Medical Equipment II - 2010
Chapter 14: Atoms and Light (4)

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Web: http://ymk.k-space.org/courses.htm

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Heating Tissue with Light

- Hyperthermia
  - Heating of tissue as part of cancer therapy
- Tissue ablation
  - Sufficient energy is deposited to vaporize tissue.
- Heating may be a side effect of phototherapy.
- Modeling
  - Source term for deposition of photon energy and
  - Term for flow of energy away in warmed blood

Bioheat Equation

- Linear equation for heat conduction

$$j_H = -K \frac{dT}{dx}$$

- Heat-conduction equation (same as Fick's)

$$\rho_t C_t \frac{\partial T}{\partial t} = K \nabla^2 T$$

- Perfusion P (analogous to clearance)
  - volume flow of blood per unit mass of tissue

Bioheat Equation

- Perfusion extra term

$$C_b \frac{\mathrm{J}}{\mathrm{K\ kg\ (blood)}} \times \rho_b \frac{\mathrm{kg\ (blood)}}{\mathrm{m^3\ (blood)}} \times \rho_t P \frac{\mathrm{m^3\ (blood)}}{\mathrm{m^3\ (tissue)\ s}} \times [(T - T_0)\ \mathrm{K}]$$

or

$$C_b \rho_b \rho_t P (T - T_0) \frac{\mathrm{J}}{\mathrm{m^3\ (tissue)\ s}},$$

$$\rho_t C_t \frac{\partial T}{\partial t} = K \nabla^2 T - C_b \rho_b \rho_t P (T - T_0)$$

Bioheat Equation

- Heat deposition by the beam
  - Beam energy fluence rate
  - Rate of absorption proportional to μ_a

$$\psi = \frac{d\Psi}{dt}.$$

- Final form of Bioheat Equation

$$\rho_t C_t \frac{\partial T}{\partial t} = K\nabla^2 T - C_b \rho_b \rho_t P(T - T_0) + \mu_a \psi.$$

Radiometry and Photometry

- Radiometry
  - Measurement of radiant energy
  - Independent of any detector
- Photometry
  - Measurement of ability of EM radiation to produce human visual sensation
- Actinometry
  - Measurement of photon flux or photon dose (total number of photons) independent of any subsequent photoactivated process

Radiometric Definitions

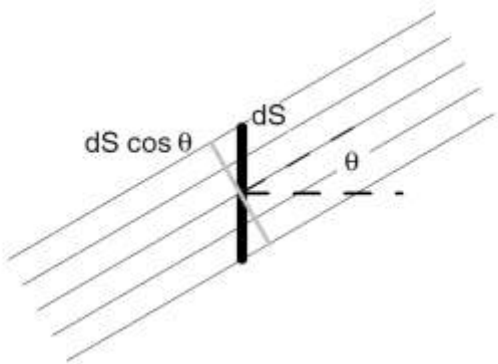
- Radiant Energy
  - The total amount of energy being considered
  - Measured in joules.
  - Emitted by a source, transferred from one region to another,or received by a detector.
- Radiant Power
  - Rate at which the energy is radiated, transferred, or received
  - Measured in Watts

Radiometric Definitions

- Point Source: Radiant Intensity
  - Radiant power per unit solid angle (no $1/r^2$)

$$\frac{dP}{d\Omega} = \frac{P}{4\pi} \quad (\mathrm{W\ sr^{-1}})$$

- Extended Source: Radiance L
  - Amount of radiant power per unit solid angle per unit surface area projected perpendicular to the direction of the radiant energy



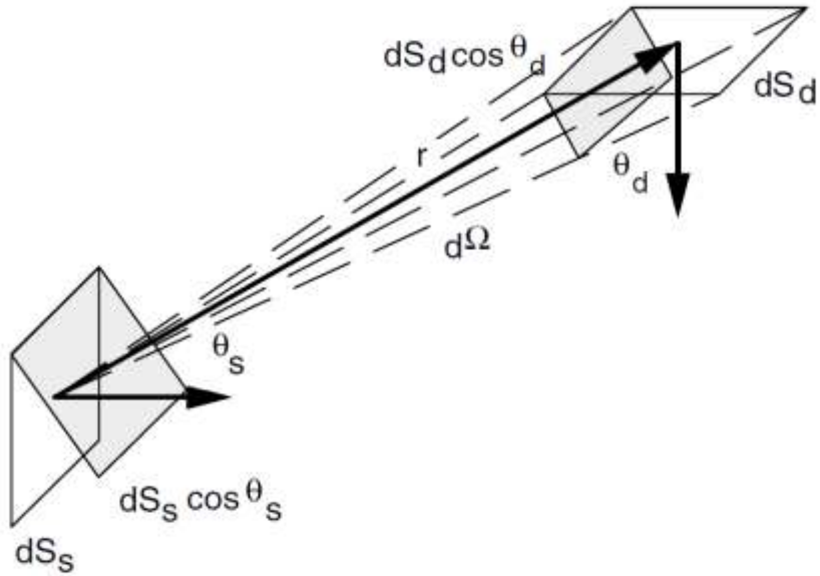
Radiometric Definitions

- Energy Striking a Surface: Irradiance E
  - Power per unit area incident on a surface
  - Point source

$$E = \frac{dP}{\cos\theta_d \, dS_d}.$$

  - Extended source

$$L dS_s d\Omega = \frac{d^2 P}{\cos\theta_s \, dS_s \, d\Omega} dS_s \, d\Omega,$$



Radiometric Definitions

- For perfectly diffuse surfaces, the radiation is isotropic ($L=L_o$)
  - Lambert's law of illumination
  - Isotropic or Lambertian surface

$$E = \frac{dS_d 2\pi L_0 \int_0^{\pi/2} \cos\theta_d \sin\theta_d d\theta_d}{dS_d} = \pi L_0.$$

$$\psi = 4\pi L_0 = 4E \quad \text{(isotropic radiation)}.$$

Radiometric Definitions

- Spectrum
  - When the energy is not monochromatic, we define amount of energy per unit wavelength interval as R_λ, with units J m^{-1} or J nm^{-1}.
  - Total energy between wavelengths *λ_1 and λ_2 is*

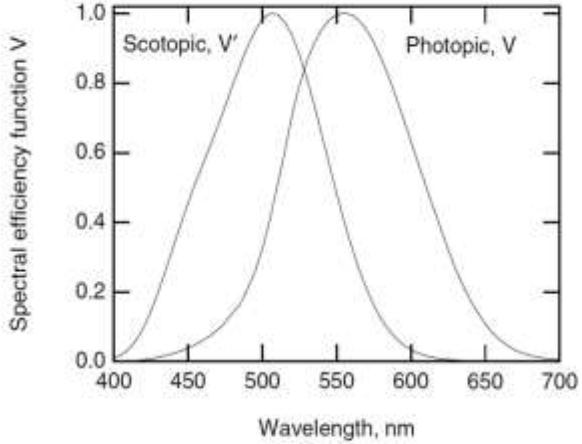
$$\int_{\lambda_1}^{\lambda_2} R_\lambda(\lambda)\, d\lambda$$

and between frequencies ν_1 and ν_2 it is,

$$\int_{\nu_1}^{\nu_2} R_\nu(\nu) d\nu.$$

Photometric Definitions

- Rods (sensitive, no color) and cones (color)
- Photopic vision
  - Normal vision at high levels of illumination in which the eye can distinguish colors.
- Scotopic vision
  - occurs at low light with dark-adapted eye.



Photometric Definitions

- Luminous flux P_v in lumens (lm)
- Peak sensitivity for photopic vision is for green light, *λ = 555 nm.*

$$P = 1\ \mathrm{W} \Longleftrightarrow P_v = 683\ \mathrm{lm},$$
$$P_v = 1\ \mathrm{lm} \Longleftrightarrow P = 1.464 \times 10^{-3}\ \mathrm{W}.$$

- Ratio P_v/P at 555 nm is Luminous efficacy for photopic vision, $K_m = 683$ lm W^{-1}
- For scotopic vision, $K_m \approx$ *1700 lm W^{-1}*

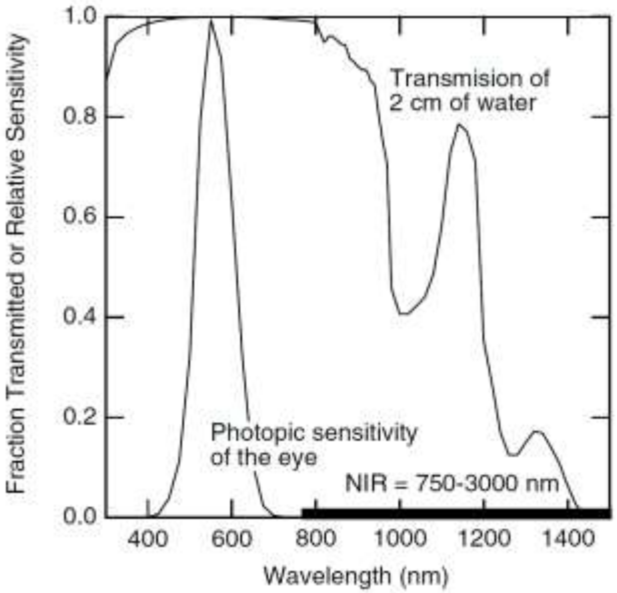
Photometric Definitions

$$P_v = K_m \int_{400\ \mathrm{nm}}^{700\ \mathrm{nm}} V(\lambda) P_\lambda(\lambda)\, d\lambda.$$

- If P were spread uniformly over the visible spectrum, overall conversion efficiency would be about 200 lm W−1
  - Incandescent lamp: 10–20 lm W^{-1}
  - Florescent lamp: 60–80 lm W^{-1}
- Number of lumens per steradian is luminous intensity, in lm sr−1 (candle)

Photometric Definitions

- Peak of the eye's spectral efficiency function is at about the peak of the sun's blackbody spectrum
  - Simple yet incorrect explanation: Evolution
  - Vertebrate eye composition
  - Insects: no water (more UV)



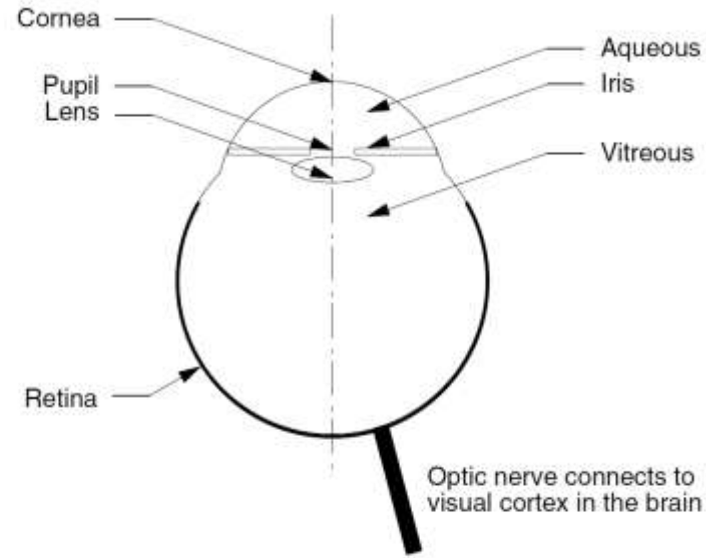
The Eye

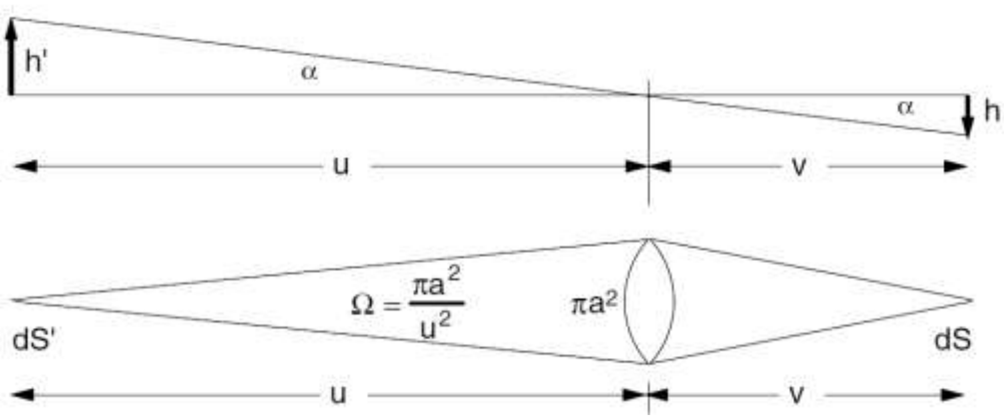
- Snell's law

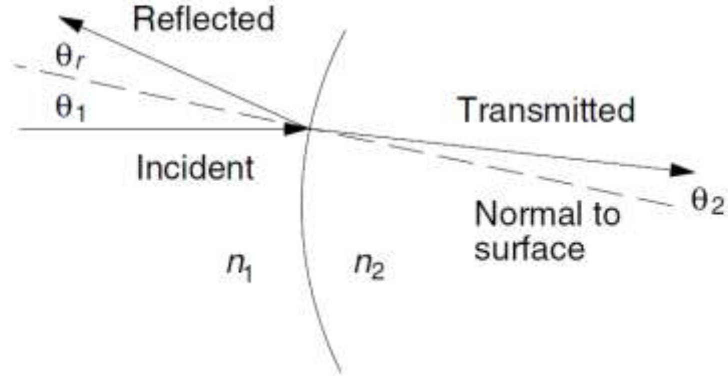
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

- Thin lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$







$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\theta_1 = \theta_r$$

The Eye

- Optometry: Vergence (diopters)

$$U = -\frac{1}{u} \quad \text{(diverging from the object)},$$

$$V = \frac{1}{v} \quad \text{(converging to the image)},$$

$$F = \frac{1}{f} \quad \text{(a converging lens)}.$$

$$V = F + U.$$

The Eye

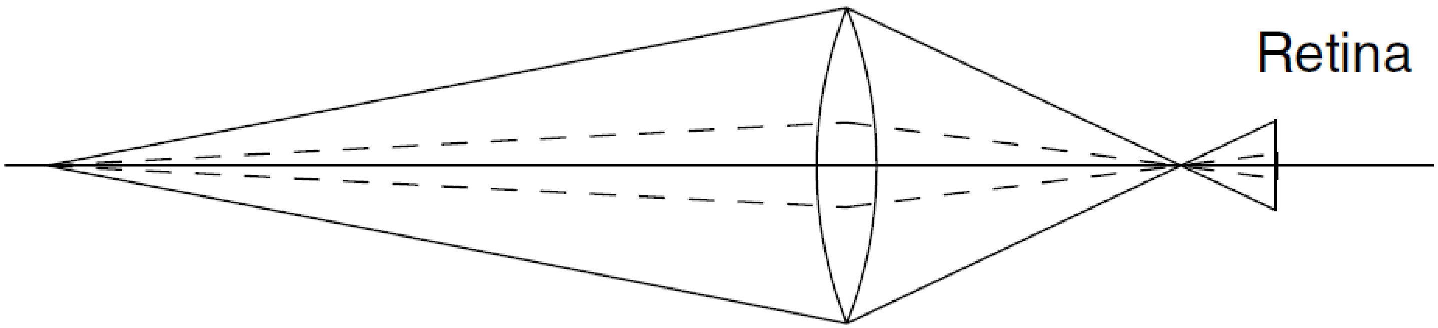
- Accomodation
  - Decreases with age: bifocals
- Emmetropic (normal) eye: $V=F$ (when $U=0$)
- Nearsightedness or myopia: $F>V$
- Farsighted or hypermetropic: $F<V$
- Astigmatism
  - Eye is not symmetric about an axis through center of lens
  - Occurs at surface of cornea: corrected by lenses

The Eye

- Chromatic aberration
  - Index of refraction varies with wavelength.
  - Nearly a 2-diopter change in overall refractive power from the red to the blue.
- Spherical aberration
  - Refractive power changes with distance from the axis of the eye.
  - Different from astigmatism, which is a departure from symmetry at different angles about the axis

The Eye

- Depth of field
  - Brighter light: smaller pupil and sharper image



Problem Assignments

- Information posted on web site
- Chapter 14 Problems: 1, 2, 3,4, 10, 11, 13, 14, 18, 19, 20, 21, 22, 23, 26, 27, 29, 30, 38, 39, 41, 43, 44, 45