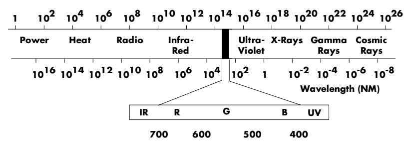
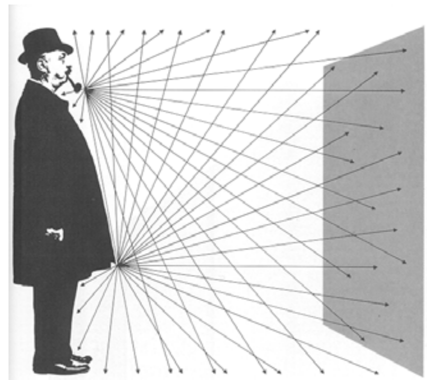
The Light Field

Electromagnetic waves and power spectrum





Ignore polarization

Ignore photons

Spatial distribution

From London and Upton

Topics

Radiometry and photometry

Light sources

Radiant intensity

Irradiance

- **Inverse square law and cosine law**

Radiance

- **Exposure proportional to radiance**
- **Radiance constant along a ray**

Radiometry and Photometry

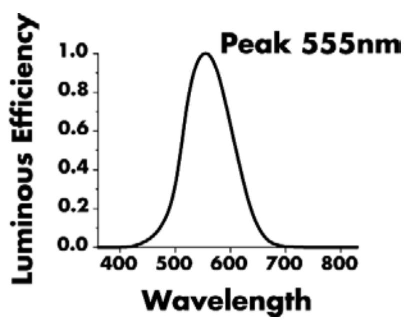
Radiant Energy and Power

Power: Watts vs. Lumens

Φ
- **Energy efficiency**
- **Spectral efficacy**

Energy: Joules vs. Talbot

- **Exposure**
  - **Film response**
  - **Skin - sunburn**



Luminance

$$Y = \int V(\lambda)L(\lambda)d\lambda$$

Radiometry vs. Photometry

Radiometry [Units = Watts]

- **Physical measurement of electromagnetic energy**

Photometry and Colorimetry [Lumen]

- **Relative perceptual measurement**
- **Sensation as a function of wavelength**

Brightness [Brils] $B = Y^{1/3}$

- **Absolute perceptual measurement**
- **Sensation at different intensities**

Blackbody

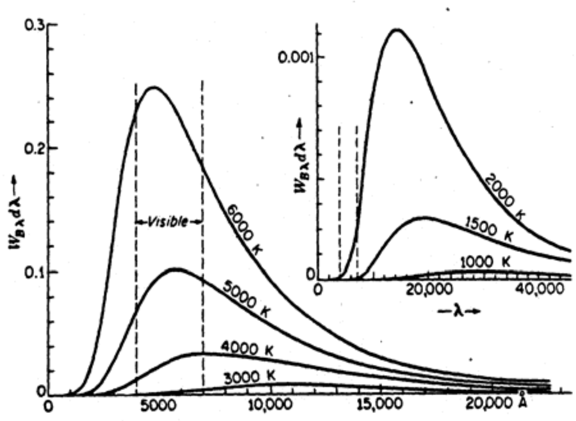


FIGURE 21F
Blackbody radiation curves plotted to scale. Ordinates give the energy in calories per square centimeter per second in a wavelength interval $d\lambda$ of 1 Å. For numerical values, see "Smithsonian Physical Tables," 8th ed., p. 314.

Tungsten

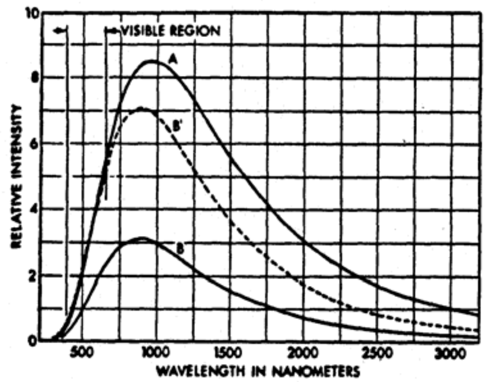
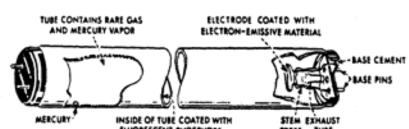


Fig. 8–1. Radiating characteristics of tungsten. Curve A: radiant flux from one square centimeter of a blackbody at 3000 K. Curve B: radiant flux from one square centimeter of tungsten at 3000 K. Curve B′: radiant flux from 2.27 square centimeters of tungsten at 3000 K (equal to curve A in visible region).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

Fluorescent



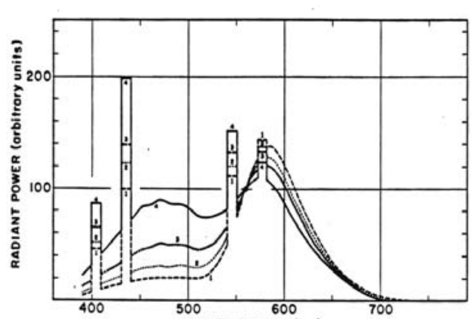


Fig. 3(1.2.3). Relative spectral radiant power distributions of common fluorescent lamps: (1) standard warm white; (2) white; (3) standard cool white; and (4) daylight. The distribution curves have been scaled by appropriate constant factors to provide a common value of 100 at $\lambda = 560$ nm.

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Sunlight

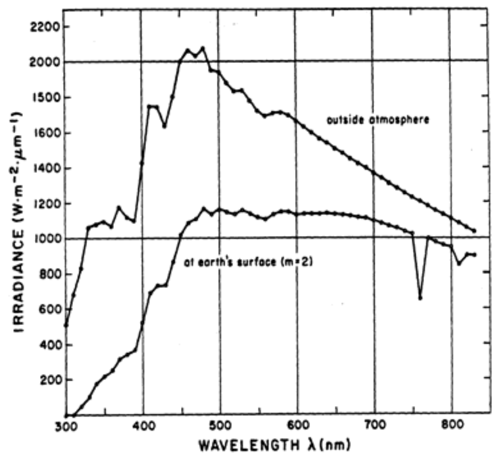


Fig. 1(1.2.1). NASA standard data of spectral irradiance ($W \cdot m^{-2} \cdot \mu m^{-1}$) for the solar disk measured outside the atmosphere (solid dots) and at the earth's surface at air mass 2 (open circles). Data points are those given in Table 1(1.2.1). Neighboring data points have been connected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

Light Source Properties

Power spectrum

Directional distribution (goniometric diagram)

Spatial distribution (area sources)

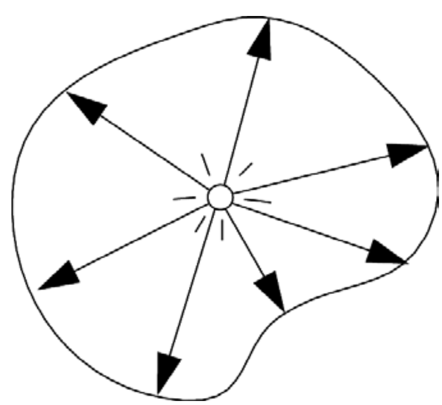
Intensity

Radiant and Luminous Intensity

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

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

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



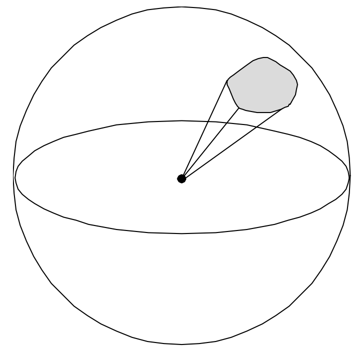
Angles and Solid Angles

- **Angle** $\theta = \frac{l}{r}$

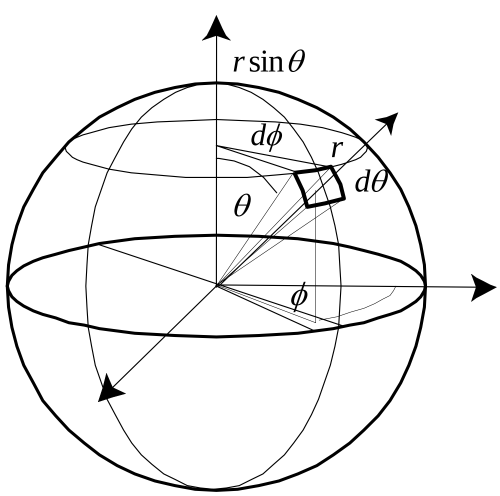
  $\Rightarrow$ **circle has 2π radians**

- **Solid angle** $\Omega = \frac{A}{R^2}$

  $\Rightarrow$ **sphere has 4π steradians**



Differential Solid Angles

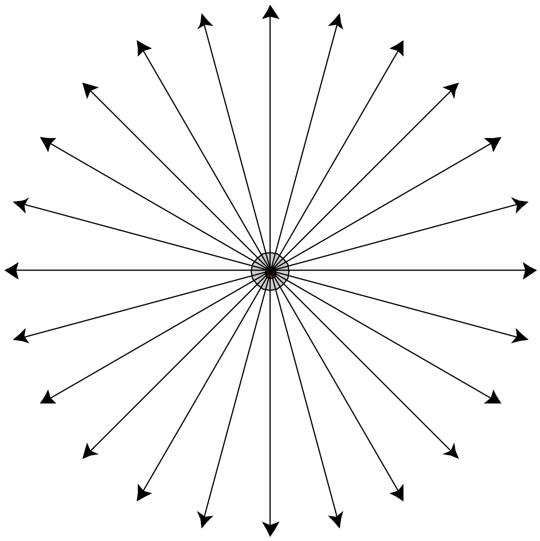


$$dA = (r\,d\theta)(r\sin\theta\,d\phi) = r^2 \sin\theta\,d\theta\,d\phi$$

$$d\omega = \frac{dA}{r^2} = \sin\theta\,d\theta\,d\phi$$

$$S = \int_0^{\pi}\int_0^{2\pi} \sin\theta\,d\theta\,d\phi = 4\pi$$

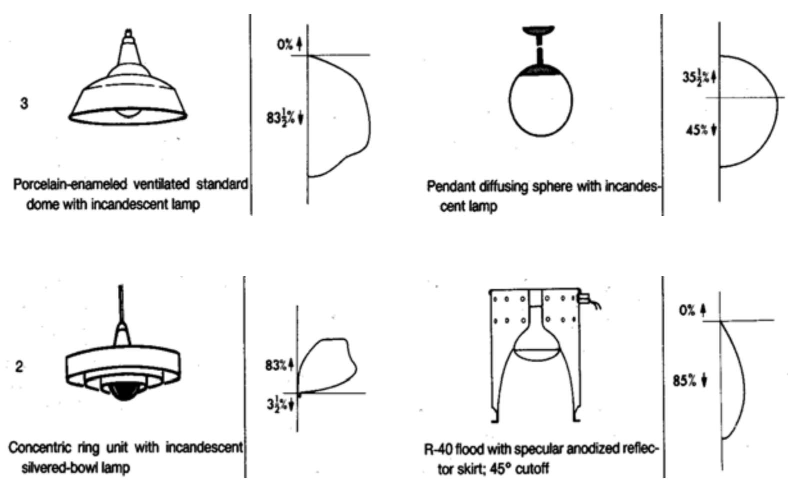
Isotropic Point Source



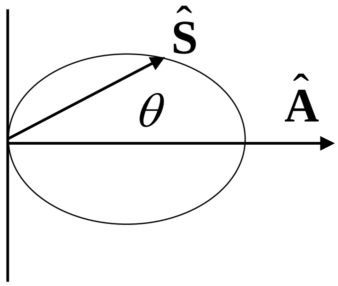
$$\Phi = \int_{S^2} I \, d\omega$$
$$= 4\pi I$$

$$I = \frac{\Phi}{4\pi}$$

Light Source Goniometric Diagrams



Warn's Spotlight



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

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

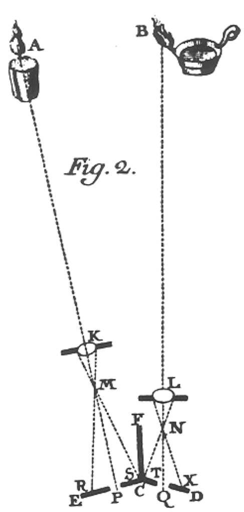
$$I(\omega) = \Phi \frac{s+1}{2\pi} \cos^s \theta$$

PIXAR Standard Light Source


```
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

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

Irradiance and Illuminance

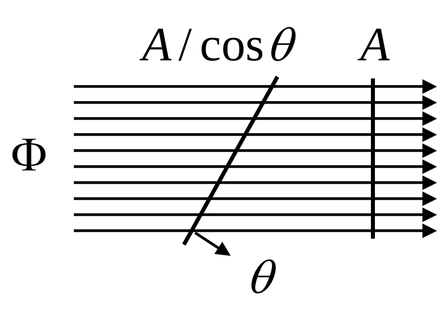
<u>Definition</u>: **The *irradiance* (*illuminance*) is the power per unit area incident on a surface.**

$$E(x) \equiv \frac{d\Phi}{dA}$$

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

Sometimes referred to as the *radiant* (*luminous*) *incidence*.

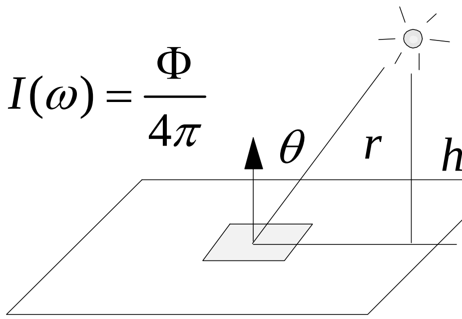
Lambert's Cosine Law



$$E = \frac{\Phi}{A/\cos\theta} = \frac{\Phi}{A}\cos\theta$$

Illumination: Isotropic Point Source

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



$$d\Phi = I\,d\omega = E\,dA$$

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

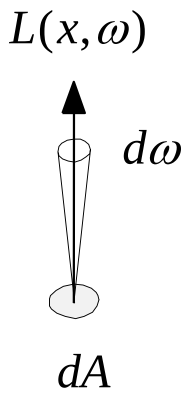
$$E = \frac{\Phi}{4\pi}\frac{\cos\theta}{r^2}$$

$$\frac{\Phi}{4\pi}\frac{\cos\theta}{r^2} \Rightarrow \frac{\Phi}{4\pi}\frac{\cos^3\theta}{h^2}$$

Radiance

Radiance

Definition 1: The surface *radiance* (*luminance*) is the intensity per unit area leaving a surface



$$L(x,\omega) \equiv \frac{dI(x,\omega)}{dA}$$

$$= \frac{d\Phi(x,\omega)}{d\omega dA}$$

$$\left[\frac{W}{sr\,m^2}\right]\left[\frac{cd}{m^2} = nit\right]$$

Typical Values of Luminance [cd/m²]

Surface of the sun	**2,000,000,000.**
Sunlight clouds	**30,000.**
Clear day	**3,000.**
Overcast day	**300.**
Moon	**0.03**

Typical Values of Illuminance [lm/m^2]

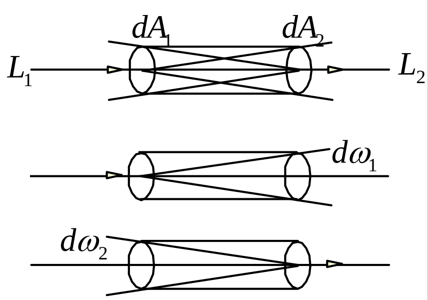
Sunlight plus skylight	100,000 lm/m^2
Sunlight plus skylight (overcast)	10,000
Interior near window (daylight)	1,000.
Artificial light (minimum)	100.
Moonlight (full)	0.02
Starlight	0.0003

Properties of Radiance

1. Radiance invariant along a ray.
   - ∴ Radiance is associated with rays in ray tracer
2. Response of a sensor proportional to radiance.
   - ∴ Image is a 2D set or rays
3. Fundamental field quantity that characterizes the distribution of light in an environment.
   - ∴ All other quantities are derived from it.

1st Law: Conversation of Radiance

The radiance in the direction of a light ray remains constant as the ray propagates from one surface to another surface



$$d\Phi_1 = L_1 d\omega_1 dA_1 = L_2 d\omega_2 dA_2 = d\Phi_2$$

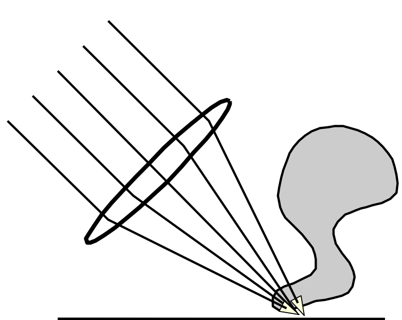
$$d\omega_1 = dA_2 / r^2$$
$$dw_2 = dA_1 / r^2$$

$$d\omega_1 dA_1 = \frac{dA_1 dA_2}{r^2} = d\omega_2 dA_2$$

$$\therefore L_1 = L_2$$

Quiz

Does radiance increase under a magnifying glass?



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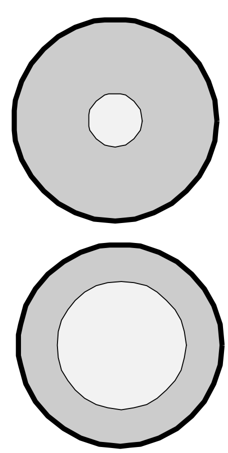
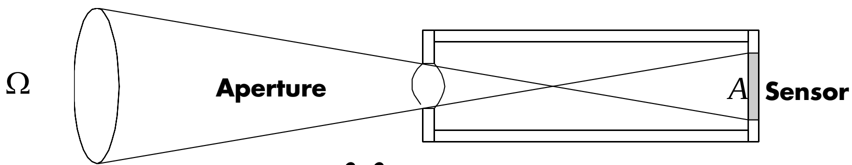


Radiance: 2nd Law

The response of a sensor is proportional to the radiance of the surface visible to the sensor.



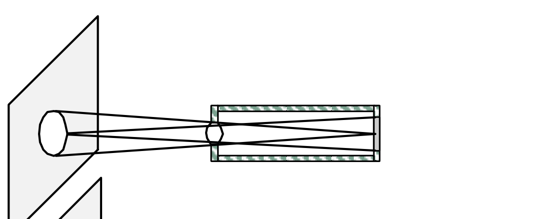
$$R = \int_A \int_\Omega L \, d\omega \, dA = \overline{L} T$$

$$T = \int_A \int_\Omega d\omega \, dA$$

L **is what should be computed and displayed.**

Quiz

Does the brightness that a wall appears to the eye depend on the distance of the viewer to the wall?



No!!

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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?", *James Kajiya*