# Clinical Visual Optics
# OPTO 223

# Week II: Photometry

DR SALWA ALSALEH

# Week II : outline

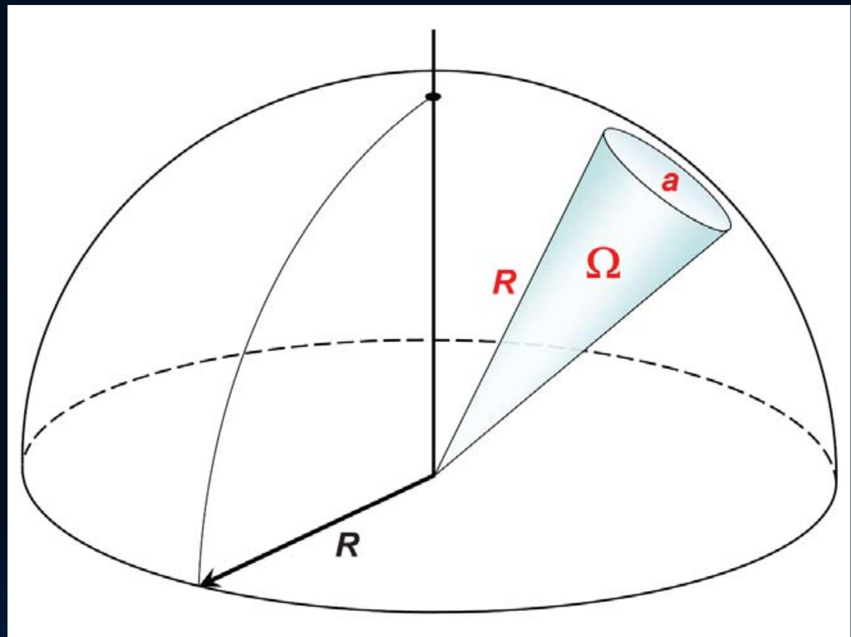
- Radiometry
- Ophthalmic standard Units of Radiometry and Photometry
- Inverse square law and cosine law of illumination
- Luminescence
- Retinal illumination

# Radiometry, Energy and Power

- **Radiometry** is the measurement of optical radiation, corresponding to wavelengths between 0.01 and 1000 μm, and includes the regions commonly called the ultraviolet, the visible and the infrared.
- Energy, $Q$, is measured in joules (J). Think of this as the number of photons in a beam of M radiation since each photon is a discrete packet of energy.
- Power $\Phi$ is the rate of change of energy with respect to time ( time derivative of energy). Measured in J/s or Watt (W)

# Solid angles

- a three-dimensional analogue of an angle, such as that subtended by a cone or formed by planes meeting at a point. It is measured in steradians, or $(sr)$

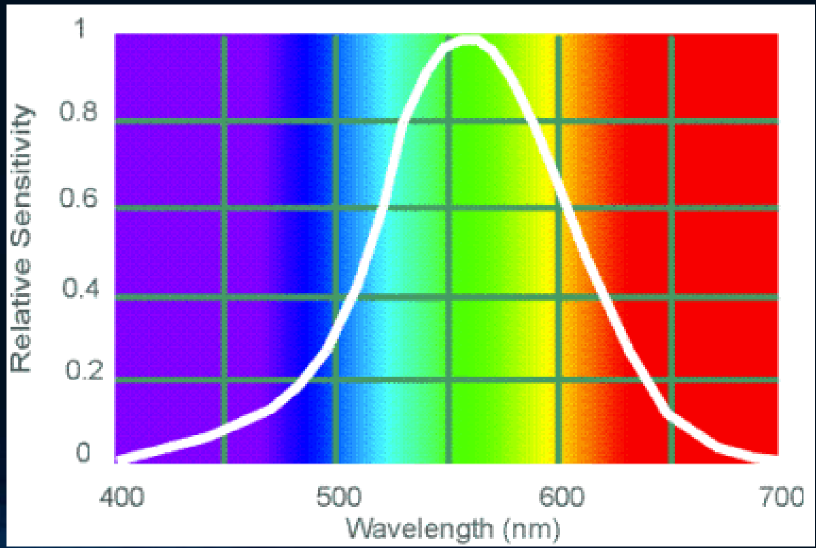


# Radiometric Quantities

- Irradiance, $E$, is measured in $W/m^2$. Irradiance is power per unit area incident from all directions onto a surface.
- Radiant exitance, $M$, which is power per unit area leaving a surface. This also has the units of $W/m^2$.
- Radiant intensity, $I$, is measured in $W/sr$. Intensity is power per unit solid angle.
- Radiance, $L$, is measured in $W/m^2sr$ . Radiance is power per unit projected area per unit solid angle.

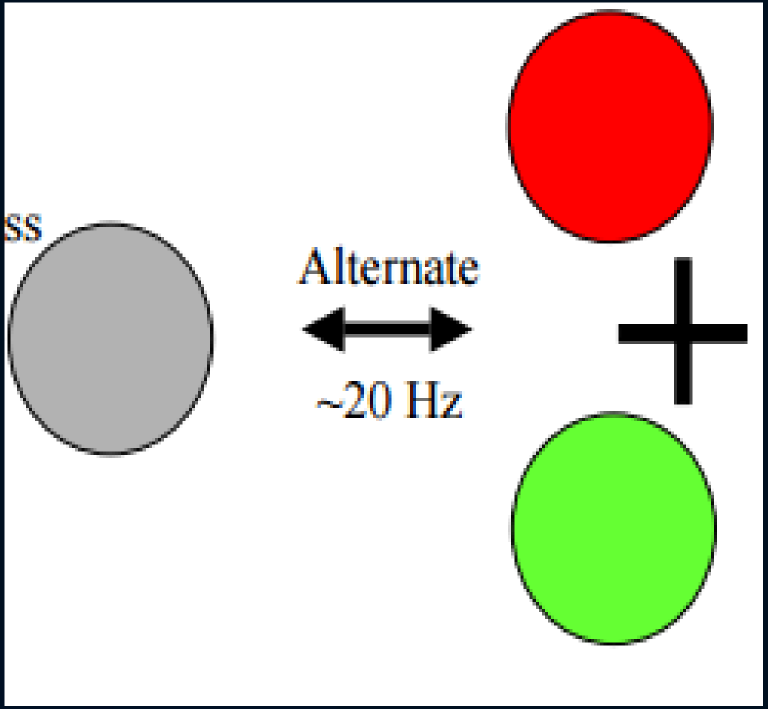
# Photometry

- Photometry is the measurement of light, which is defined as electromagnetic radiation which is detectable by the human eye. It is thus restricted to the wavelength range from about 360 to 830 nanometers.
- Photometry is just like radiometry except that everything is weighted by the spectral response of the eye!



# Measuring Response Curves

- Heterochromic flicker photometry is a technique for measuring the sensitivity of the eye to different wavelenghts.
- At this frequency, the spot will appear to flicker. The observer adjusts the brightness of the red spot until flicker is gone. Brightness of red spot to brightness of green spot is the relative sensitivity.



# Radiometric vs. Photometric Units

| Radiometry | Photometry |
|---|---|
| Total energy content of radiation | The radiation that human can see |
| Measures radiant flux, power [Watt] | Measures luminous flux [Lumen] |
| Radiant intensity [W/sr] | Luminous intensity [candela, cd=Lm/sr] |
| Irradiance [$W/m^2$] | Illuminance [lux,$lx=lm/m^2$] [footcandle,$fc=lm/ft^2$] |
| Radiance [$W/(m^2.sr)$] | Luminance [$lm/(m^2.sr)$ , $cd/m^2$] |

# Luminous Flux

- Luminous Flux (think Power), $\Phi_V$, is in units of Lumens (lm) and is given by:.

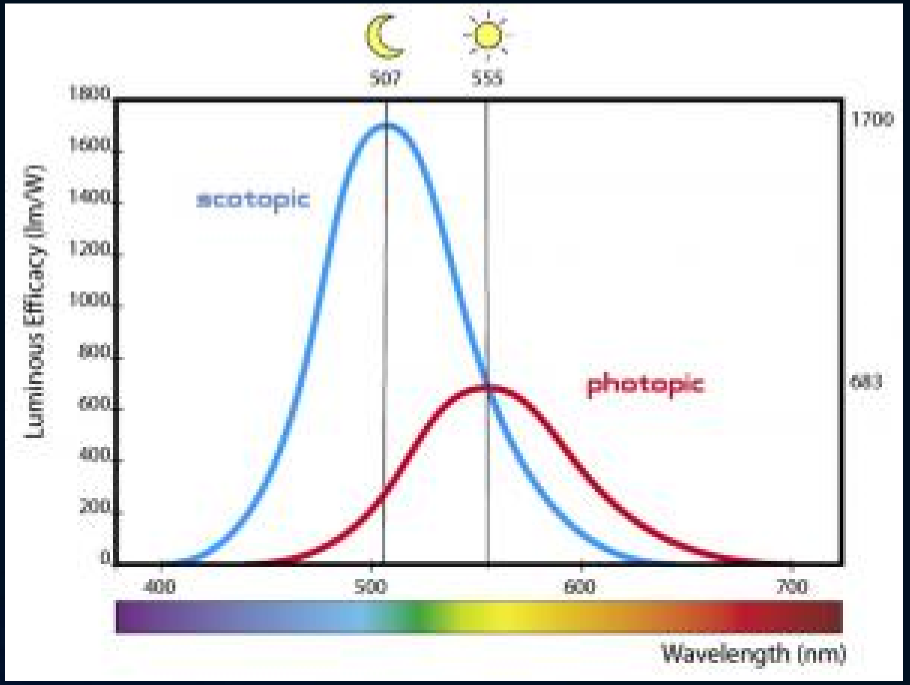
$$\Phi_V = 683 \int \Phi(\lambda)\, V(\lambda) d\lambda$$

With $V(\lambda)$ is the photopic response curve. From the above formula, There are 683 lm per W at a wavelength of 555 nm

# Scotopic vision

- Under low lighting condition, the previous formula is modified to become:

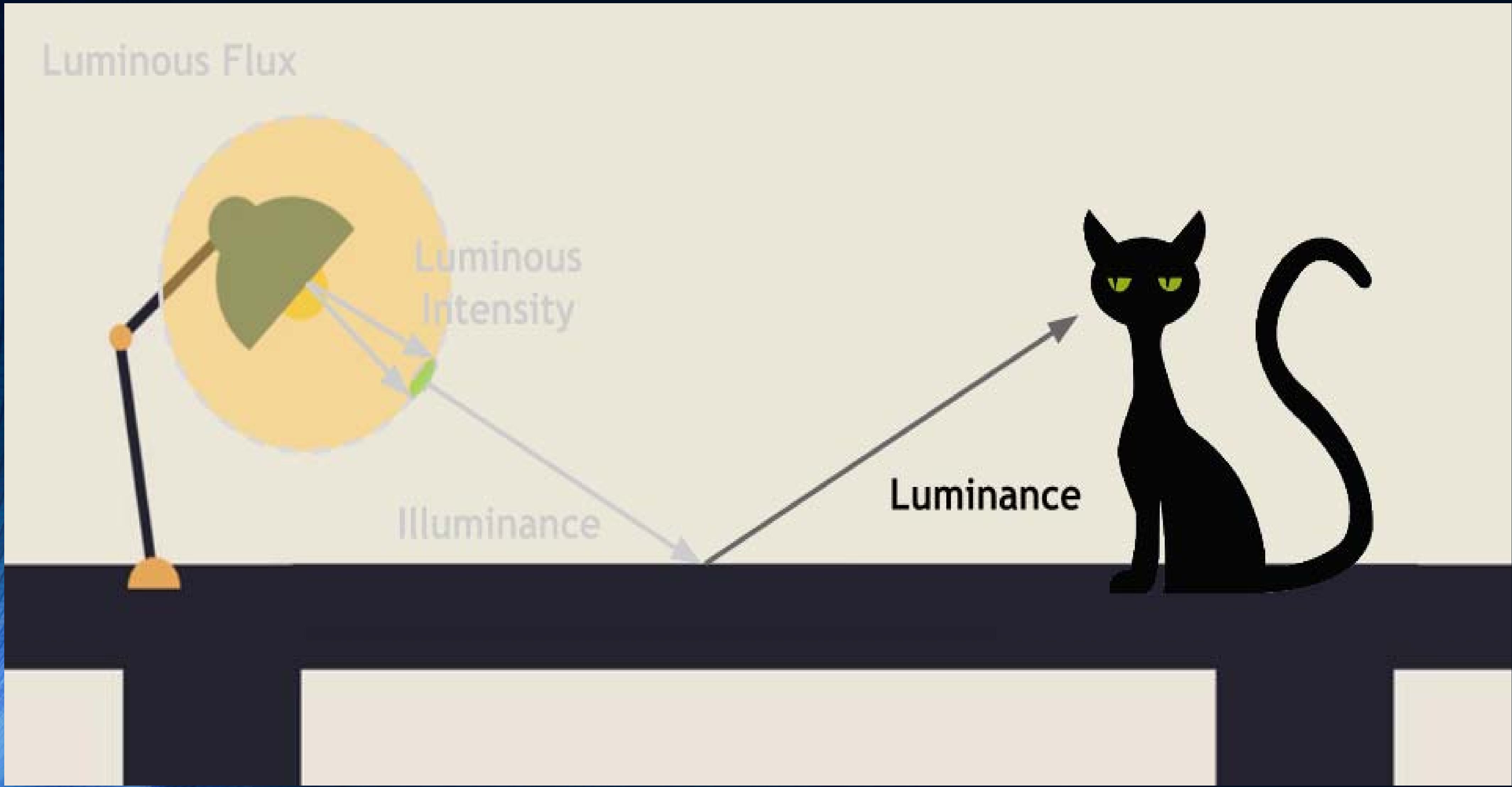
$$\Phi_V = 1700 \int \Phi(\lambda)\, V_S(\lambda) d\lambda$$




With $V_S(\lambda)$ is the **Scotopic** response curve

# Photometric Quantities

- Illuminance, $E_v$, is measured in $lm/m^2$ (aka lux). Irradiance is the photopically weighted power per unit area incident from all directions onto a surface. Most light meters measure this quantity.
- Luminous intensity, $I_v$, is measured in $lm/sr$ (aka candela, cd). Intensity is spectrally weighted power per unit solid angle. Typically, only for small sources.
- Luminance, $L_v$, is measured in $lm/m^2 - sr$ (aka $cd/m^2$). Luminance is the spectrally weighted power per unit projected area per unit solid angle. It gives the “brightness” of an source.


Luminous Flux
Luminous Intensity
Illuminance
Luminance

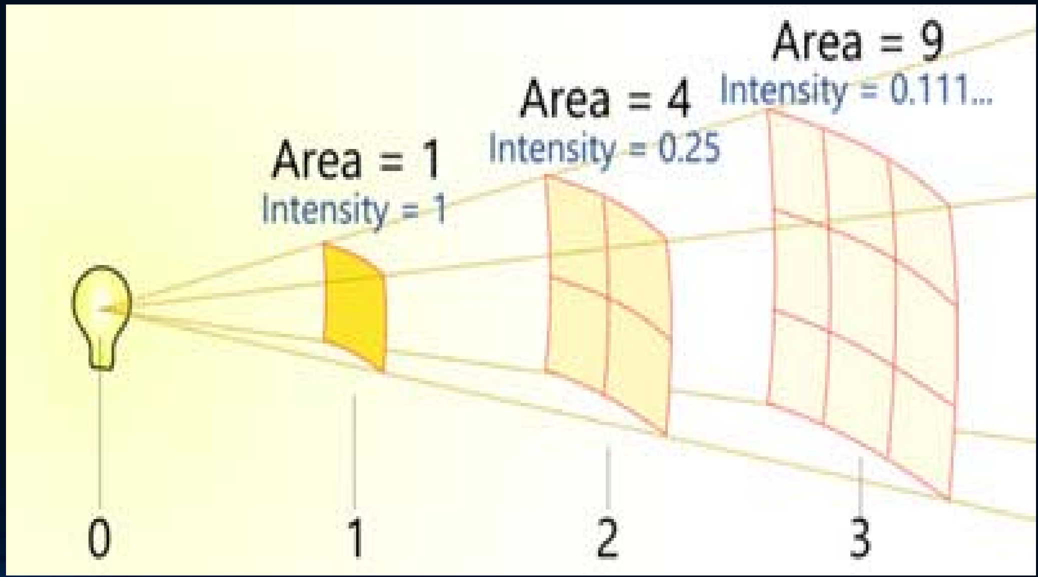
# Luminance

| Scene | Luminance ($cd/m^2$) |
|---|---|
| Clear Day | $10^4$ |
| Overcast Day | $10^3$ |
| Heavily Overcast Day | $10^2$ |
| Sunset Overcast Day | 10 |
| 15 Minutes After Sunset, Clear | 1 |
| 30 Minutes After Sunset, Clear | $10^{-1}$ |
| Bright Moonlight | $10^{-2}$ |
| Moonless Clear Night | $10^{-3}$ |
| Moonless Overcast Night | $10^{-4}$ |

# Inverse square law

- Because the light illuminates areas as we have seen. The luminescence of light is inversely proportional to the distance from the light source. This behavior is known a lot in physics and known as the inverse square law:

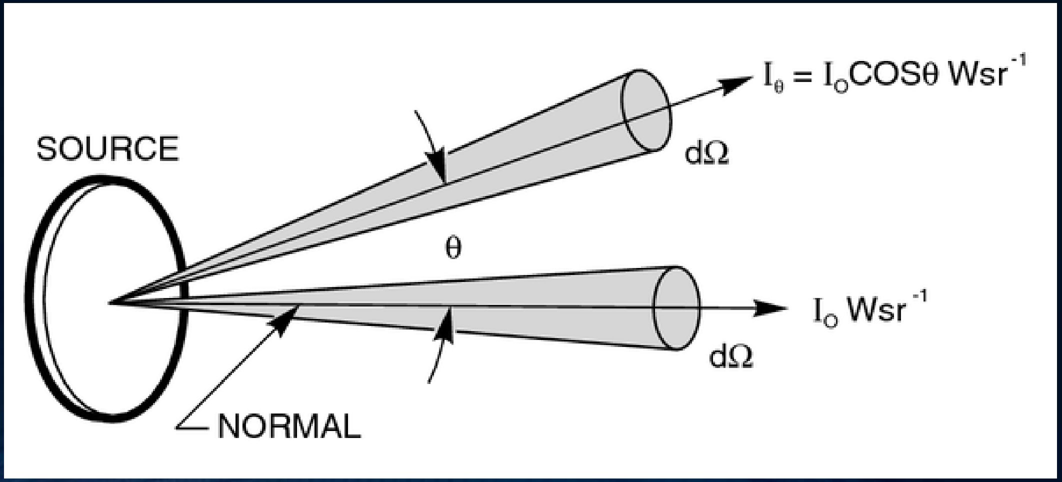
$$E = \frac{I}{r^2}$$



# Lambert Cosine Law

- Flux per unit solid angle leaving a surface in any direction is proportional to the cosine of the angle between that direction and the normal to the surface. A material that obeys Lambert's cosine law is said to be an isotropic diffuser; it has the same sterance (luminance, radiance) in all directions.

$$I(\theta) = I(0)cos\theta \text{ (Lambert's cosine law)}$$



- If the radiance at each angle is constant then

- $L_e = I(\theta)/Acos(\theta) = I(0)\cos(\theta)/Acos(\theta) = I(0) / A$

- Thus, when a radiating surface has a radiance that is independent of the viewing angle, the surface is said to be perfectly diffuse or **a Lambertian surface.**

# Retinal Illuminance

- A common unit for measuring Retinal Illuminance is the Troland, instead of lux.
- $Troland \; = \left(Luminance\ in\ \frac{cd}{m^2}\right) \times (Pupil\ Area\ in\ mm^2)$
- Retinal Illuminance (Trolands) = 278 $E_v$ (lux)

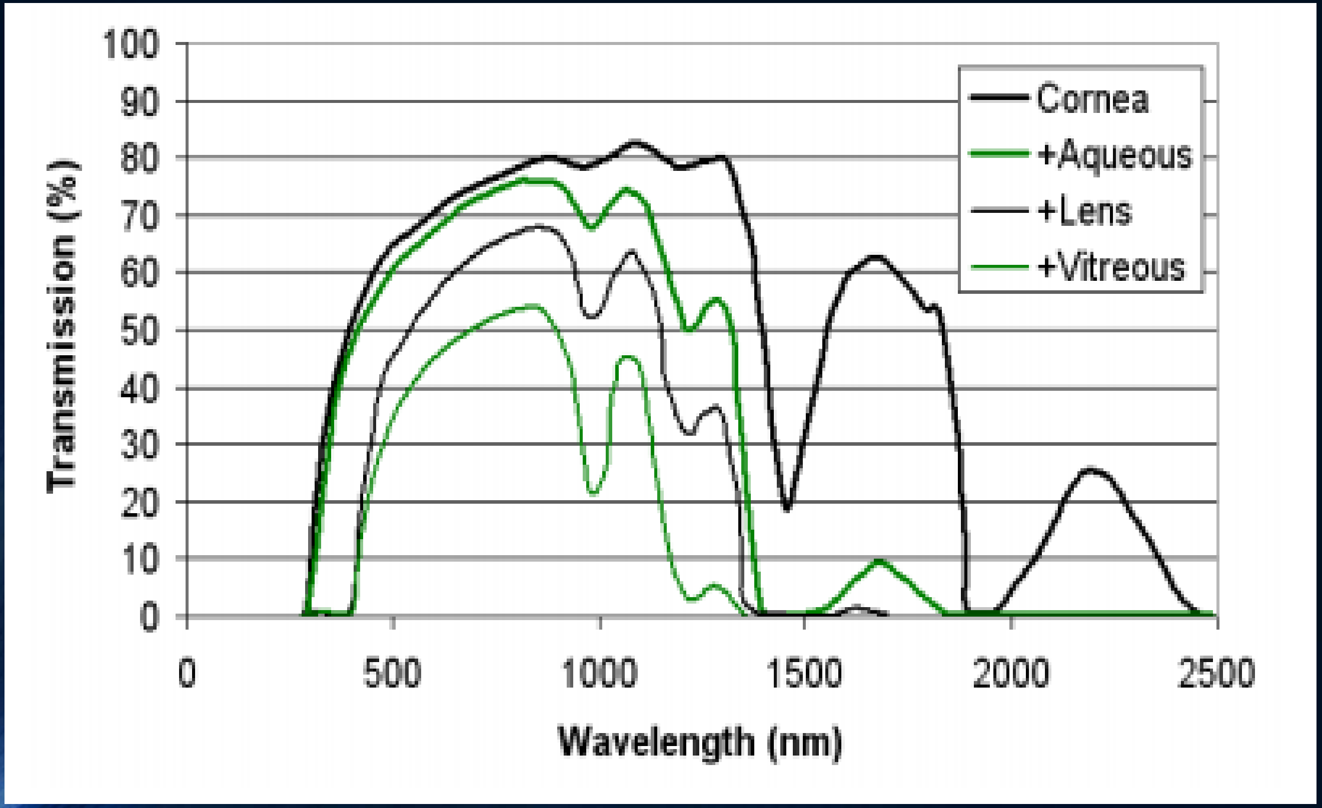
<u>Example:</u> A piece of paper in sunlight has a luminance of about 10000 $cd/m^2$. Typical pupil sizes in bright sum are 2 mm (10000 $cd$ $/m^2$)($\pi 1^2$) = 31400 Trolands

# An Extra bit !

- Ocular Tissue Absorption :

| Wavelength | Absorbing Structure | Effects |
|---|---|---|
| 180 nm - 315 nm | Cornea | Photokeratitis (Welder's Flash) |
| 315 nm - 400 nm | Lens | Cataracts |
| 400 nm -780 nm | Retina | Retinal Lesions |
| 780 nm -1.4 µm | Lens & Retina | Glassblower's Cataracts & Retinal Lesions |
| 1.4 µm - 3.0 µm | Cornea & Lens | Glassblower's & Thermal damage |
| 3.0 µm - 1.0 mm | Cornea | Thermal damage |

# Ocular Transmission curve



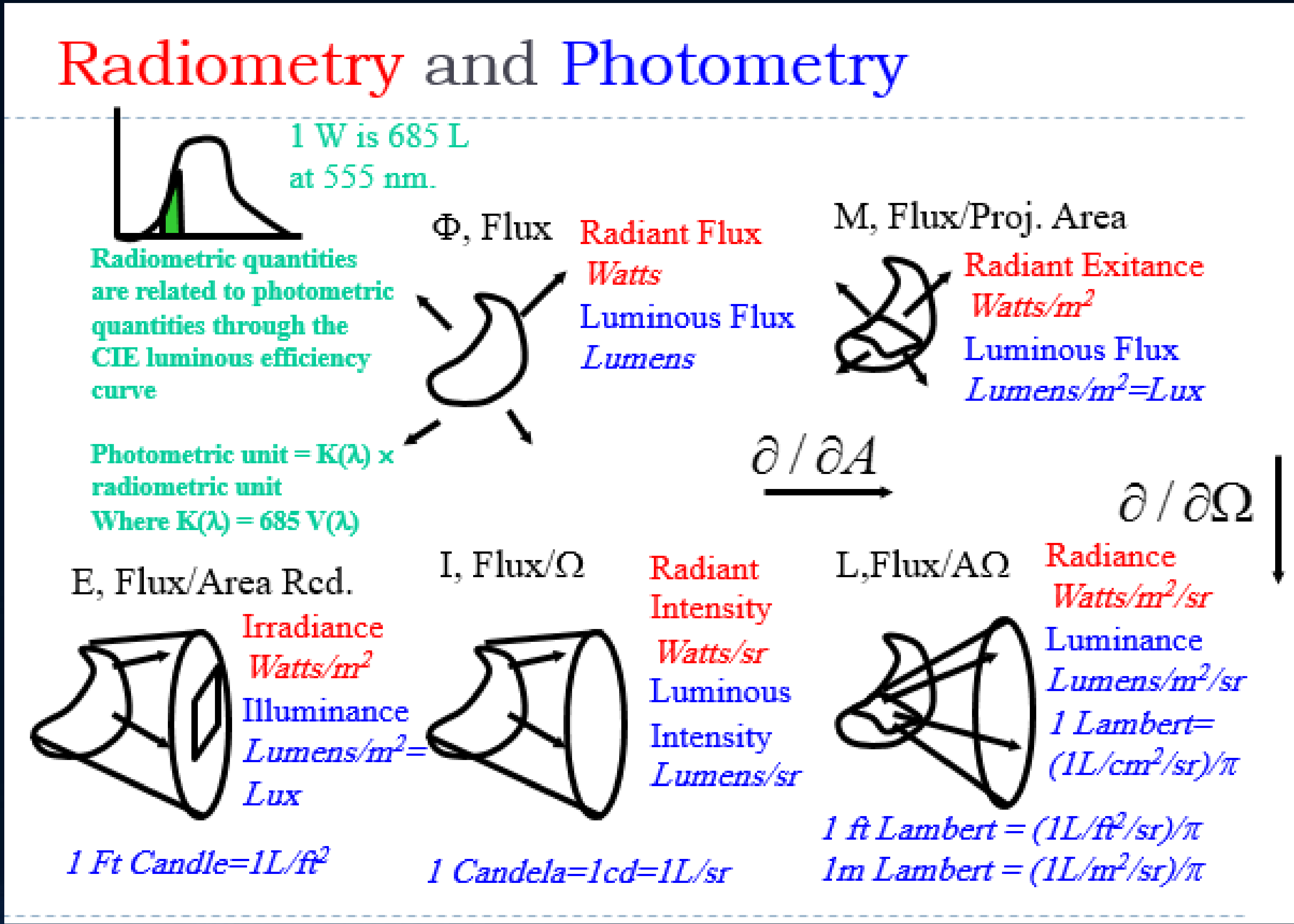
# Photokeratitis

- • Also, known as welder’s flash and snow blindness.
- • Front surface of cornea is covered by thin layer of epithelial cells that regenerate on a weekly basis.
- • UV-B damages these cell and pain and poor vision can result.
- • Typically, only lasts a couple of days until new epithelial cells resurface the cornea.

# Glassblower’s Cataract

- Intensely heated glass gives off lots of infrared radiation (think of blackbody sources)
- Chronic exposure to these wavelengths (10-15 years) can cause premature cataracts

# Summery



Radiometry and Photometry
1 W is 685 L
at 555 nm.
Radiometric quantities are related to photometric quantities through the CIE luminous efficiency curve
Photometric unit = K(λ) x radiometric unit
Where K(λ) = 685 V(λ)
Φ, Flux
Radiant Flux
Watts
Luminous Flux
Lumens
M, Flux/Proj. Area
Radiant Exitance
Watts/m2
Luminous Flux
Lumens/m2=Lux
∂/∂A
∂/∂Ω
E, Flux/Area Rcd.
Irradiance
Watts/m2
Illuminance
Lumens/m2=
Lux
I, Flux/Ω
Radiant Intensity
Watts/sr
Luminous Intensity
Lumens/sr
L,Flux/AΩ
Radiance
Watts/m2/sr
Luminance
Lumens/m2/sr
1 Lambert=
(1L/cm2/sr)/π
1 ft Lambert = (1L/ft2/sr)/π
1m Lambert = (1L/m2/sr)/π
1 Ft Candle=1L/ft2
1 Candela=1cd=1L/sr

# End of lecture II

- Extra reading for this week include,

Measuring luminesce and other radiometric quantities.  Black body radiation.  Radiometry of LASERS.

UV effects on eyes, in terms of radiometric quantities.

- Homework I is due to next week .

Have a nice week !