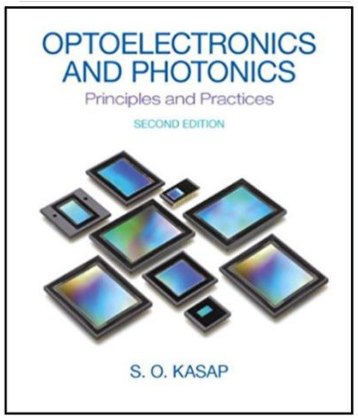
Optoelectronics-I

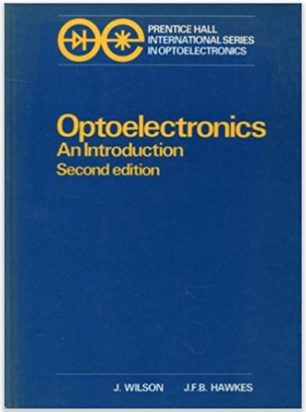
Chapter-13

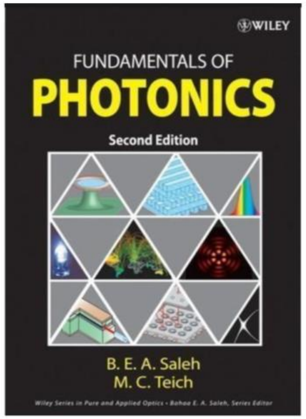
Assoc. Prof. Dr. Isa NAVRUZ

Lecture Notes - 2018

Recommended books







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Radiometry and Photometry

Objectives

When you finish this lesson you will be able to:

- ✓ Describe the Radiometry and Photometry
- ✓ Define radiant energy and power
- ✓ Define irradiance and intensity
- ✓ Explain the solid angle
- ✓ Explain photometric units, lumen, lux and candela
- ✓ Define luminous flux, illuminance and luminous intensity
- ✓ Explain laws in Photometry

Radiometry

Radiometry is the measurement of the energy content of electromagnetic radiation fields and the determination of how this energy is transferred from a source , through a medium, and to a detector.

In the radiometric measurements, the power are usually obtained in watt unit.

For a steadily emitting source, the radiometric measurement usually implies measurement of the power of the source.

Radiant Energy (Q) is the energy emitted , transferred , or received in the form of electromagnetic radiation. The unit of radiant enerrgy is the Joule (J).

Radiant Power (P) or radiant flux is the power (energy per unit time t) emitted , transferred , or received in the form of electromagnetic radiation. Unit: Watt (W)

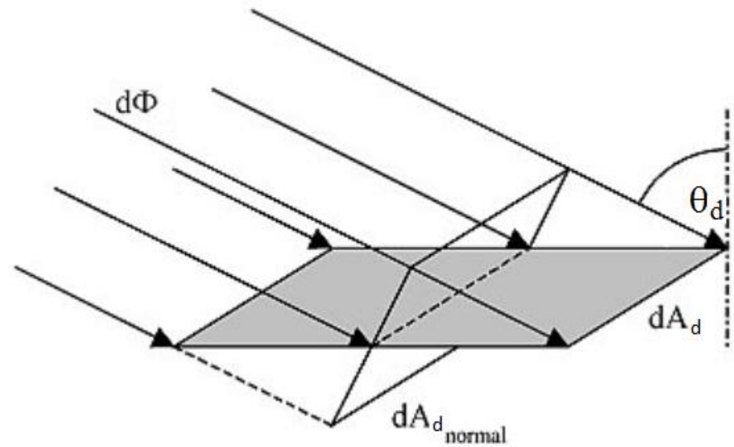
$$\Phi = \frac{dQ}{dt}$$

Radiometry

Irradiance (E) is the ratio of the radiant power incident on an infinitesimal element of a surface to the projected area of that element , dA_d

Unit : W/m^2)

$$E = \frac{d\Phi}{\cos\theta_d \, dA_d}$$

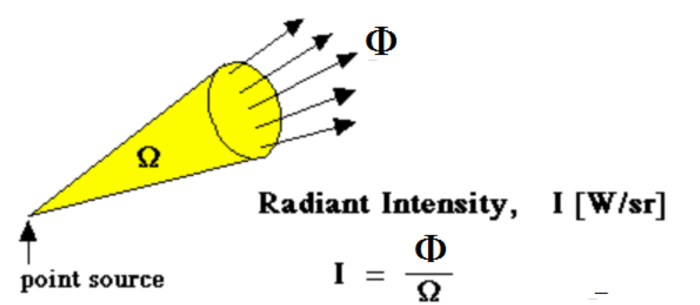


θ_d is the angle between the normal of the surface and direction of the radiation.

Intensity (I) Radiant intensity (often simply ‘‘intensity’’) is the ratio of the radiant power leaving a source to an element of solid angle $d\Omega$ propagated in the given direction.

Unit : watt/steradian (W/sr)

$$I = \frac{d\Phi}{d\Omega}$$



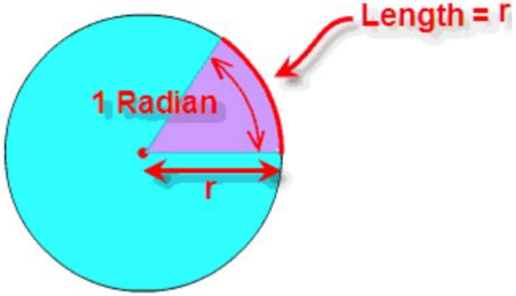
Note that in the physical optics , the word *intensity* refers to the magnitude of the Poynting vector and thus more closely corresponds to irradiance in radiometric nomenclature .

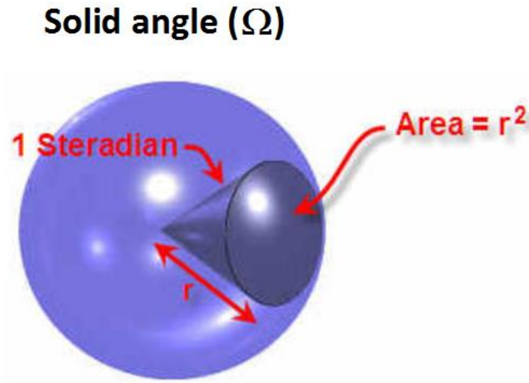
Radiometry

Solid Angle is the ratio of a portion of the area on the surface of a sphere to the square of the radius *r* of the sphere .

Unit : steradian (sr)

$$d\Omega = \frac{dA}{r^2}$$



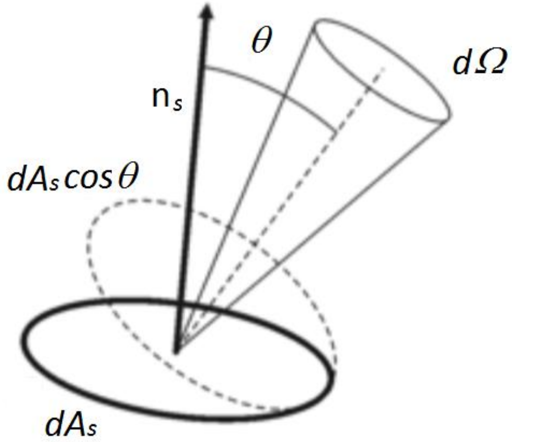


The angle of circle $= \frac{2\pi r}{r} = 2\pi \text{ rad}$

The solid angle of sphere $= \frac{4\pi r^2}{r^2} = 4\pi \text{ sr}$

Radiance (L) is the ratio of the radiant power at an angle θ to the normal of the surface element , to the infinitesimal elements of both projected area and solid angle. *Unit:* W /sr m^2

$$L = \frac{d^2\Phi}{\cos\theta \, dA_s \, d\Omega}$$



Radiometry

Polychromatic Radiation

The spectral distribution of radiant power is denoted as either radiant power per wavelength interval or radiant power per frequency interval.

Φ_λ *Unit* : watt/nanometer (W/nm)
or
$\Phi\nu$ *Unit* : watt/hertz (W/Hz)

The total radiant power over the entire spectrum is

$$\Phi = \int_0^\infty \Phi_\lambda \, d\lambda$$

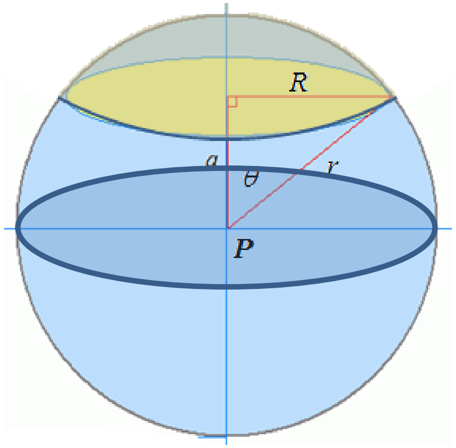
or

$$\Phi = \int_0^\infty \Phi_\nu \, d\nu$$

$$\nu = c/n\lambda \Rightarrow d\nu = \frac{c}{n\lambda^2} d\lambda$$

Radiometry

Example: Consider a point P on a line normal to the center of a disk. The point is a distance a from the center of the disk, which has a radius R.



(a) Show that the solid angle subtended by the disk at the point is

$$\Omega = 2\pi a\left[\frac{1}{a} - \frac{1}{\sqrt{a^2 + R^2}}\right].$$

(b) Show that, when the point P is very far from the disk, the solid angle reduces to zero.

(c) Show that, when P is very close to the disk, the solid angle becomes 2π.

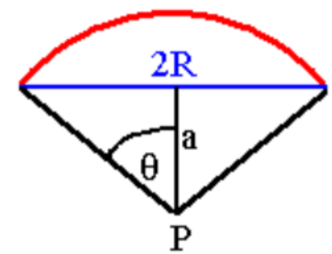
Radiometry

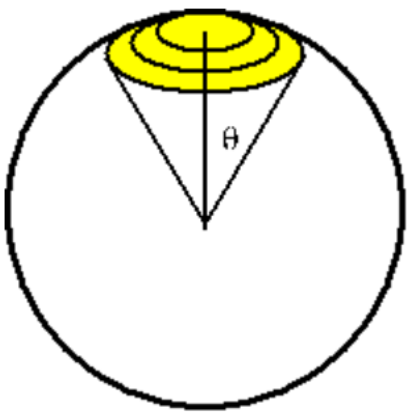
Solution:

(a) Consider some surface S enclosing a point P. Now imagine a small cone, which intersects an infinitesimal area, dA, on S.

By definition, the solid angle is

$$d\Omega = \frac{dA}{r^2}$$





$$A = \pi R^2$$

$$\left.\begin{array}{l} dA = 2\pi R\, dR \\ R = r \cdot \sin\theta \end{array}\right\} \Rightarrow dA = 2\pi r \sin\theta \cdot r\, d\theta$$

$$dR = r \cdot \underbrace{\cos\theta}_{1}\, d\theta$$

$$dR = r \cdot d\theta$$

$$\Omega = \frac{1}{r^2} \int dA$$

$$\Omega = \frac{1}{r^2} \int_0^{\theta} 2\pi r^2 \sin\theta\, d\theta$$

$$\boxed{\Omega = 2\pi \left(1 - \cos\theta\right)}$$

$$\cos\theta = \frac{a}{\sqrt{a^2 + R^2}}$$

$$\Omega = 2\pi \left(1 - \frac{a}{\sqrt{a^2+R^2}}\right) = 2\pi a \left(\frac{1}{a} - \frac{1}{\sqrt{a^2+R^2}}\right)$$

Radiometry

Solution:

(b) If a goes to infinity, then $a/(a^2+R^2)^{1/2}$ goes to 1.
So $\Omega = 2\pi(1-1) = 0$

(c) If P is very close to the disk, then a is very small compared to R. So, $a/(a^2+R^2)^{1/2}$ can be neglected. We can say that $\Omega = 2\pi$ and surface area equals to half of the sphere.

Photometry

The geometrical principles defined for radiometry are the same for photometry. However, the spectral sensitivity of the detector is defined specifically by considering the human eye.

Photometric quantities are related to radiometric quantities via the spectral efficiency functions defined for CIE Standard Observer (Standard Color Matching Functions).

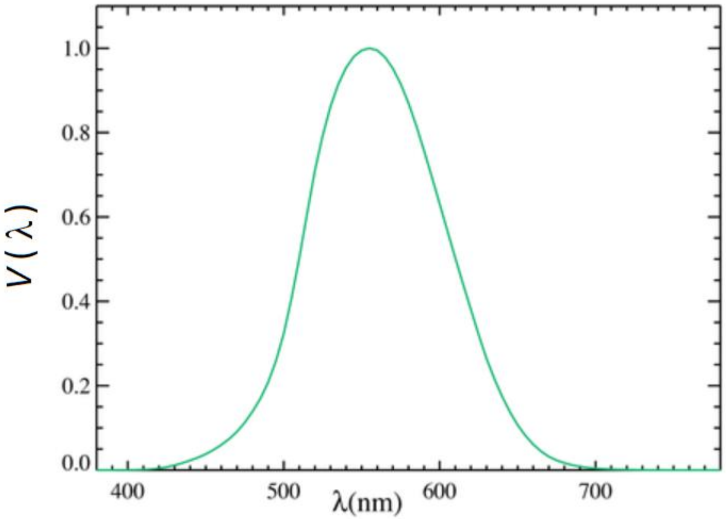
Luminous Flux

The photometric luminous flux is equivalent of radiant power. The unit is the lumen that is equivalent to the watt. Luminous flux is spectral radiant flux weighted by the appropriate eye response function.

Symbol: Φ_v, *Unit*: lumen (lm)

$$\Phi_v = K_m \int \Phi_\lambda V(\lambda)\, d\lambda$$

Here K_m is a constant, and $V(\lambda)$ a function representing the wavelength- dependent sensitivity of the eye.



Photometry

Illuminance*:* Illuminance is the photometric equivalent of irradiance; that is , illuminance is the luminous flux per unit area.

Symbol: E_v *Unit*: lumen/meter^2 (lm/m^2) or Lux (Lx)

$$E_v = \frac{d\Phi_v}{\cos\theta_d \, dA_d} = \frac{d\left[K_m \int \Phi_\lambda V(\lambda)\, d\lambda\right]}{\cos\theta_d \, dA_d}$$

Luminous Intensity Luminous intensity is the photometric equivalent of radiant intensity. Luminous intensity is the luminous flux per solid angle.

Symbol: I_v *Unit*: candela or lumen/steradian (cd or lm/sr)

$$I_v = \frac{d\varphi_v}{d\Omega} = \frac{d\left[K_m \int \Phi_\lambda V(\lambda)\, d\lambda\right]}{d\Omega}$$

Photometry

Luminance: Luminance is the photometric equivalent of radiance . Luminance is the luminous flux per unit area per unit solid angle .

Symbol: L_v *Unit*: candela/meter^2 (cd/m^2)

$$L_v = \frac{d\Phi_v}{\cos\theta_s \, dA_s \, d\Omega} = \frac{d\left[K_m \int \Phi_\lambda V(\lambda)\, d\lambda\right]}{\cos\theta_s \, dA_s \, d\Omega}$$

Radiometric Quantity	Unit	Photometric Quantity	Unit	Relationship with the lumen
Radiant Flux	W (watt)	Luminous Flux	lm (lumen)	lm
Radiant Intensity	W/sr	Luminous Intensity	cd (candela)	lm/sr
Irradiance	W/m^2	Illuminance	lx (lux)	lm/m^2
Radiance	W/sr/m^2	Luminance	cd/m^2	lm/sr/m^2

Photometry

Examples	
Illuminance	**Surfaces illuminated by:**
0.0001 lux	Moonless, overcast night sky
0.002 lux	Moonless clear night sky
0.27–1.0 lux	Full moon on a clear night
50 lux	Family living room lights
80 lux	Office building hallway/toilet lighting[7][8]
100 lux	Very dark overcast day
320–500 lux	Office lighting
400 lux	Sunrise or sunset on a clear day.
1000 lux	Overcast day; typical TV studio lighting
10 000–25 000 lux	Full daylight (not direct sun)
32 000–100 000 lux	Direct sunlight

Energy efficiency
(or luminous efficacy)

5-10 lm/W – Incandescent
10-20 lm/W - Halogen
45-70 lm/W - CFL
50-100 lm/W - fluorescent
80-150 lm/W – LED
80-120+ lm/W – HID

Incandescent CFL HID

Laws in Photometry

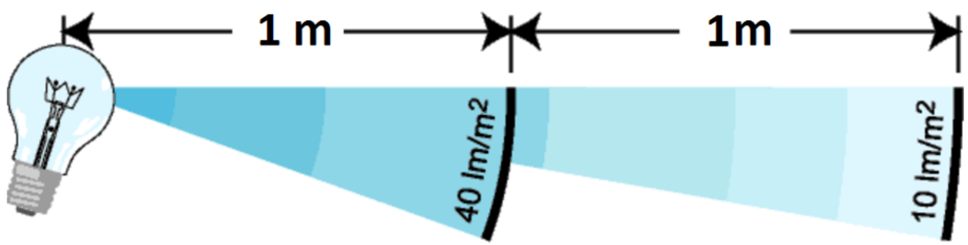
The Inverse Square Law:

The inverse square law defines the relationship between the illuminance from a point source and distance.

It states that the intensity of light per unit are inversely proportional to the square of the distance from the source.

$$E_v = \frac{I_v}{d^2}$$

Where E_v is the illuminance
I_v is the luminous intensity
d is the distance



Inverse square law

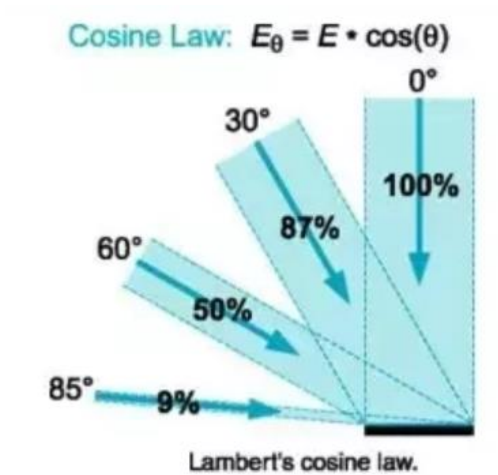
Exercise: Consider a lamp of 505 lumens. What are the illuminances of the lamp 1 meter and 4 meters away?

we can accept the lamp as a point light source

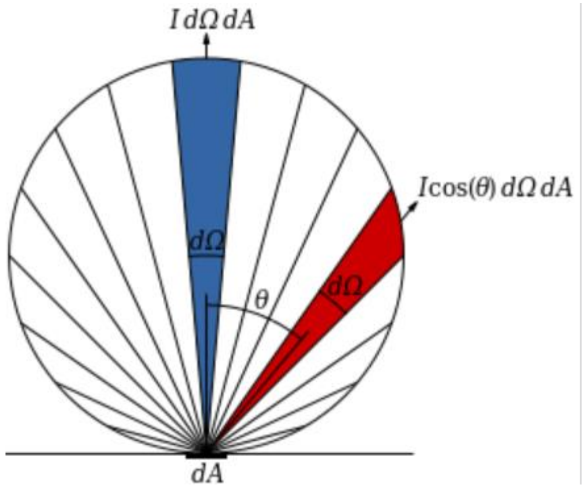
$I_v = 505/(4\pi) = 40.19\ Lm/sr \quad E_{v\,(r=1)} = I_v = 40.19\ Lx \quad and \quad E_{v\,(r=4)} = 40.19/16 = 2.512\ Lx$

Laws in Photometry

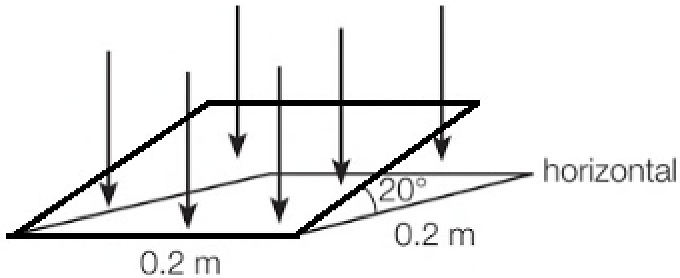
Lambert's cosine law
The radiant intensity or luminous intensity observed from an ideal diffusely reflecting surface or ideal diffuse radiator is directly proportional to the cosine of the angle θ between the direction of the incident light and the surface normal. This law is known as the **cosine emission law**



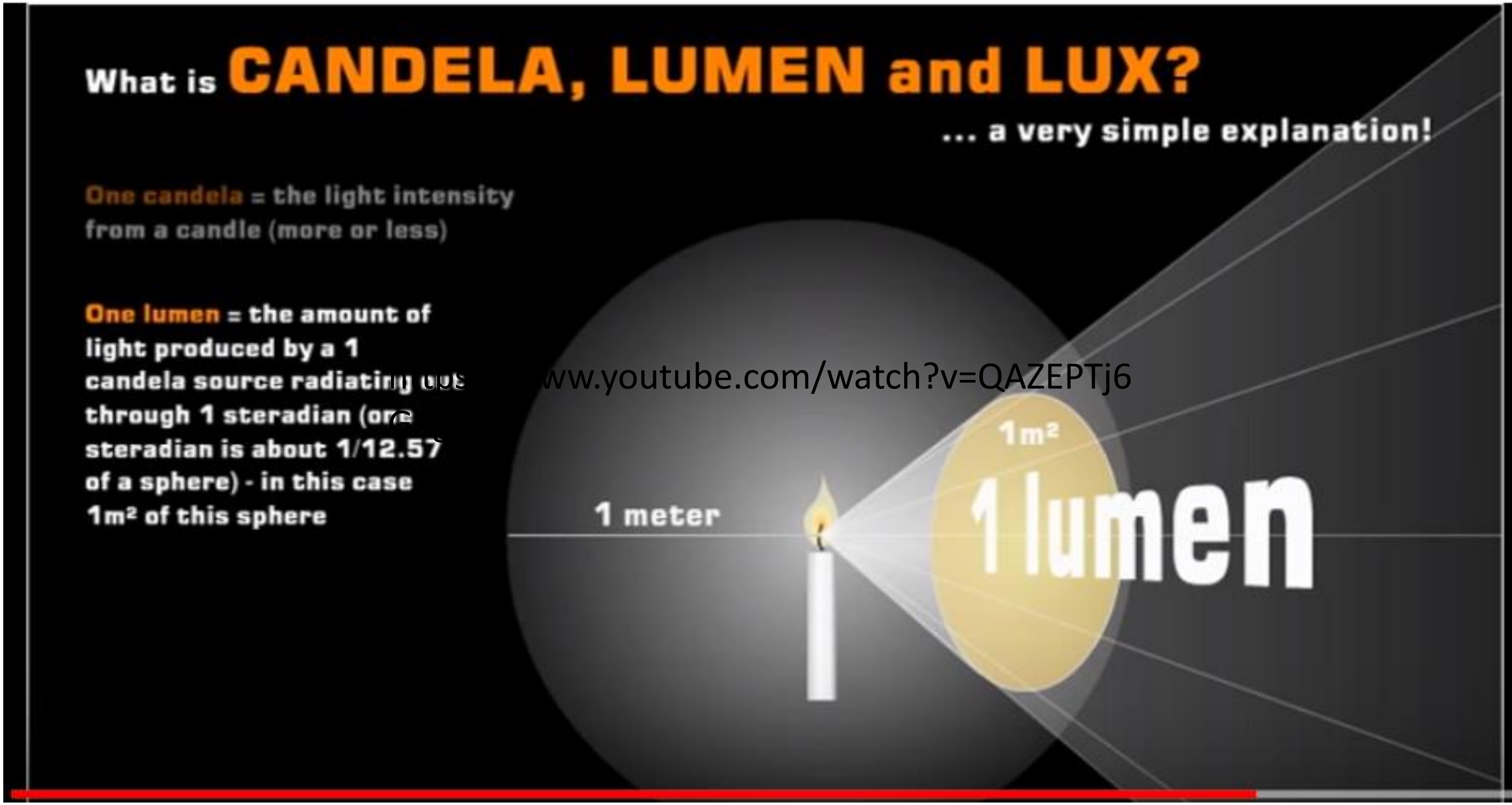
Lambert's cosine law.



Exercise: A beam of monochromatic green light with luminous flux ϕ=17 Lm falls vertically on a square sheet of paper of side 0.2m which is tilted 20°. Calculate the illuminance on the paper surface



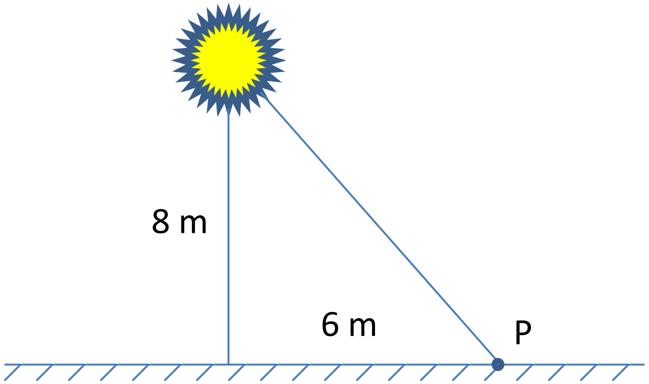
Lumen Lux Candela



https://www.youtube.com/watch?v=QAZEPTj6GXg

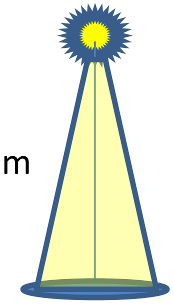
Lumen, Lux and Candela

Question: A lamp giving out 1200 Lm in all directions is suspended 8 m above the working plane. Calculate the illumination at the P point on the working plane 6 m away from the foot of the lamp.



Answer: 0.76 Lm/m^2

Question: A spotlight of 30 cd is located 3 m above a table. The beam is focused on a surface area of 0.4 m^2. Find the Luminous intensity of the beam.



$$\Phi = 4\pi I = 4\pi.30 = 377\ Lm$$

$$\Omega = \frac{0.4}{3^2} = 0.0444\ st$$

$$I_{surface} = \frac{377}{0.0444} = 8490\ cd$$