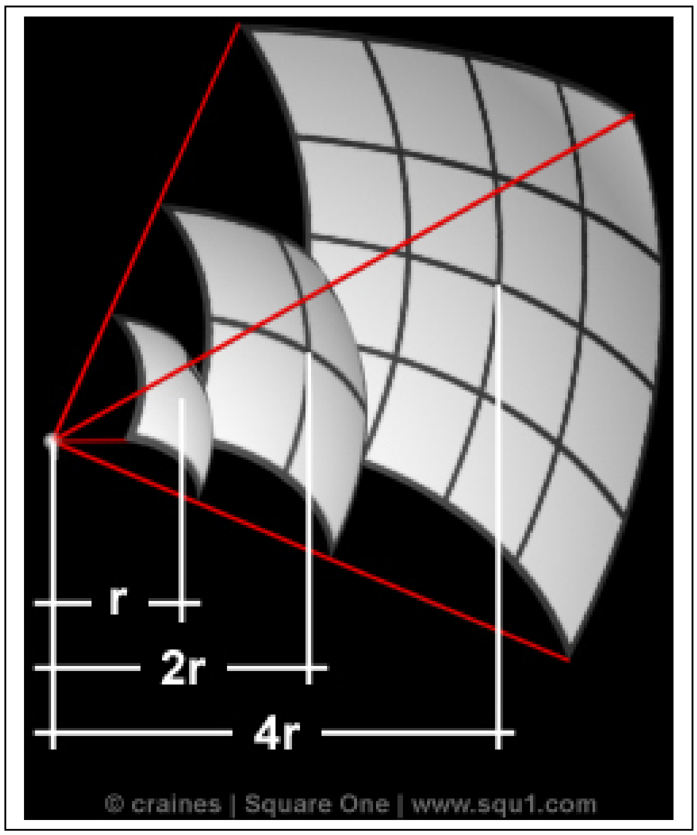
(Note the surface area of the diffuser as viewed in a given direction is the area of a circle, i.e. πr^2)

Object	Luminance (nit)
Sun	1650,000,000
Filament in clear incandescent bulb	7,000,000
Fluorescent lamp (surface)	8000
Full moon	2500
Computer Screen	100
White paper with 400 lux illuminance	100
Grey paper with 400 lux illuminance	50

Transmission of light: The inverse square law

When light travels through clean air, it is not absorbed. So if light is emitted from a small source (light bulb) the total amount of light does not change as we get further from the source.

But, … the area it has to illuminate gets larger



One can write

$$E = \text{Luminance} = \frac{\text{Luminous intensity}}{(\text{distance})^2} = \frac{I}{d^2}$$

Transmission of light: The inverse square law

Example. What is the illuminance at distances of 2.0 m and 4.0 m from a light bulb of intensity 120 cd?

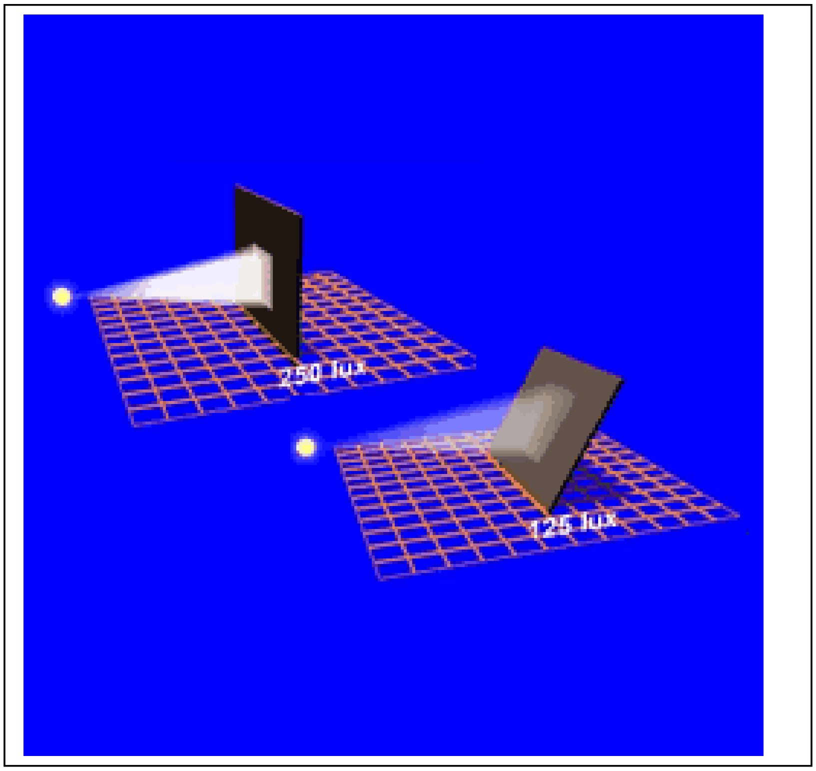
$$E = \frac{120}{2.0^2} = 30.0 lux$$

$$E = \frac{120}{4^2} = 7.5 lux$$

At twice the distance the illuminance is 4 times smaller.

Transmission of light: The cosine rule

A surface that is at an oblique angle is illuminated by the same amount of light as when it is orientated perpendicular to the light source.



But, the light is falling over a large area so the illuminance is less.

The Nth pole and Sth pole are cold and the equatorial regions are warm because the sun strikes the poles at an oblique and while shining directly overhead in the tropics.

(Question: there are two defects with diagram on this page, what are they?)

Transmission of light: The cosine rule

For light shining on a surface at an incident angle of β we can write

$$E = E_n \cos(\beta)$$

where E_n would be the illuminance if the light was shining directly on a perpendicular surface and E is the illuminance for light at the incident angle.

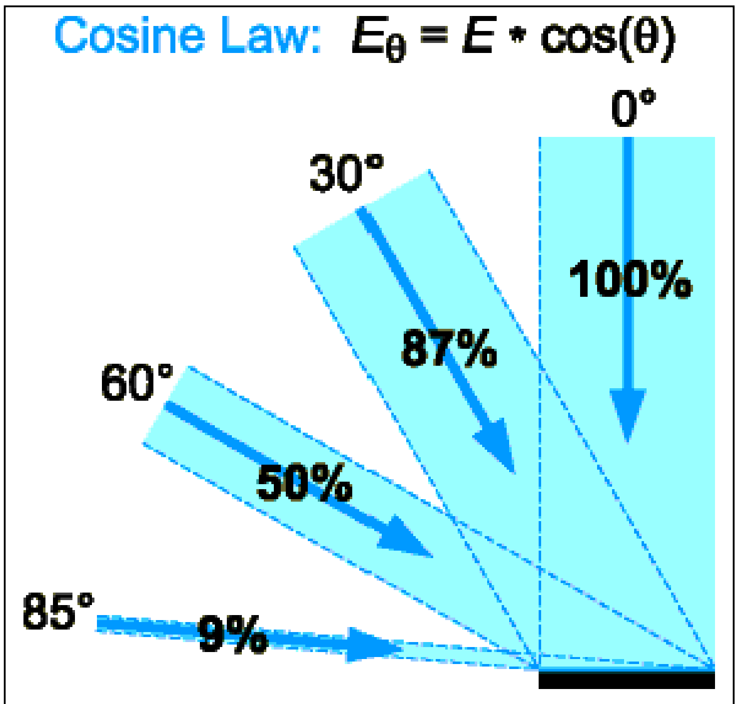


Fig. 6.3 Lambert's cosine law.

Note, the incident angle is the angle between the light direction and a line perpendicular to the surface.

Example. The illuminance on a book you are reading is 600.0 lux when directly under the light source. What would the illuminance be if you moved a distance to another chair such that light was now striking the book at an angle of 30^o?

$E = 600 \cos(30^o) = 600.0 \times 0.866 = 520$ lux.

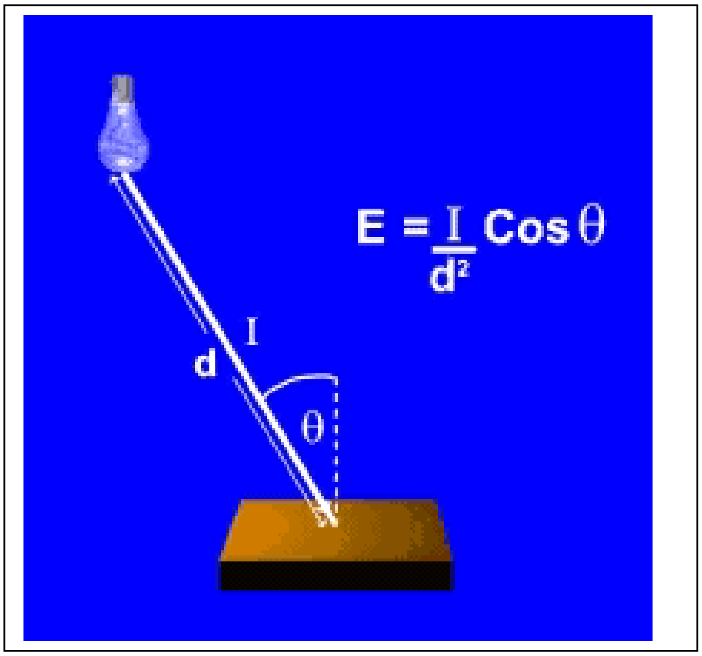
Example. You are in a spotlight beam and the intensity is 8,000 cd. The spot-light has a surface area of 0.10 m^2. What is the Luminance of the spot light surface?

The luminous intensity of the spot light surface is

$8000/0.10 = 80{,}000$ cd/m^2.

Combined inverse square and cosine rules

It is possible to combine the inverse square law and the cosine rule together



$$E = \frac{I\cos(\beta)}{d^2}$$

Example. A 50.0 cd light source shines on picture 3.6 m away and the picture is orientated at an angle of 20^o. What is the illuminance?

E = 600 cos(30^o) = 600.0×0.866 = 520 lux.

Reflection of light from surfaces

When light fall on a surface,

- some is reflected. The property describing the reflection is the reflectance (ρ)
- some is absorbed. The property describing the absorption is the absorbance (ρ)
- some is transmitted. The property describing the transmission the transmittance (τ)

These are fractions and must add up to 1.0

$$\alpha + \rho + \tau = 1$$

The numerical values of these properties can be different for light of different wavelengths.

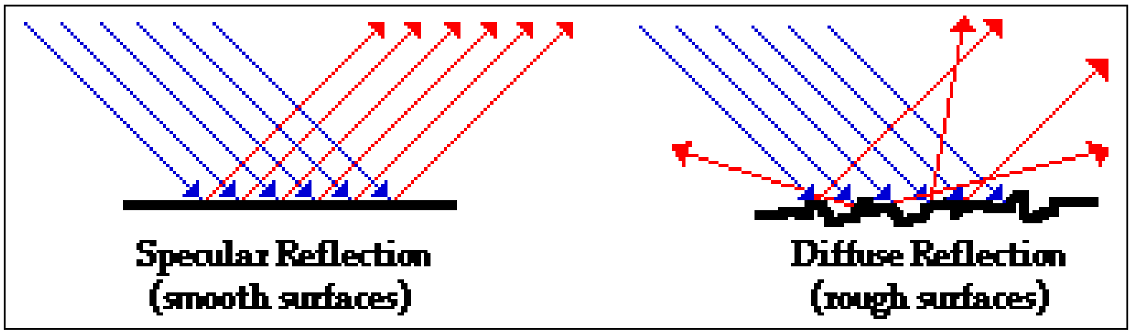
Materials are sometimes characterised as transparent, translucent or opaque.

- Transparent materials (e.g. glass) allow light to pass freely through without distortion. There is always some reflection from a transparent material.
- A translucent material will allow light to pass through but distortion will be present. An example is frosted glass or amber, or diffuser for fluorescent tube.
- An opaque material completely stops light from passing through it. An example would be a piece of wood.

Reflection of light from surfaces

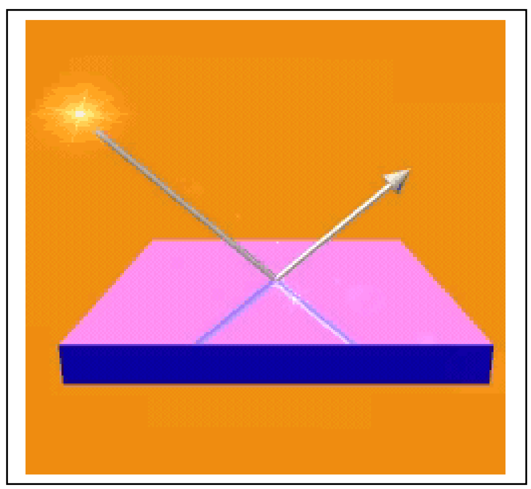
There are two basic modes of reflection from a surface. These are

- *specular* (or direct) reflection
- *diffuse* reflection.



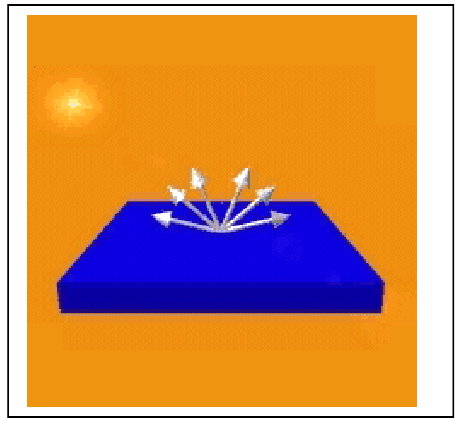
In diffuse reflection the surface does not appear to be smooth. What can happen is that light can be reflected in all directions (some times this is called scattering).

Specular reflection occurs when light reflects from a mirror. A narrow beam of light is reflected as a narrow beam of light. About 80% of the light is reflected depending on the surface.

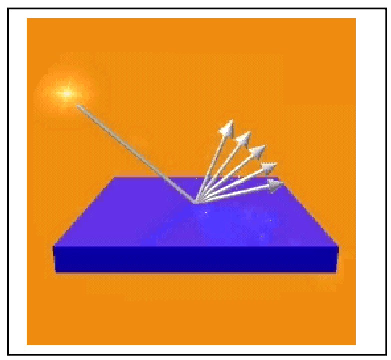


Diffuse reflection of light from surfaces

In uniform diffuse reflection it is assumed that light is reflected uniformly in all directions regardless of the direction of the incoming light.

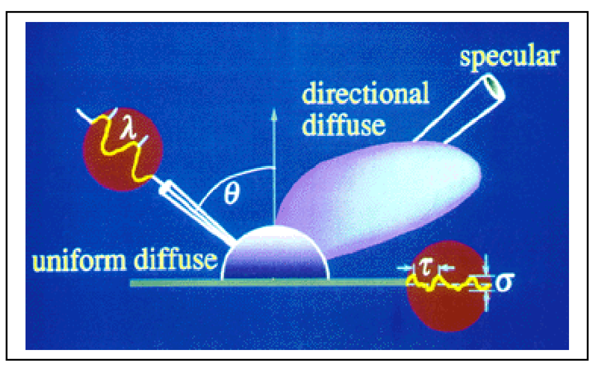


In spread reflection, the light reflects in a specific direction as in specular reflection but there is some diffuse reflection strongest towards the reflected direction. An example of this is gloss paint.



In semi-diffuse reflection, the reflection is diffuse with a directional bias. Semi-diffuse and spread reflections pretty much the same thing.

All reflections consist of spread or semi-diffuse reflections to some degree.



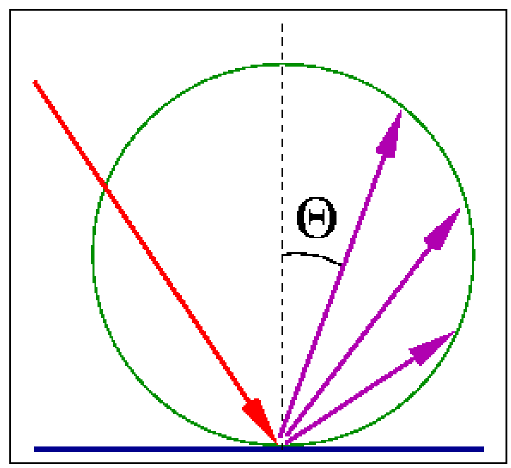
Uniform diffuse reflection.

Ideal diffuse reflectors are sometimes call Lambertian reflectors

The luminance of the surface is going to be the same irrespective of the direction of the surface.

The distribution of luminous intensity follows a cosine rule.   This is sometimes called Lamberts Law (there are some other Lamberts laws).

$$L_\theta = L_n \cos(\theta)$$



L_n is the intensity in the perpendicular (normal) direction to the surface.

This cosine rule occurs for similar reasons as the earlier cosine rule, in effect the area of the surface view from an oblique angle seems to be smaller.

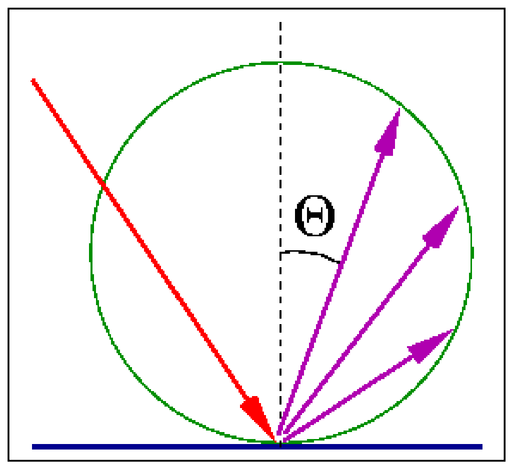
The Apostlib (asb)

Determining the luminance of reflected light coming from a surface is complicated by the different intensities that come from the surface in different directions.

Suppose you are looking at an illuminated surface (assuming uniform diffuse reflection) with an area A = 1.0 m, and the intensity of the reflected light looking when directly down at the surface is I = 1.0 cd.

Then the luminance of the surface will be

$L = I/A = 1.0/1.0 = 1.0$ cd/m^2.



It can be shown by mathematical analysis that the total luminous lux emitted from the surface is π lumens.

A 1.0 m^2 surface that has a perpendicular luminance of 1.0 cd/m^2 is said to have a luminance of π *apostilbs* (abs). So by definition 1 apostlib = (1/π) cd/m^2.

The *apostlib* is a unit of luminance based on luminous flux while the nit = cd/m^2 unit is an intensity based unit of luminance.

Why the Apostlib (asb)?

Suppose a perfect diffuse reflecting surface of area *A* is uniformly illuminated with 20 lux.

Then the luminance of the surface is just 20 asb.

And the luminous flux emitted from the surface is 20 lumen.

Using the *asb* makes it easy to determine how much light is emitted from a surface if its illuminance is known.

The luminance factor

The luminance factor for a surface is the ratio of the luminance when lit in a certain way and looked at in a certain direction to the luminance of a perfectly reflecting and uniformly diffusing surface when lit and looked at in the same way.

$$LFactor = \frac{\text{Luminance of surface}}{\text{Luminance of uniform diffuse surface}}$$

So, since the illuminance of a uniform diffuse surface in asb is equal to the illumination in lux one can also write

$$LFactor = \frac{\text{Luminance of surface (in asb)}}{\text{Illumination in lux}}$$

Reflectance

The reflectance measures the amount of light reflected from a surface. It can be given as a number, 0.80 or as a percentage 80%.

$$\rho = \text{Reflectance} = \frac{\text{Luminous flux reflected (all directions)}}{\text{Total luminous flux hitting surface}}$$

The reflectance cannot be greater than 100%.

Transmittance

The transmittance gives an estimate of the amount of light that passes through a transparent or translucent material without being absorbed or reflected.

$$\text{Transmittance} = \frac{\text{Luminous flux leaving (all directions)}}{\text{Total luminous flux hitting surface}}$$

It can be given as a number, 0.70 or as a percentage 70%.