Optics 2 Review
Spectrometry & Photometry

Overview
Spectrometry: examining the absorption and emission of light and other radiation by matter.
Photometry: measurement of light as it is perceived by the human eye.

Spectrometry
Demonstrates that light has a particle nature as well as a wave nature.
Relies on an understanding of how electrons move between shells in an atom to absorb and release photons.

The Bohr Model
Electrons exist in discrete energy levels (shells) around the nucleus of an atom.
The shell closest to the nucleus is the "ground state".
When electrons move form one energy level to another a specific amount (quantum) of energy is either absorbed or released.

Energy Absorption
Photons are absorbed as electrons move from the ground state to a higher level (excited state).

Spontaneous Emission
When an excited electron moves back to the ground state a photon is released (emitted).
This occurs naturally since ground state is preferred.
Compare this to Stimulated Emission in a LASER.

Energy of a Photon
Energy is directly proportional to the light wave's frequency.
The higher the frequency the more energy.
Energy is inversely proportional to wavelength.
The longer the wavelength, the less energy in the photon.
Energy is measured in electron volts (eV).

$\Delta E = hf$ h is Planck's constant = 4.136×10^{-15}

Emission & Absorption Spectra

Dispersion: separating light into component wavelengths
Refraction: use prism to separate wavelengths (shorter wavelength refracted more)
Diffraction: use a spectrometer

Absorption Spectrum (Discontinuous)

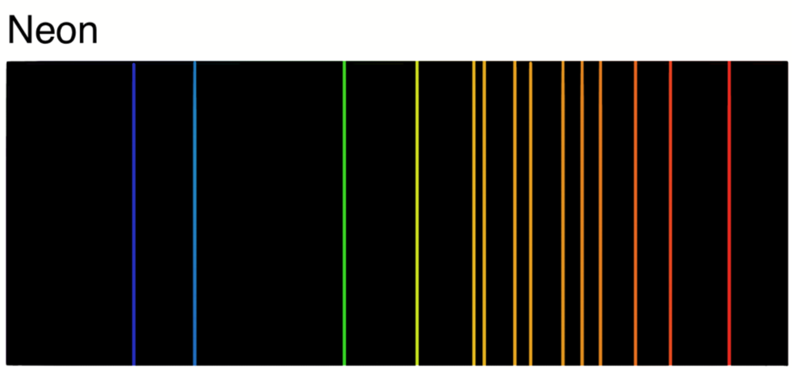
In an absorption spectrum the black lines are wavelengths absorbed by the cold gas (non-excited).

Continuous Emission Spectrum

Solids and Liquids (with rare exceptions) give only continuous absorption and emission spectra.
See ALL wavelengths without interruption.

Emission Line Spectrum

In an emission spectrum the colored lines are wavelength emitted by the excited gas.
When excited gas emits same wavelengths as it absorbs in the cold state.



Sources of Optical Radiation

Sunlight
Incandescent Lamps
Fluorescent Lamp
LED (Light Emitting Diode)
Discharge Tubes (Gas Tubes)

Sodium Fluorescein

Absorbs higher frequency (shorter wavelength) “cobalt blue” and emits lower frequency (longer wavelength) yellow-green light.

Blackbody Radiators

A theoretical model (not real) of an "ideal absorber".

Absorbs ALL Electromagnetic Radiation (EMR) at a particular temperature.

Emits ALL wavelengths when heated (ideal emitter/radiator).

The peak intensity wavelength is inversely proportional to the temperature of the blackbody.

As temperature increases the peak intensity moves to a lower wavelength.

Wien Displacement Law

The wavelength of peak intensity in blackbody emission decreases as temperature increases.

Peak wavelength in nm = $\lambda max = b/T$

b: Wien's displacement constant = 2.898×10^6 nm-K

T: absolute temperature in Kelvin (0°C = +273.15K)

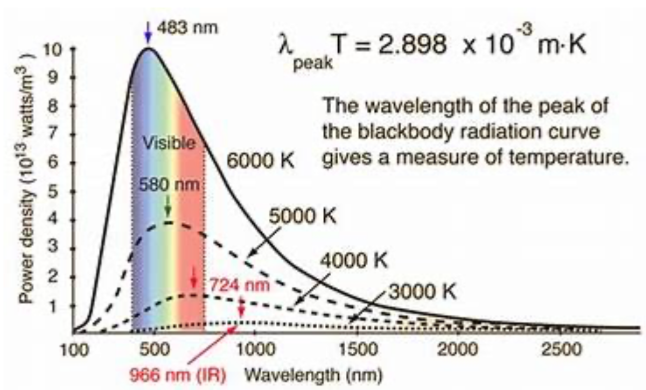
As T gets larger, peak intensity is at lower wavelength

Total Radiant Exitance

Area ("M") under / within blackbody radiation curve for a given temperature.

$M = \sigma T^4$ (T in Kelvin) $\sigma = 5.67 \times 10^{-8}$ w/m^2k^4 (Stefan-Boltzmann constant)

Area M increases by a power of 4 with increased T.



(credit: http://www.hyperphysics.phy-astr.gsu.edu/hbase/wien.html)

Graybodies and Emissivity

Graybodies emit a certain percentage "ε" of what a blackbody would emit at a certain temperature (peak wavelength does not change).

A graybody has similar distribution to that of a blackbody material except at a lower intensity.

Selective Radiator

Emissivity varies with wavelength.

Emissivity (ε)

Emissivity is the ratio of the thermal radiation from a surface to the radiation from blackbody.

$M = \varepsilon\sigma T^4$

For blackbody: $\varepsilon = 1$

For graybody: $\varepsilon < 1$

LASERS

Light Amplification by Stimulated Emission of Radiation

Stimulated Emission

Incident photon passes by electron in excited state.

Energy of incident photon equals energy difference between excited and ground states for excited electron.

Characteristics for LASER Light

Monochromatic

Coherent (photons all in the same phase, frequency, and direction)

Directional

Powerful

Photometry

Photometry: measuring light in terms of its perceived brightness to the human eye
Radiometry: measuring electromagnetic radiation (EMR) including visible light

Light Bulbs (specification)
Watts: electrical consumption
Lumens: light output

Lumens: perceived amount of output or brightness of a source
- Takes into account the color sensitivity of the human eye.
- The more lumens the brighter the source.

Wattage: defines how much energy a light bulb uses to produce a certain brightness or luminous output (number of lumens).

Color Temperature
- A way to describe the appearance of light.
- Measured in Kelvin (K) from 1,000 to 10,000 K

Kelvin
- Absolute zero (0K) is equivalent to -273.15°C (-459.67°F).
- Conversion from Celsius to Kelvin T(K) = T(°C) + 273.15.

Color Temperature
- A heated metal object glows with various colors (orange, yellow, blue) depending on temperature.
- Color temperature is meant to replicate Kelvin temperature of heated metal object.

Light Output
- Based on Area
  - Point Source: zero area
  - Extended Source: finite area
- Based on Wavelength
  - Monochromatic Source: Single Wavelength
  - Polychromatic Source: Multiple Wavelengths

Brightness: the visual system's sensitivity to color

Luminosity Curve or Vλ curve

Brightness depends on how the visual system detects light and color.

Photopic: Daylight or Cone vision

Scotopic: Night or Rod vision

Radiometry

Absolute measure of light.

Not compensated for eye's sensitivity to color.

Measures all types of EMR.

Photometry

Measure of light compensated for eye's sensitivity to color.

Wavelength dependent.

Measures visible EMR.

Measures of Quantity of Light Emitted

Energy (E)

Flux (Φ)

Intensity (I)

Luminance (L)

The Candela (cd)

Unit of measurement of the luminous intensity of a source.

One candela is equal to $1/60^{th}$ of the luminous intensity per square of a blackbody at the temperature of solidification of platinum.

Luminous Flux

The transfer of light from a source is luminous flux (ϕ).

The rate at which energy flows.

Energy in the visible spectrum.

Unit is the lumen.

Measures of Quantity of Light Received

Illumination / Illuminance / Irradiance (E)

Amount of light falling on an object or surface

Must Distinguish Between:

1. The amount of light emitted by a point source
   Luminous Flux and Luminous Intensity
2. The amount of light received on a surface
   Illumination or Illuminance
3. The amount of light emitted or re-emitted by a surface
   Luminance (brightness)

Quantum Concept: Wavelike photon

Light of given wavelength exists in packets

E = hf and f = c/λ therefore: E = hc / λ

Radiometric Unit: Radiant Energy: Joule
Photometric Unit: Luminous Energy: Talbot

Shorter wavelengths have more energy.
Higher frequencies have more energy.

Flux

Joules / sec = watts (Φ) (not the same as electrical watt

Talbot / sec = Lumens (Φ)

Sensitivity is a function of wavelength.

Intensity (I)

Radiant Intensity: watts / steradian (I)

Luminous Intensity: lumens / steradian (I)

Angle vs Solid Angle (Radian vs Steradian)

Radian (rad)

$$1\, radian(rad) = \frac{arc\ of\ same\ length\ as\ radius}{radius}$$

Full circle has 2π radians (2πr)
Semi-circle has π radians (πr)

Steradian (ω) omega
3D geometry of a solid angle

$$\omega = \frac{area}{distance^2} = \frac{A}{d^2}$$

Sphere = 4π steradians
Hemisphere = 2π steradians
Flat Surface = π steradians

Example Problems

A source has an area of 3000 cm^2 and a solid angle of 0.30 steradians. What is the distance of the source?

$$\omega = \frac{area}{distance^2}$$

$d^2 = A/\omega$ $\quad$ $d^2 = 3000\ cm^2 /0.30$ $\quad$ $d = (10{,}000)^{-1/2}$

d = 100cm

If a point source emits 100 lumens in 2π steradian, what is the candle power of the source?

Candle power = cd = lumens/steradian = I

$$candle\ power = \frac{flux}{solid\ angle} = \frac{\phi\ (lumens)}{\omega\ (steradians)} = \frac{100}{2\pi} = 15.92\ candela$$

Illumination

Inverse Square Law

The illuminance onto a surface decreases exponentially with the square of the distance from a point source.

$E = I/d^{2.}$

E = (lux): (illuminance)
I = candela (cd): intensity
d = (cm or m): distance from point source

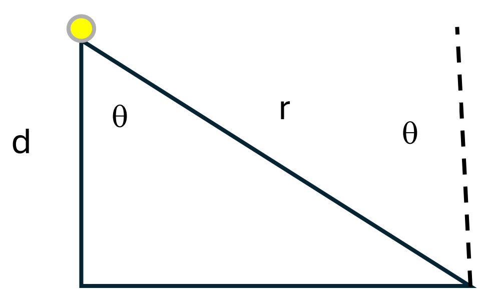
Lambert's Cosine Law

Lambertian Reflection

The property of a surface where light is scattered equally in all directions, regardless of the angle at which it hits the surface.

When the surface is not normal / perpendicular to the source, the perceived / apparent surface area is reduced, and the illuminance decreases linearly with the angle of the surface from the normal.

The projected area is reduced by the amount of the angle from normal.
Called the foreshorten area.
Area varies as the cosine of the normal area.



d: distance from source to normal

r: distance from source due to angle

$A_\theta = A_0 \cos\theta$

E = lux

I = candela

r = cm or m

θ = degrees

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