Light Sources and Illumination

Properties of light sources

- Power Spectrum
- Radiant and luminous intensity
- Directional distribution – goniometric diagram
- Shape

Illumination

- Irradiance and illuminance
- Area light sources

Blackbody

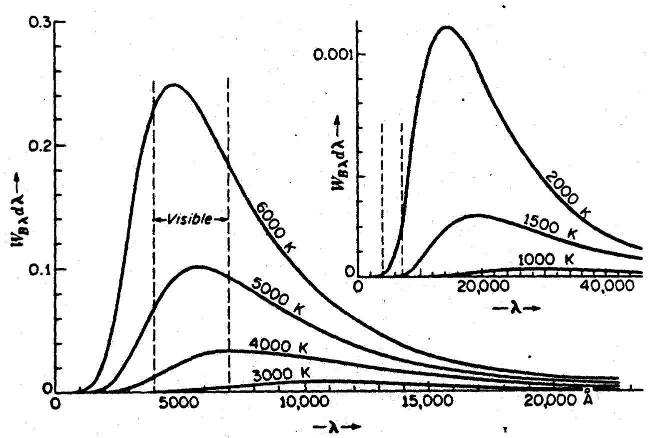


FIGURE 21F
Blackbody radiation curves plotted to scale. Ordinates give the energy in calories per square centimeter per second in a wavelength interval $d\lambda$ of 1 Å. For numerical values, see "Smithsonian Physical Tables," 8th ed., p. 314.

Tungsten

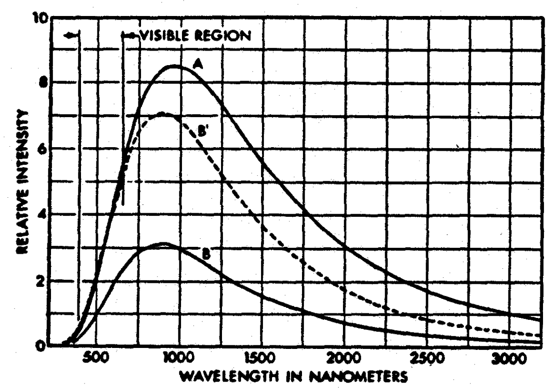
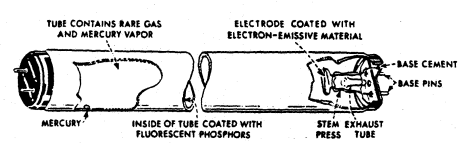


Fig. 8–1. Radiating characteristics of tungsten. Curve A: radiant flux from one square centimeter of a blackbody at 3000 K. Curve B: radiant flux from one square centimeter of tungsten at 3000 K. Curve B′: radiant flux from 2.27 square centimeters of tungsten at 3000 K (equal to curve A in visible region). (The 500-watt 120-volt general service lamp operates at about 3000 K.)

Flourescent



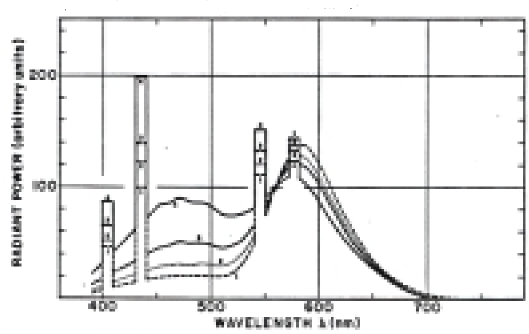


Fig. 3(1.2.3). Relative spectral radiant power distributions of common fluorescent lamps: (1) standard warm white; (2) white; (3) standard cool white; and (4) daylight. The distribution curves have been scaled by appropriate constant factors to provide a common value of 100 at λ = 560 nm.

Sunlight

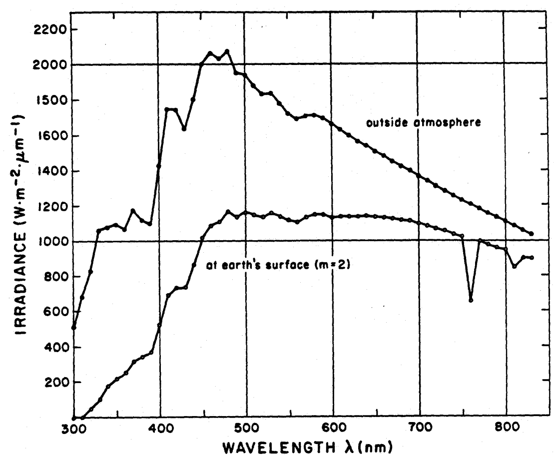


Fig. 1(1.2.1). NASA standard data of spectral irradiance ($W \cdot m^{-2} \cdot \mu m^{-1}$) for the solar disk measured outside the atmosphere (solid dots) and at the earth's surface at air mass 2 (open circles). Data points are those given in Table 1(1.2.1). Neighboring data points have been connected by straight lines for illustrative purposes only.

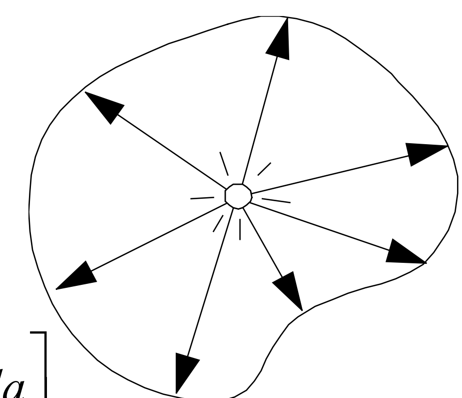
Radiant and Luminous Intensity

Definition: The *radiant* (*luminous*) *intensity* is the power per unit solid angle from a point.

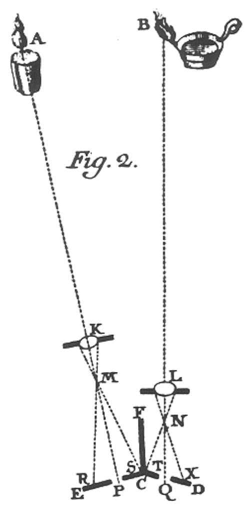
$$I(\omega) \equiv \frac{d\Phi}{d\omega}$$

$$\Phi = \int_{S^2} I(\omega)\, d\omega$$

$$\left[\frac{W}{sr}\right] \quad \left[\frac{lm}{sr} = cd = candela\right]$$



The Invention of Photometry



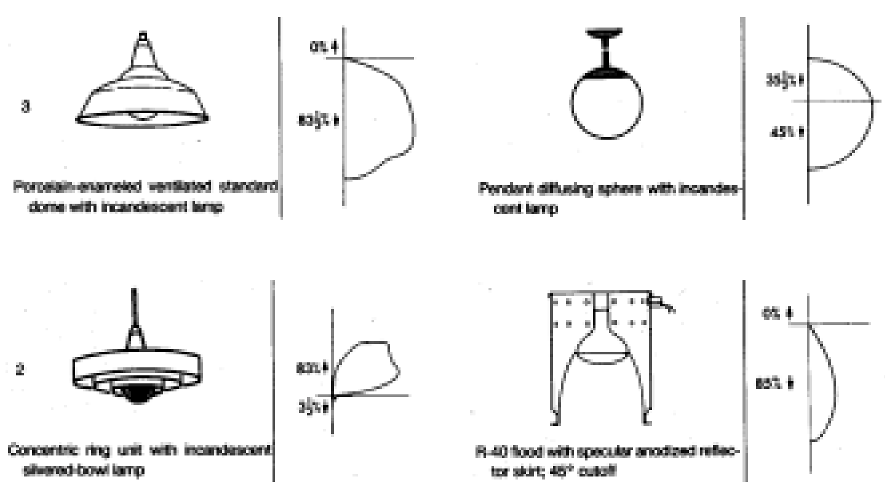
Bouguer's classic experiment

- Compare a light source and a candle
- Intensity is proportional to ratio of distances squared

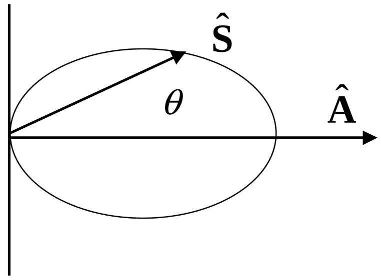
Definition of a standard candle

- Originally "standard" candle
- Currently 550 nm laser w/ 1/683 W/sr
- 1 of 6 fundamental SI units

Goniometric Diagrams



Warn's Spotlight

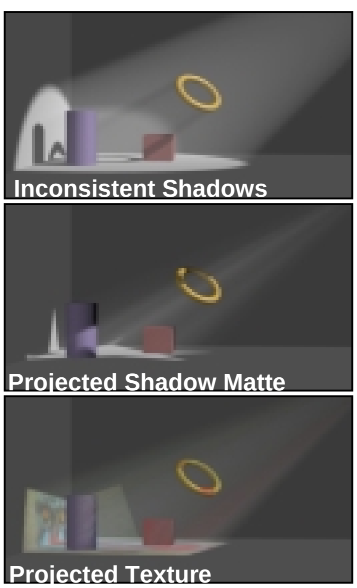


$$I(\omega) = \cos^s \theta = (\hat{\mathbf{S}} \bullet \hat{\mathbf{A}})^s$$

$$\Phi = \int_0^{2\pi} \int_0^1 I(\omega)\, d\cos\theta\, d\varphi = 2\pi \int_0^1 \cos^s \theta\, d\cos\theta = \frac{2\pi}{s+1}$$

$$I(\omega) = \Phi \frac{s+1}{2\pi} \cos^s \theta$$

PIXAR Standard Light Source



Inconsistent Shadows

Projected Shadow Matte

Projected Texture

Ronen Barzel UberLight( )

```
{
    Clip to near/far planes
    Clip to shape boundary
    foreach superelliptical blocker
        atten *= …
    foreach cookie texture
        atten *= …
    foreach slide texture
        color *= …
    foreach noise texture
        atten, color *= …
    foreach shadow map
        atten, color *= …
    Calculate intensity fall-off
    Calculate beam distribution
}
```

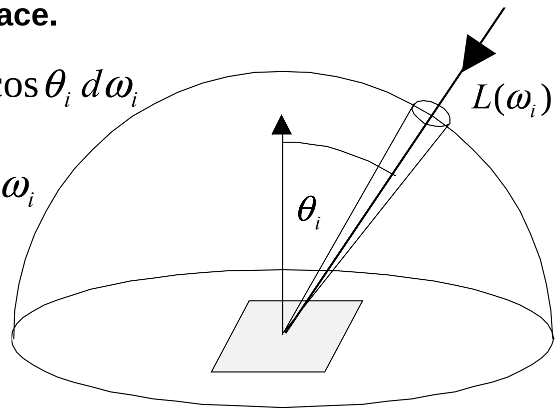
Irradiance and Illuminance

<u>Definition</u>: The *irradiance* (*illuminance*) is the power per unit area incident on a surface.

$$dE(x) \equiv \frac{d^2\Phi}{dA} = L(x,\omega_i)\cos\theta_i \, d\omega_i$$

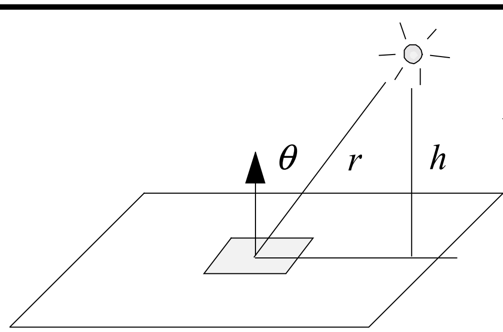
$$E(x) = \int_{H^2} L(x,\omega_i)\cos\theta_i d\omega_i$$

$$\left[\frac{W}{m^2}\right] \left[\frac{lm}{m^2} = lux\right]$$



This is sometimes referred to as the* radiant *and* luminous incidence*.

Isotropic Point Sources

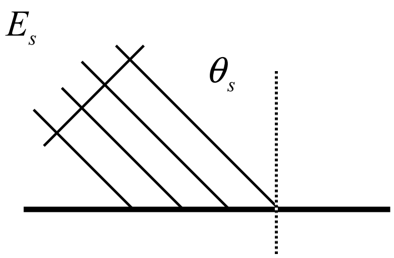


$$I(\omega) = \frac{\Phi}{4\pi}$$

$$d\Phi = E\,dA = I\,d\omega = \frac{\Phi}{4\pi}\frac{\cos\theta}{r^2}dA = \frac{\Phi}{4\pi}\frac{\cos^3\theta}{h^2}dA$$

- **Note inverse square law fall off.**
- **Note cosine dependency**

Distant or Directional Source

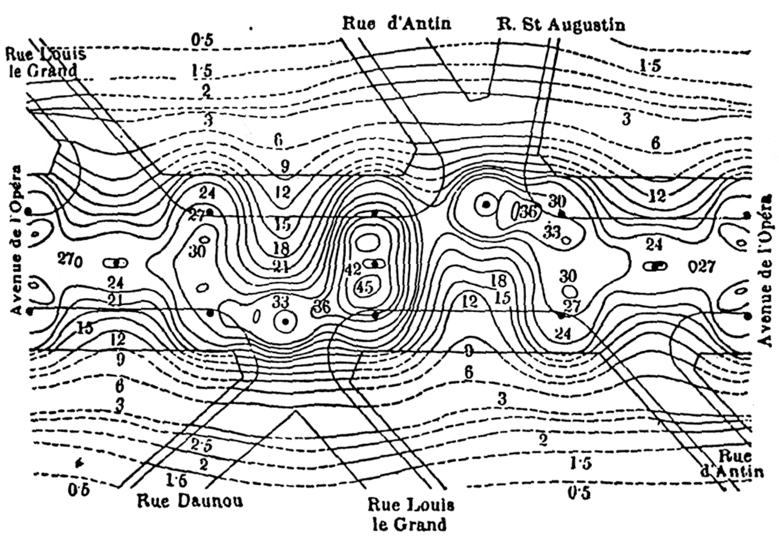


$$E = \int_{H^2} L(\omega)\cos\theta \, d\cos\theta \, d\varphi$$

$$L(\theta,\varphi) = E_s \, \delta(\cos\theta - \cos\theta_s)\delta(\varphi - \varphi_s)$$

$$\int_{H^2} L(\theta,\varphi)\cos\theta \, d\cos\theta \, d\varphi$$
$$= \int_{H^2} E_s \delta(\cos\theta - \cos\theta_s)\delta(\varphi - \varphi_s)\cos\theta \, d\cos\theta \, d\varphi$$
$$= E_s \cos\theta_s$$

Irradiance Distribution

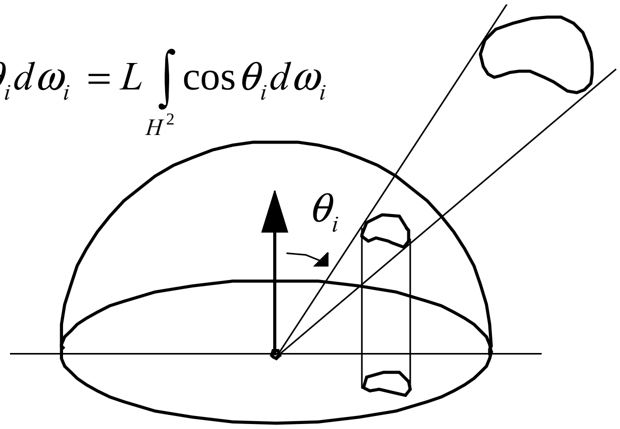


Isolux contours

Irradiance from Area Sources

$$E(x) = \int_{H^2} L(x,\omega_i)\cos\theta_i d\omega_i = L \int_{H^2} \cos\theta_i d\omega_i$$

$$\int_{H^2} \cos\theta \, d\omega = \pi$$



Projected Solid Angle

Radiosity formulation = Differential Form Factor

Note: Things are considerably complicated by shadows

Luminance of Common Light Sources

Surface of the sun	**2,000,000,000. cd/m^2**
Sunlight clouds	**30,000.**
Clear day	**3,000.**
Overcast day	**300.**
Moonlight	**0.03**
Moonless	**0.00003**

The Sky

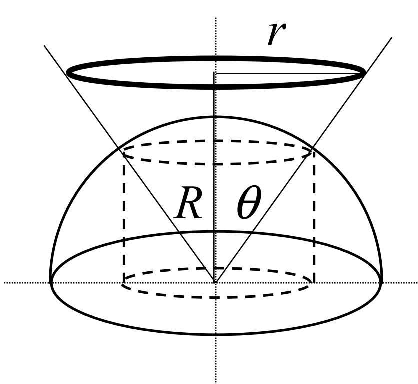
Plate 5-16. Fisheye view of clear sky at the South Pole. (Photographed by the author)

Plate 5-17. View of slightly hazy sky in Wisconsin. (Photographed by the author)

From Greenler, Rainbows, halos and glories

Disk Source

Geometric Derivation



Algebraic Derivation

$$E = \int_{1}^{\cos\theta_d} \int_{0}^{2\pi} L \cos\theta \, d\phi \, d\cos\theta$$

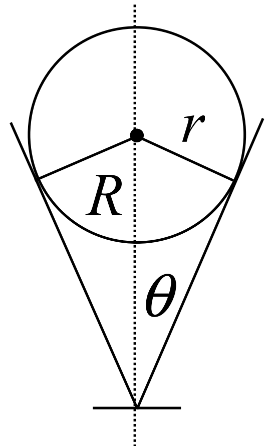
$$= 2\pi L \left. \frac{\cos^2\theta}{2} \right|_{1}^{\cos\theta_d}$$

$$= L\pi \sin^2\theta_d$$

$$= L\pi \frac{r^2}{r^2 + R^2}$$

Spherical Source

Geometric Derivation



Algebraic Derivation

$$E = \int L \cos\theta \, d\omega$$
$$= L\pi \sin^2 \theta$$
$$= L\pi \frac{r^2}{R^2}$$

The Sun

Solar constant (normal incidence at zenith)

Irradiance **1353 W/m^2**

Illuminance **127,500 Lumen/m^2 = 127.5 Kilo-Lux**

Solar angle

α = .25 degrees = .004 radians (half angle)

$\omega = \pi \sin^2 \alpha = 6 \times 10^{-5}$ steradians

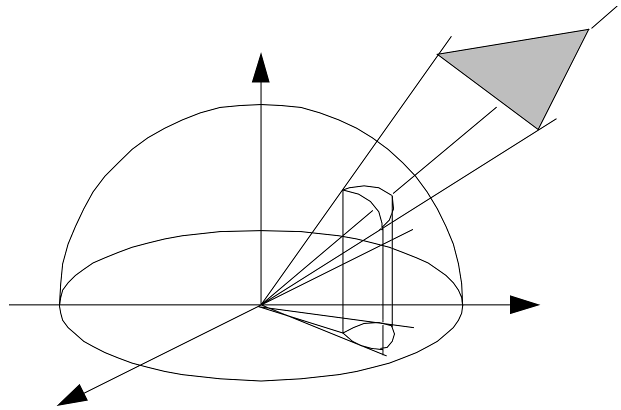
Radiance

$$L = \frac{E}{\omega} = \frac{1.353\times10^3 W/m^2}{6\times10^{-5} sr} = 2.25\times10^7 \frac{\mathrm{W}}{m^2 \cdot sr}$$

Pluto (6 tera-meters) 50 Lux - read a newspaper

Deep space -> 20 micro-lux (see, but not read!)

Polygonal Source



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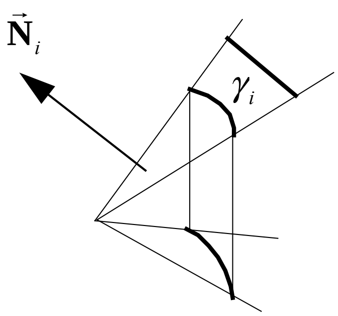
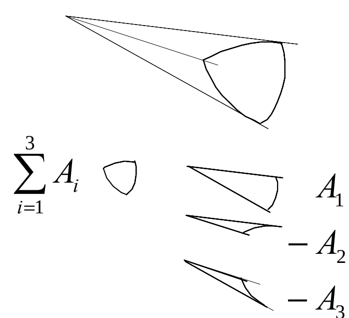
Lambert's Formula





$$A_i = \gamma_i \vec{\mathbf{N}} \bullet \vec{\mathbf{N}}_i \qquad \sum_{i=1}^{n} A_i = \sum_{i=1}^{n} \gamma_i \vec{\mathbf{N}} \bullet \vec{\mathbf{N}}_i$$

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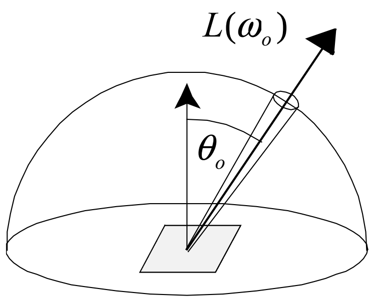
Radiosity and Luminosity

Definition: **The *radiosity* (*luminosity*) is the energy per unit area leaving a surface.**



$$B(x) = \int_{H^2} L(\omega_o)\cos\theta_o \, d\omega_o$$

This is officially referred to as the* radiant *and* luminous exitance*.

Uniform Diffuse Source

$$\begin{aligned} B &= \int L\cos\theta \, d\omega \\ &= L\int\cos\theta \, d\omega \\ &= \pi L \end{aligned}$$

$$L = \frac{B}{\pi}$$

$$blondel = apostilb = \tfrac{1}{\pi} nit = \tfrac{1}{\pi} cd / m^2 \qquad (skot = 10^{-3} apostilb)$$

$$lamberts = \tfrac{1}{\pi} cd / cm^2$$

$$foot-lamberts = \tfrac{1}{\pi} cd / ft^2 \qquad (glim = 10^{-3} foot-lambert)$$

Radiometric and Photometric Terms

Physics	Radiometry	Photometry
Energy	Radiant Energy	Luminous Energy
Flux (Power)	Radiant Power	Luminous Power
Flux Density	Irradiance Radiosity	Illuminance Luminosity
Angular Flux Density	Radiance	Luminance
Intensity	Radiant Intensity	Luminous Intensity

Photometric Units

Photometry	Units		
	MKS	CGS	British
Luminous Energy	Talbot		
Luminous Power	Lumen		
Illuminance Luminosity	Lux	Phot	Footcandle
Luminance	Nit Apostilb, Blondel	Stilb Lambert	Footlambert
Luminous Intensity	Candela (Candle, Candlepower, Carcel, Hefner)		

"Thus one nit is one lux per steradian is one candela per square meter is one lumen per square meter per steradian. Got it?" ***Kajiya***