Teknik Optik

@btatmaja

Pokok Bahasan

1. Sumber cahaya: jenis-jenis cahaya (laser, led dll), pembangkitan cahaya, dan karakteristik cahaya
2. Kuantifikasi sumber cahaya: **radiometri dan fotometri**
3. Modifikasi karakteristik cahaya: modulasi, demodulasi, pemanduan cahaya (slab wave guide dan fiber optik), ekspansi, kolimasi, atenuasi dan modifikasi parameter gelombang cahaya (amplitudo, frekuensi, fasa dan polarisasi)
4. Pendeteksian informasi optis: tranduktansi sinyal optis → **Metrology**
5. Material optik: medium isotrop, anisotrop, aktifitas optik, **elektro optik** dan magneto optic + **Acousto optik**
6. **Pendekatan sistem linier dalam optik**
7. Berbagai metoda dalam teknik optik: fotografi, **holografi,** spektroskopi, **interferometri,** difraktometri, polarimetri, moire, komunikasi optik, optical remote sensing, **optical image processing**

Radiometry & Photometry

Radiometry is the measurement of optical radiation, which is electromagnetic radiation within the frequency range between 3×10^{11} and 3×10^{16} Hz.

Photometry is the measurement of light, which is defined as electromagnetic radiation that is detectable by the human eye (360 to 830 nm).

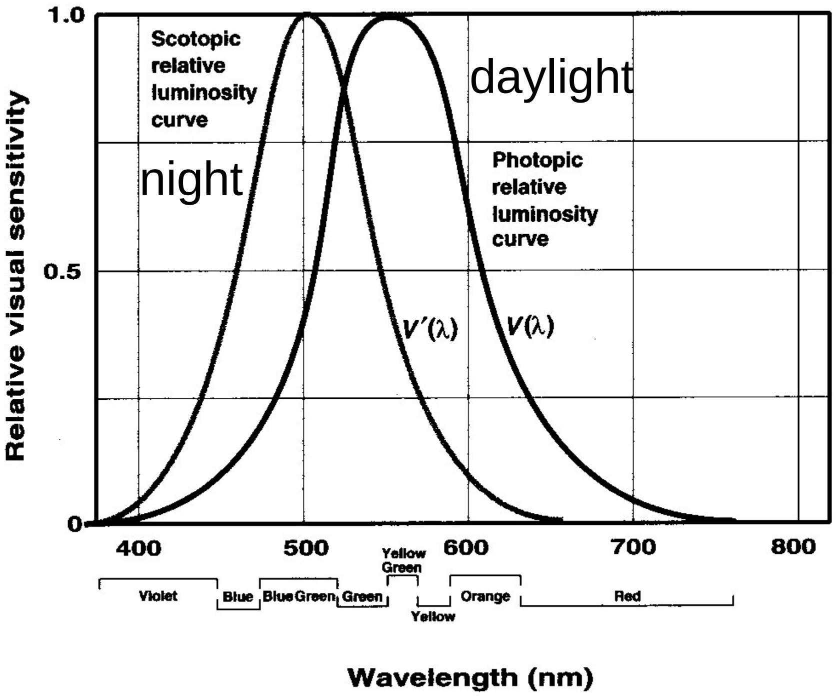
QUANTITY	RADIOMETRIC	PHOTOMETRIC
power	watt (W)	lumen (lm)
power per unit area	W/m^2	lm/m^2 = lux (lx)
power per unit solid angle	W/sr	lm/sr = candela (cd)
power per unit area per unit solid angle	W/m^2-sr	lm/m^2-sr = cd/m^2 = nit

Photometry=photo+metry=visible light + measurement

Visual Sensitivity:

The eye is not equally sensitive to the different colors of light in the visible spectrum.

Luminosity Curve:



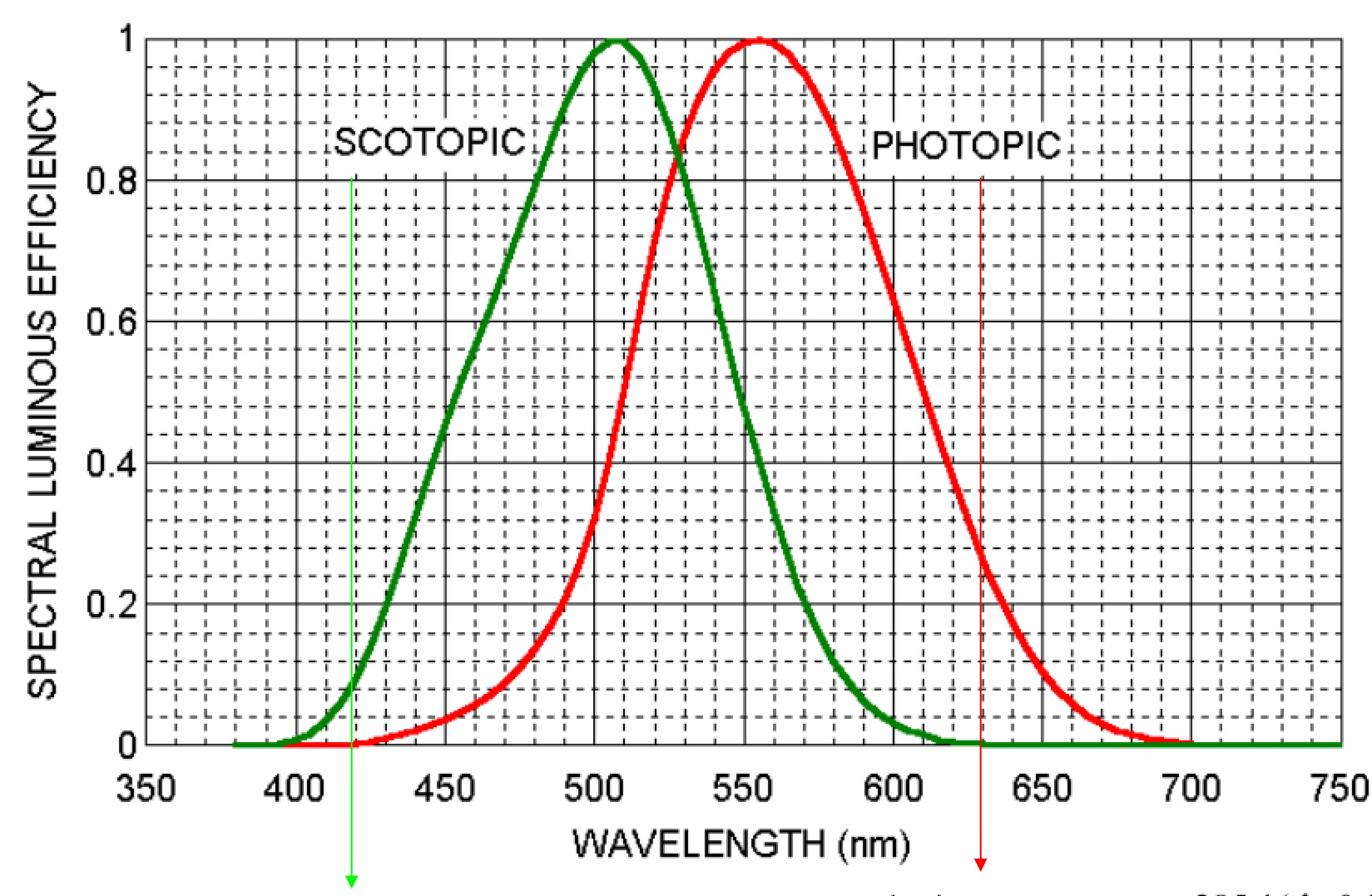
For the average light adapted eye at moderate intensities (*photopic vision*) the maximum visual effect is obtained with light of wavelength 55 5nm (yellow-green).

For average dark adapted eye, the maximum is around 500 nm.

Table 18.4 Luminous Efficiency Functions $V(\lambda)$ and $V'(\lambda)$ for Photopic and Scotopic Vision

Wavelength λ (nm)	Photopic $V(\lambda)$	Scotopic $V'(\lambda)$
380	0.00004	0.000589
390	0.00012	0.002209
400	0.0004	0.00929
410	0.0012	0.03484
420	0.0040	0.0966
430	0.0116	0.1998
440	0.023	0.3281
450	0.038	0.455
460	0.060	0.567
470	0.091	0.676
480	0.139	0.793
490	0.208	0.904
500	0.323	0.982
510	0.503	0.997
520	0.710	0.935
530	0.862	0.811
540	0.954	0.650
550	0.995	0.481

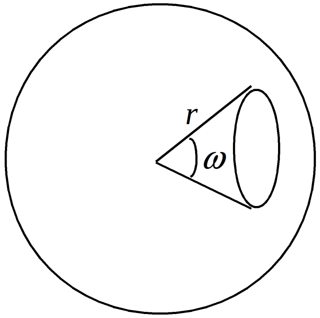
Another approach:



$$V'(\lambda) \cong 0.992 e^{-321.9(\lambda-0.503)^2}$$

$$V(\lambda) \cong 1.019 e^{-285.4(\lambda-0.559)^2}$$

Solid Angle:



$$solid\ \ angle\ \ \omega = \frac{area}{r^2}$$

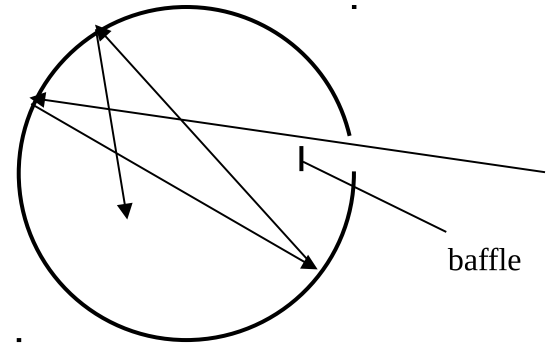
The total solid angle around a point is 4π (steradians).

Example:

Calculate the solid angle subtended at the center of a sphere, radius 2 m, by an area of 2.5 m^2 on the surface of the sphere.

$$\omega = \frac{area}{r^2} = \frac{2.5}{2^2} = 0.625\ \ \text{steradian}$$

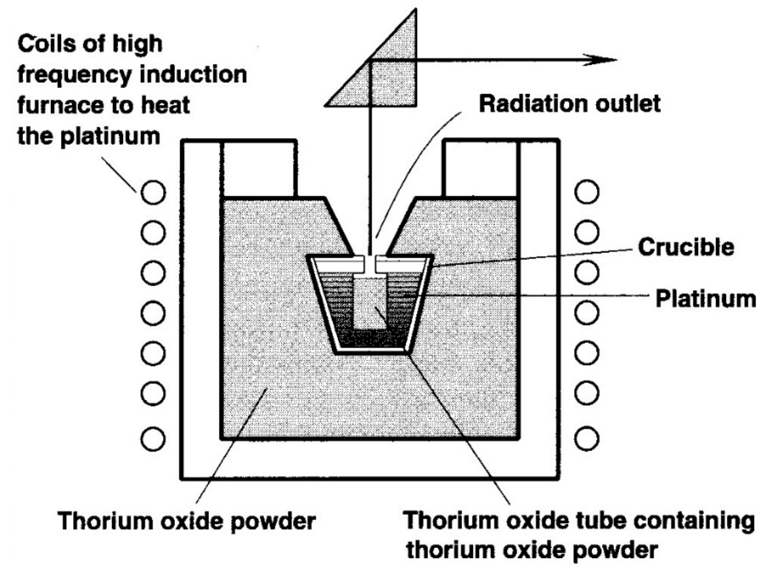
Standard Source and Candela:



A standard requires a constant luminous output for all the time.

The present primary standard source of light is based on the concept of a *black body radiator*. The radiation solely depends on its temperature and does change with time.

International black body standard



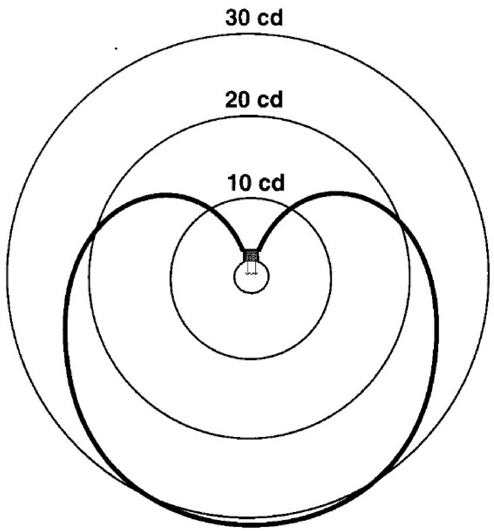
One candela is equal to one sixtieth (1/60) of the luminous intensity per square centimeter of a black body at the temperature of solidification of platinum (1773°C).

Electric lamps are used as everyday working standards for luminous intensity, and are sometimes called sub-standards. They are calibrated periodically with the primary standard in case there is any deterioration in their light output.

Luminous Flux and Intensity:

Luminous flux Φ: the rate at which light energy flows. Unit: lumen

One lumen is the luminous flux emitted into a unit solid angle (1 steradian) from a point source of intensity 1 candela. $\Phi = I\omega$



Luminous intensity of a source: $I = \dfrac{\Phi}{\omega}$

For a specified direction: $I = \dfrac{\mathbf{d\Phi}}{d\omega}$

$$\text{mean spherical intensity} = \frac{\Phi}{4\pi} \ \text{cd}$$

Example:

A source of light has a mean spherical intensity of 20 cd. How much total flux does it emit?

$$\Phi = I\omega = 4\pi \times 20 = 251.3 \ \text{lm}$$

Example:

A source has an intensity of 250 cd in a particular direction. How much flux is emitted per unit solid angle in that direction?

$$\Phi = I\omega = 250 \times 1 = 250 \ \text{lm}$$

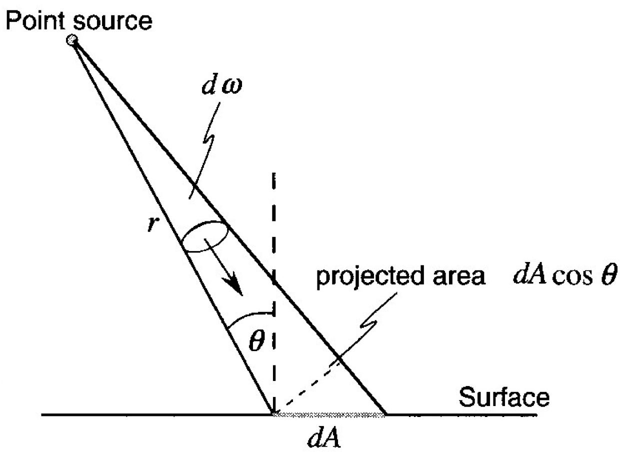
Illuminance:

$$E = \frac{\Phi}{A} \quad \frac{\text{lm}}{m^2} \qquad\qquad E = \frac{\mathbf{d\Phi}}{dA}$$

The illuminance at a point on a surface does not depend on the nature of the surface since it is only concerned with incident light.

$$d\Phi = I d\omega \qquad\qquad E = I\frac{d\omega}{dA}$$

$$d\omega = \frac{dA\cos\theta}{r^2} \qquad\qquad E = \frac{I}{r^2}\cos\theta$$



Two laws:

The illuminance at a point on a surface is inversely proportional to the square of the distance between the point and the source. This law applies strictly only in the case of point sources.

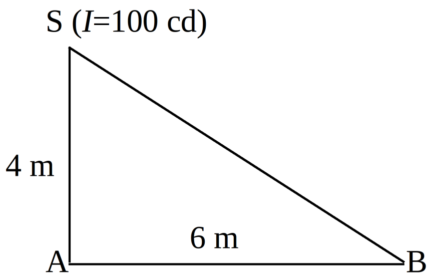
The second is that if the normal to an illuminated surface is at an angle θ to the direction of the incident light, the illuminance is proportional to the cosine of θ.

Example:

A point source of light S, of intensity 100 cd, is suspended 4 m above a horizontal surface. What is the illuminance on the surface (i) at the point vertically below the source, (ii) at 6 m from this point?

$I=100\ \text{cd};\ \ r_A=4\ m;\ \ \theta_A=0^\circ$

$$E_A=\frac{I}{r_A^2}\cos\theta_A=6.25\ \text{lux}$$



$I=100\ \text{cd};\ \ r_B=7.211\ m;\ \ \cos\theta_B=\dfrac{4}{r_B}$

$$E_B=\frac{I}{r_B^2}\cos\theta_B=1.07\ \text{lux}$$

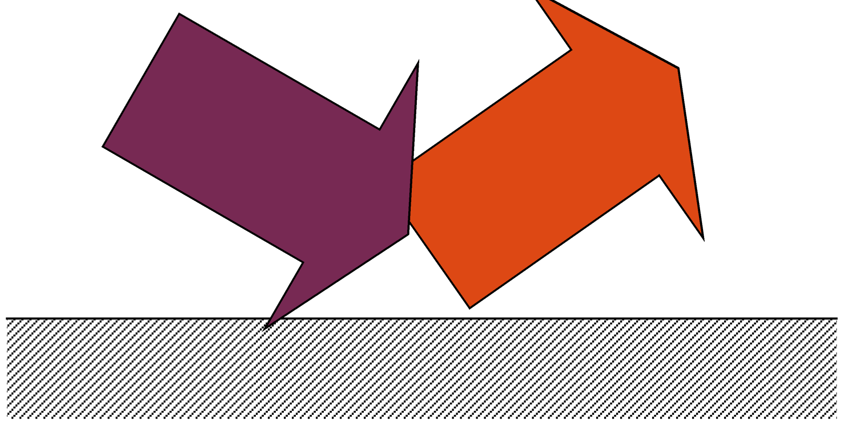
Example:

Light falls normally on a surface at 4 m from a point source of light. If the surface is moved to a distance 3 m from the source, at what angle must the surface be inclined in order that the illuminance is the same value?

For $\theta=0°$, $\quad E_A=\dfrac{I}{r_A^2}\cos\theta_A=\dfrac{I}{16}$

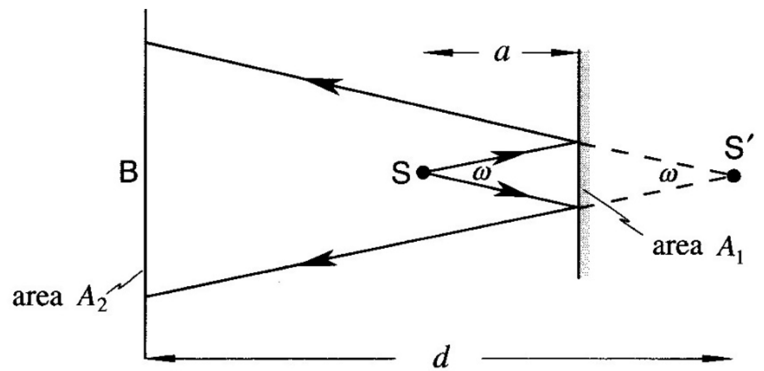
Afer movement: $\quad E_A=\dfrac{I}{r_A^2}\cos\theta=\dfrac{I}{9}\cos\theta \qquad\qquad \theta=55.77^\circ$

Reflectance:



$$\rho = \frac{\text{luminous flux per unit area reflected by a surface}}{\text{luminous flux per unit area incident on the surface}}$$

Reflecting Mirror:



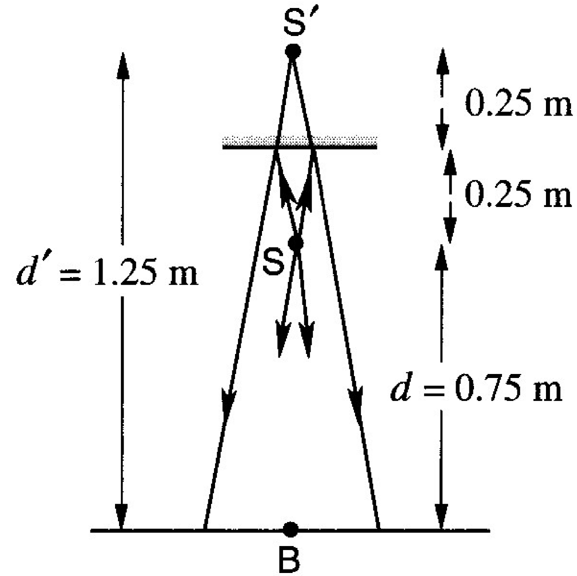
The illuminance on the surface at B due to the reflected light is,

$$E_B = \frac{\rho\Phi}{A_2} = \frac{\rho I\omega}{A_2} = \frac{\rho I}{A_2}\frac{A_2}{d^2} = \frac{\rho I}{d^2}$$

The illuminance at B, due to the reflected light, is as if from a source of intensity ρI situated at the position of the image in the mirror.

Example:

A small 50 cd source which may be assumed to radiate uniformly in all directions, is placed 75 cm above a horizontal table, and a plane mirror is fixed horizontally 25 cm above the source. If the mirror reflects 85% of the incident light, calculate the illuminance on the table at the point vertically below the source.

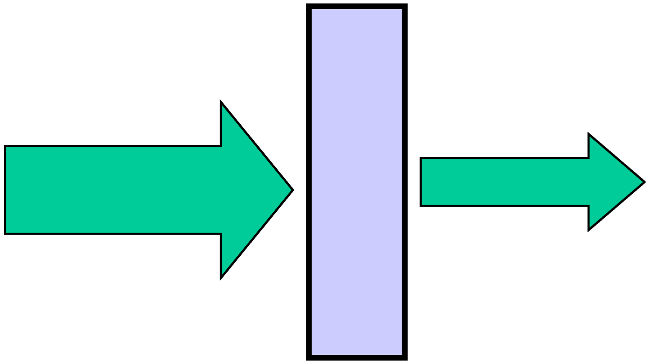


By direct light: $E_B = \frac{I}{r_1^2}\cos\theta = \frac{50}{0.75^2} = 88.9 \text{ lux}$

By reflection: $E_B' = \frac{I'}{r_2^2}\cos\theta = \frac{\rho I}{(0.75+0.25+0.25)^2} = 27.2 \text{ lux}$

Total illuminance $= E_B + E_B' = 116.1 \text{ lux}$

Transmittance:



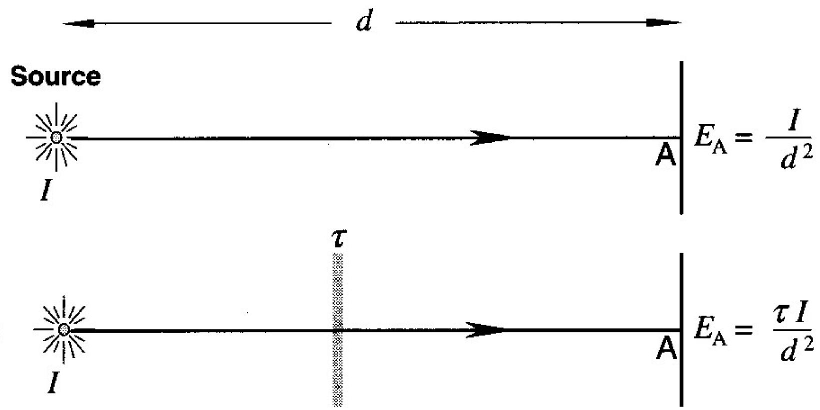
$$\tau = \frac{\text{luminous flux per unit area transmitted by the body}}{\text{luminous flux per unit area incident on the surface}}$$

It depends on the nature and thickness of the substance. It may also depend on the wavelength of the light used.

Neutral substances: materials that display an almost constant transmittance across the whole visible spectrum.

Example:

A point light source of intensity 200 cd is 2.5 m from a screen. Calculate the illuminance on the screen for normal incidence. If a neutral filter of transmittance 45% is placed between the source and the screen, what is the new value of the illuminance? Where must the source be placed such that, with the above mentioned filter in place, and with normal incidence, the illuminance on the screen is restored to its original value?



Without filter:

$$E_1 = \frac{I}{d_1^2}\cos\theta = \frac{200}{2.5^2} = 32 \text{ lux}$$

With filter:

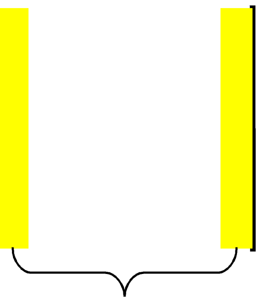
$$E_2 = \frac{\tau I}{d_2^2}\cos\theta = \frac{200\tau}{d_2^2} \text{ lux}$$

$$\because E_1 = E_2 \quad \therefore d_2 = 1.68\ m$$

Optical Density:

For a transparent plate: $\tau = T_1 T_m T_2$

If the material's thickness has increased by a factor of *N*, then the transmittance of the material is changed to $(T_m)^N$.



Transmittance at two surfaces: $T_1 = T_2 = \dfrac{4nn'}{\left(n+n'\right)^2}$

Optical density D of a substance is defined as, $D = \log \dfrac{1}{\tau}$

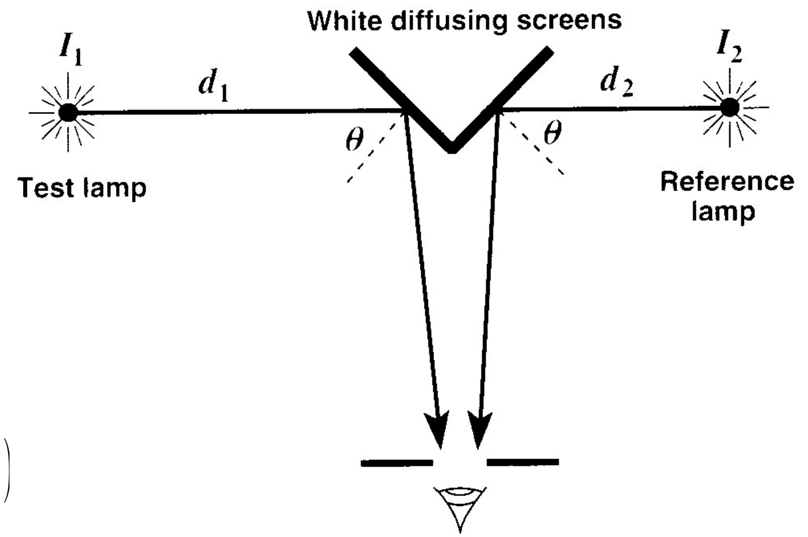
$$D = \log \frac{1}{T_1} + \log \frac{1}{T_m} + \log \frac{1}{T_2} = D_1 + D_m + D_2$$

The optical density of the sample is simply the sum of the optical densities of the surfaces and the stated material.

To find new optical density we can simply multiply the optical density D_m of the material by whatever factor that gives the new thickness.

Photometer (visual):

Principle: If two adjacent identical white reflecting surfaces appear to be equally bright when illuminated with two sources, then the surfaces will be receiving the same illuminance and the boundary between the surfaces will be difficult to see.



Illuminance on the left hand screen $E_L = \left(I_1/d_1^2\right)$

Illuminance on the right hand screen $E_R = \left(I_2/d_2^2\right)\cos\theta$

$$I_1 = I_2\left(\frac{d_1}{d_2}\right)^2$$

Weber-Fechner Law for human eye to judge the equality of brightness of two surfaces: If *L* is a value for the prevailing luminance of a surface and *dL* is the minimum noticeable increment, then

$$\frac{dL}{L} = constant$$

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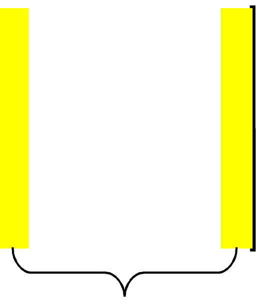

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To find new optical density we can simply multiply the optical density D_m of the material by whatever factor that gives the new thickness.

Example:

At 2 mm thickness, a certain tinted glass has a transmittance for a specified wavelength of 0.47. Determine the transmittance at 4 mm and 5 mm thickness. n_g=1.5.

$$T_1 = T_2 = \frac{4nn'}{(n'+n)^2} = \frac{4\times1\times1.5}{(1.5+1)^2} = 0.96$$

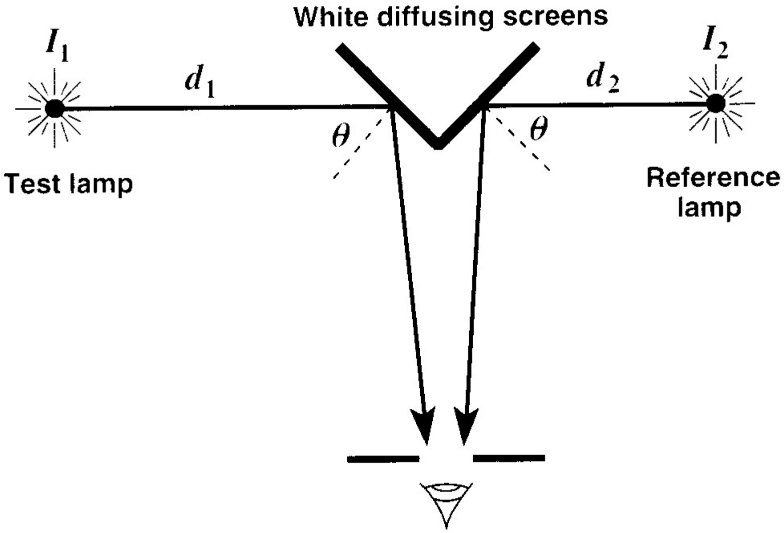
At 2mm thickness: $T_m = \dfrac{\tau}{T_1 T_2} = \dfrac{0.47}{0.96^2} = 0.51$

At 4mm thickness: $\tau = T_1 (T_m)^{4/2} T_2 = 0.96 \times 0.51^2 \times 0.96 = 0.24$

At 5mm thickness: $\tau = T_1 (T_m)^{5/2} T_2 = 0.96 \times 0.51^{2.5} \times 0.96 = 0.17$

Photometer (visual):

Principle: If two adjacent identical white reflecting surfaces appear to be equally bright when illuminated with two sources, then the surfaces will be receiving the same illuminance and the boundary between the surfaces will be difficult to see.



Illuminance on the left hand screen $E_L = \left(I_1 / d_1^2\right)$

Illuminance on the right hand screen $E_R = \left(I_2 / d_2^2\right)\cos\theta$

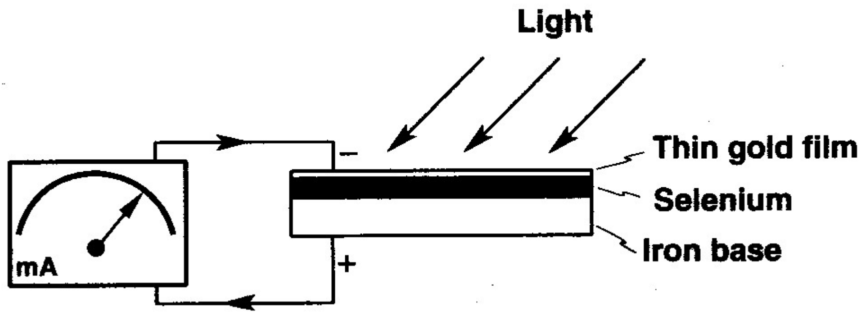
$$I_1 = I_2\left(\frac{d_1}{d_2}\right)^2$$

Weber-Fechner Law for human eye to judge the equality of brightness of two surfaces: If *L* is a value for the prevailing luminance of a surface and *dL* is the minimum noticeable increment, then

$$\frac{dL}{L} = constant$$

Photometer (non-visual):

The non-visual (physical) photometers directly measure the illuminance falling on them. The most commonly used non-visual photometers are photovoltaic cells.



Due to the photoelectric effect, electrons are emitted from the selenium layer when light is incident on the cell. A thin transparent gold film is deposited on the top of Se-layer.

Luminous Efficacy:

To describe the effectiveness of a source, two concepts are used:

$$\text{luminous efficiency} = \frac{\text{luminous flux emitted}}{\text{total flux radiated}} \quad \left(\frac{\text{lumens}}{\text{lumens}}\right)$$

$$\text{luminous efficacy} = \frac{\text{luminous flux emitted by a lamp}}{\text{power consumed}} \quad \left(\frac{\text{lumens}}{\text{watts}}\right)$$

Luminous efficiency indicates the fraction of total flux radiated that is actually visible.

Luminous efficacy is the fraction of the total consumed power that is used to emit the visible light. A large amount of energy can be wasted in the form of heat or infrared radiation.

Example:

A football pitch 110 m by 87.5 m is illuminated for evening matches by equal banks of 1000 W lamps supported on 16 towers, which are located around the ground to provide approximately uniform illuminance of the pitch. Assuming 35% of the total light emitted reaches the playing area and that an illuminance of 800 lm/m^2 is necessary for TV purposes, calculate the number of lamps on each tower. The luminous efficacy of each lamp may be taken as 25 lm/W.

$$E=\frac{\Phi}{A}=\frac{25000\times N\times 0.35}{110\times 87.5}=800\ \mathrm{lm/m^2}$$

$$N=880$$

Kerjakan di buku
Catatan anda

Tugas

- Jelaskan perbedaan fotometri dan radiometri beserta kuantitas dan unit satuannya.
- Bandingkan laser pointer dengan 670 dan 635 nm (dengan diameter beam yang sama). Berapa lumen output keduanya dan apa kesimpulan saudara (λ vs brightness).

Hint: Gunakan table 18.4 HOE atau pendekatan untuk mencari V(λ).