Lecture 8

Units

Radiometric Units

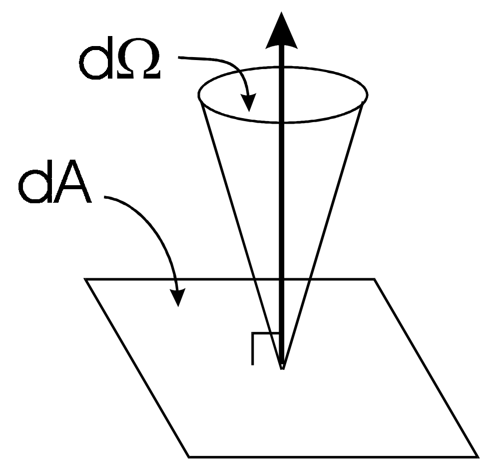
- History and definition are intertwined (candle-power)
- Two sets of units
  - Standard Physics Units (W, J, m, etc)
  - “Eye weighted” numbers
- Eye weighting - luminous efficiency curves are level-dependent
- The plane wave is a special case and very atypical
- Defined by history - not by logic!!
- Energy is the fundamental unit (J)
- Power is energy per unit time (W)
- Fundmental Unit is “Radiance”
- Radiance has units of $Wm^{-2}sr^{-1}(\alpha^{-1})$ where α is a measure of the spectrum (frequency or wavelength)
- If α is missing, then it is the integral over all frequencies
- If α present then it measures the spectral interval

The Units of “Spectral Interval”

- Possibilities for α
  - Wavelength (mm, µm, nm, etc)
  - Frequency (Hz, MHz, Ghz, Thz, etc)
  - Wavenumber (the inverse of wavelength) cm^{-1} (yes that does give a unit of $(cm^{-1})^{-1}$ which is NOT cm)
  - Photon Energy (J, eV)
- Since photon energy is h*f*, and $\lambda^{-1} = f/c$ the last three are all measures of frequency and are linearly related to each other.
- Frequency units are inversely related to wavelength units
- Formulae with wavenumber, frequency and energy are proportional to each other and can be transformed by appropriate multiplicative factors
- Wavelength formulae are different

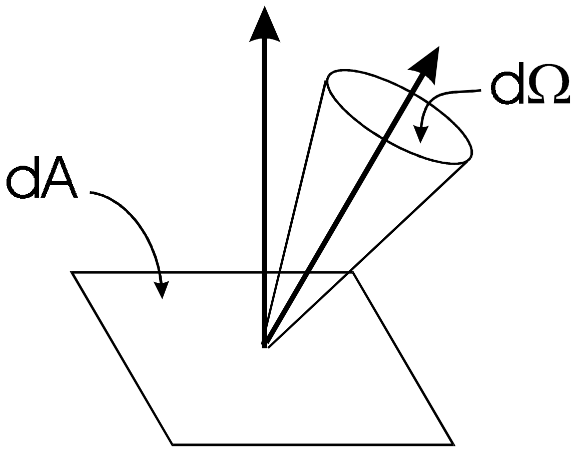
Definition of Radiance (L)

- The Radiance L can be defined as “the power passing through unit area in unit solid angle about the normal to the area (per unit spectral interval)”
- $dW = L\, dA\, d\Omega\, d\alpha$
- Typical units are...
  - $Wm^{-2}sr^{-1}\mu m^{-1}$
  - $Wm^{-2}sr^{-1}(cm^{-1})^{-1}$
  - $Wm^{-2}sr^{-1}Hz^{-1}$
  - $Erg\ sec^{-1}cm^{-2}\ sr^{-1}$ $Å^{-1}$ (ouch!!)
- Radiance is a vector



Definition of Irradiance (E)

- Is the total power (per spectral interval) passing through unit area
- Is in some sense the integral of Radiance
- But need to worry about "projected area"
- $E = \int L \cos\theta \, d\Omega$
- Hemispheric...
.
- Spherical....



Notes on Irradiance (E)

- If we do a hemispheric integral with a uniform radiance the Irradiance $E = \pi L$
- If we do a spherical integral with a uniform radiance then the Irradiance = 0
- Typical units are...
  - $Wm^{-2}\mu m^{-1}$
  - $Wm^{-2}(cm^{-1})^{-1}$
  - $Wm^{-2}Hz^{-1}$
  - Erg sec^{-1} cm^{-2} $Å^{-1}$ (ouch!!)
- Irradiance is a vector

Radiant Intensity

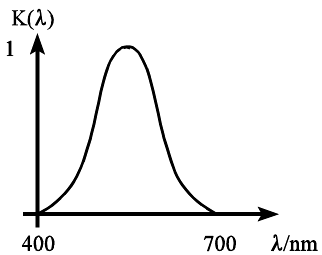
- Radiant intensity is the power radiated by a source into unit solid angle
- $dP = I d\Omega$
- If the source is isotropic the $P = 4\pi I$
- Typical units are...
  - $Wsr^{-1}\mu m^{-1}$
  - $Wsr^{-1}(cm^{-1})^{-1}$
  - $Wsr^{-1}Hz^{-1}$
  - Erg sec^{-1} sr^{-1} $Å^{-1}$ (ouch!!)

It Depends Upon Your Point of View

- What you are interested in is often determined by the situation you find yourself in
- "Point" sources
  - Total Power
  - Radiant Intensity
- "Extended" sources
  - Total power
  - Irradiance (Radiant Exitance)
  - Radiance
- Receivers
  - Radiance
  - Irradiance

Photometric Units

- Photometric units are weighted by the Eye response
- The Power corresponds to the “luminous flux” defined as $\int P(\lambda)K(\lambda)d\lambda$
- $K(\lambda)$ is the eye response and is supposed to be standard
- Difficult to directly relate P and K unless the spectral distribution is known
- Defined in terms of freezing point of platinum (~2040.8K)
  - Photometric Units do not have a “spectral interval” term

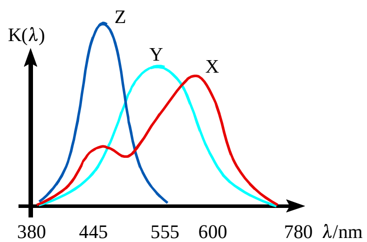


Photometric Units

- Power becomes Luminous Flux (lumens)
- Radiant Intensity becomes Luminous Intensity (candle power) (candela) $1cm^2$ of a source of freezing platimum is 60cd normal to the surface ($cd \equiv lm\ sr^{-1}$)
- Irradiance becomes Illumination
  - footcandle ($lm\ ft^{-2}$) in British units
  - lux ($lm\ m^{-2}$) in metric (approved SI unit)
- Radiance becomes Luminance
  - nit ($lm\ m^{-2}\ sr^{-1}$)

Colorimetry

- A similar approach is used to define color scales in colorimetry
- Three weighting factors ($K_x(\lambda)$, $K_y(\lambda)$, $K_z(\lambda)$) are used to define color with peak responses at 600, 555 and 445 respectively
- These are supposed to represent standard reference stimuli
- $K_y(\lambda)$ is defined identically to the luminosity standard



Integrated Photometric Units

- These units are derived from integrated emission from a surface assuming that the emission is uniform in solid angle (Lambertian surface)
- Illumination of 1 $lm\ m^{-2}$ corresponds to a Luminance of 1 apostlib (1 apostlib = $1/\pi$ nit)
- Illumination of 1 $lm\ cm^{-2}$ corresponds to a Luminance of 1 lambert (1 lambert = $10^4/\pi$ nit)
- Illumination of 1 $lm\ ft^{-2}$ corresponds to a Luminance of 1 foot-lambert