Biomedical Optics II

Basic optics

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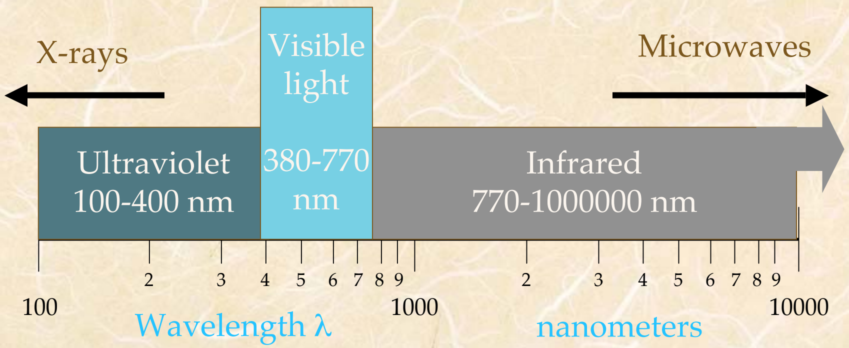
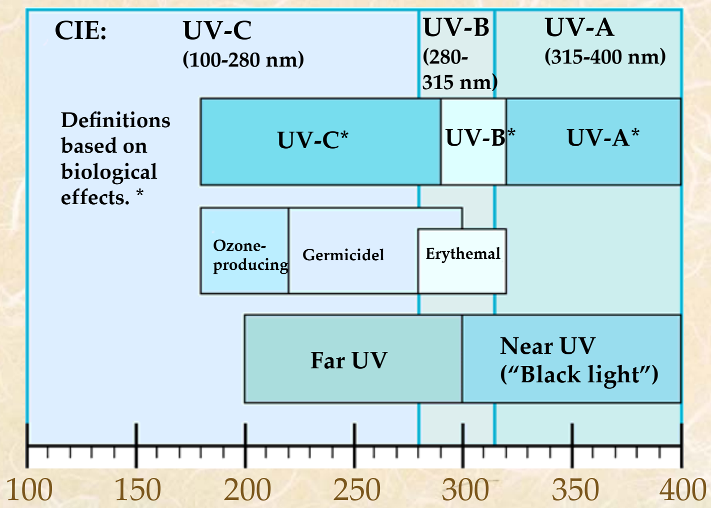
Postulates of ray optics

- Light travel in the form of rays. The rays are emitted by light sources and can be observed when they reach an optical detector
- An optical medium is characterized by a quantity $n \geq 1$, called the refractive index. The refractive index is the ratio of speed of light in free space c_0 to that in the medium c. Therefore, the time taken by light to travel a distance d equals $d/c = nd/c_0$. It is thus proportional to the product nd, known as the optical path length.

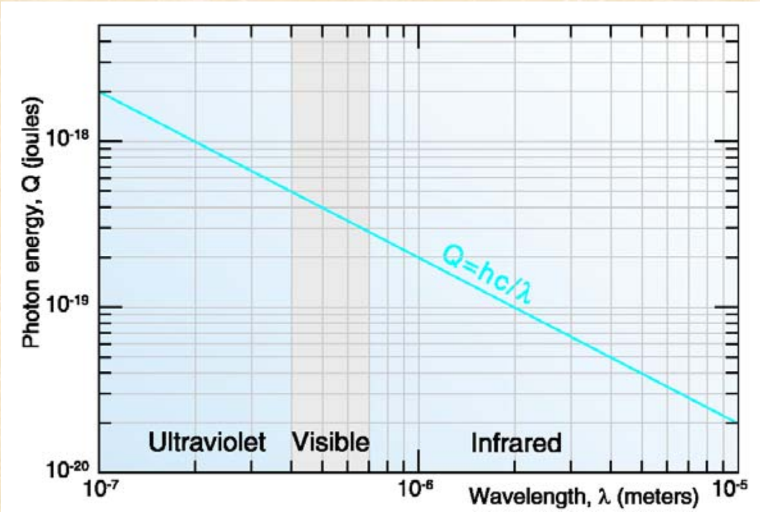
What is Light?



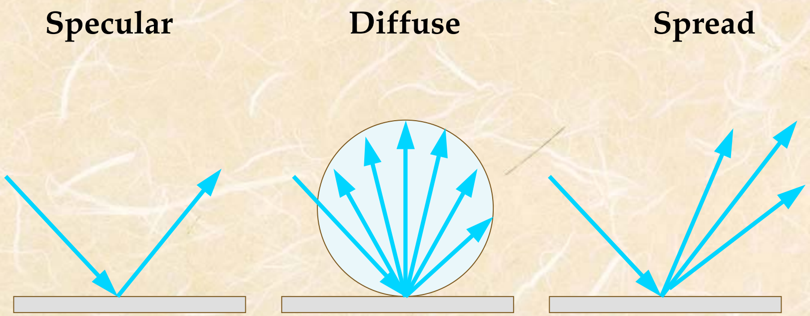
Short wavelength's



Photon energy vs wavelength

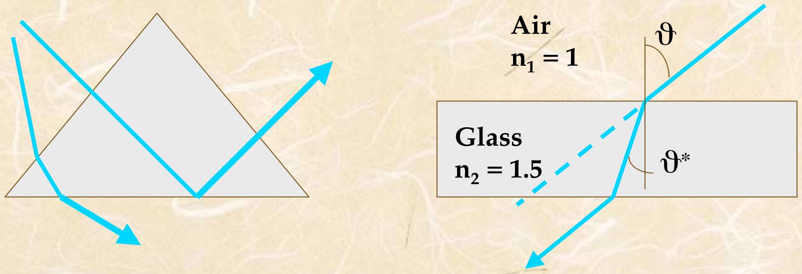


Reflection differences

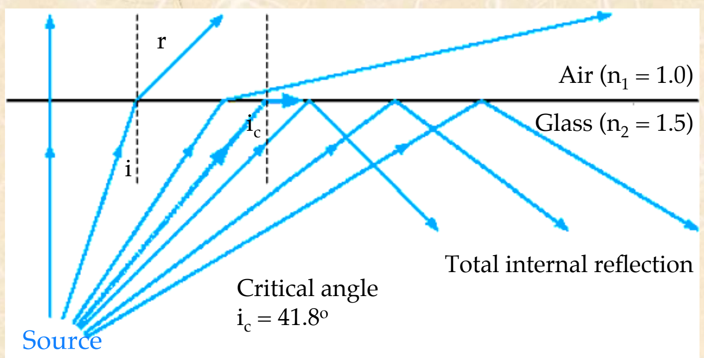


Snells law

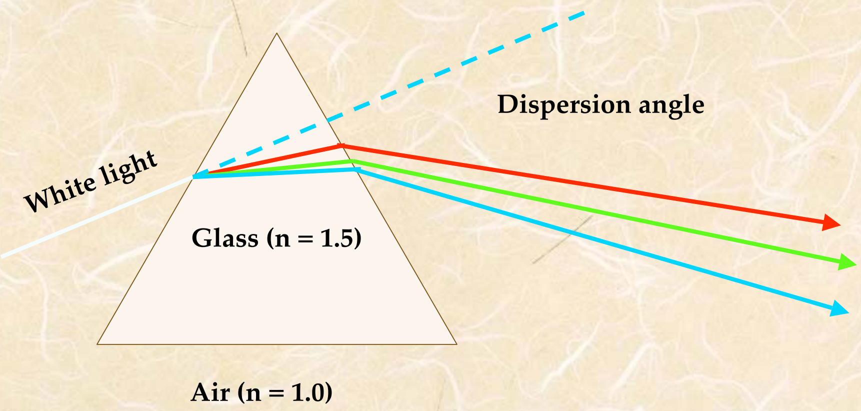
$n_1 * \sin(\vartheta) = n_2 * \sin(\vartheta^*)$



Refraction and reflection

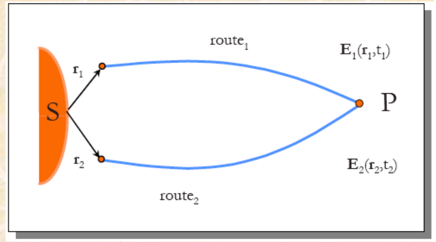


Prisms



Coherence

Study of the correlation properties between the phases of monochromatic wave components in radiation



Temporal coherence (longitudinal coherence)
spectral purity of the source
Spatial coherence (lateral coherence)
size of the source

In point P:

$$E_P = E_1(r_1,t) + E_2(r_2,t)$$

Square-law detector:

$$I_P = \langle E_P * E_P^* \rangle = \langle (E_1 + E_2) * \rangle \langle (E_1^* + E_2^*) * \rangle$$

$$= I_1 + I_2 + 2\mathrm{Re}\langle E_1 E_2^* \rangle$$

(polarizations assumed to be the same)

Assume S to be stationary:

$$t_1 = t \text{ and } t_2 = t + \tau$$

Blackbody radiation

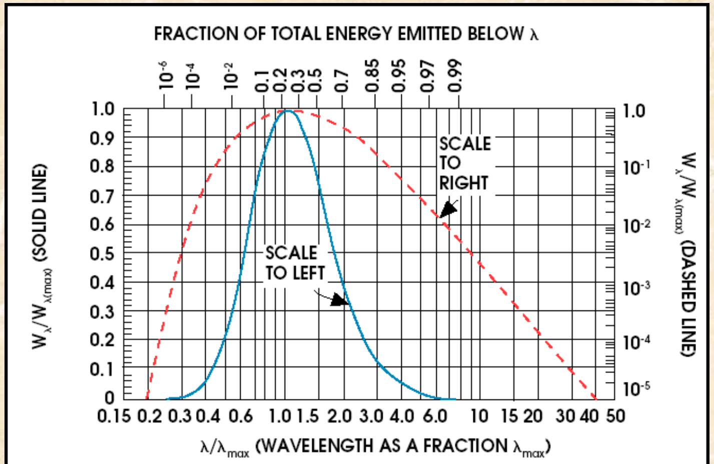
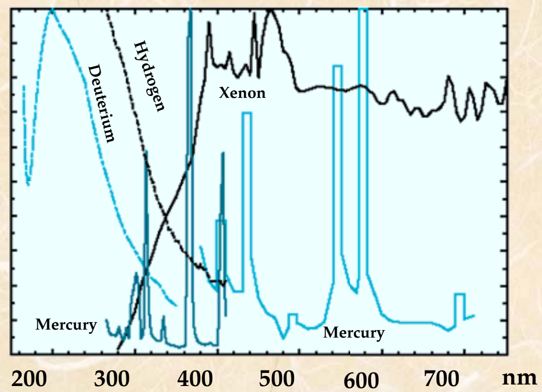
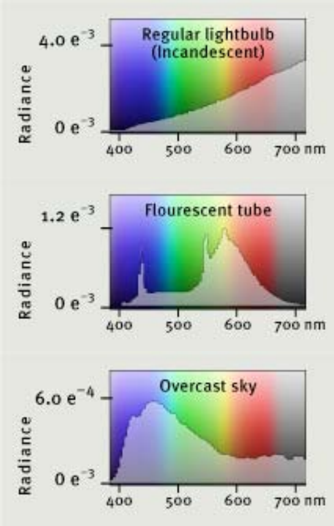


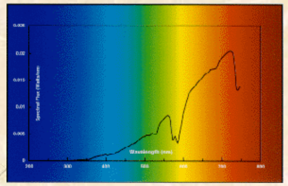
Figure 1. *Spectral distribution of blackbody radiation.*

Luminant sources



Spectra

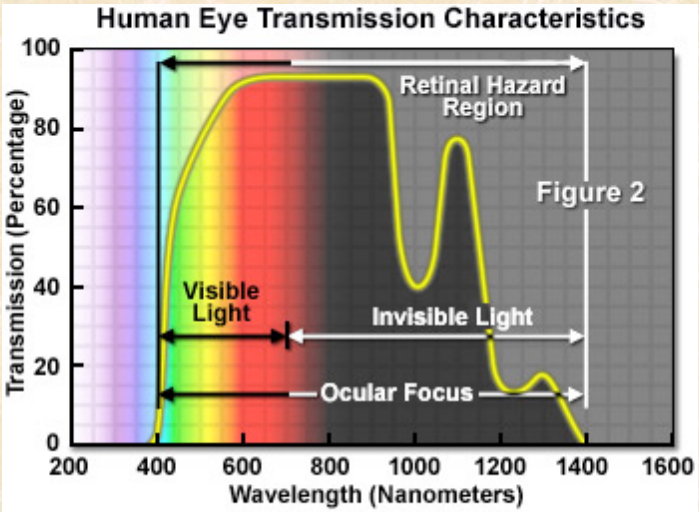




Effects of light

Photobiological Spectral Domain (CIE Band)	Eye Effects	Skin Effects
Ultraviolet C (200-280 nm)	Photokeratitis	Erythema (Sunburn) Skin Cancer
Ultraviolet B (280-315 nm)	Photokeratitis	Erythema (Sunburn) Accelerated Skin Aging Increased Pigmentation
Ultraviolet A (315-400 nm)	Photochemical UV Cataract	Pigment Darkening Skin Burn
Visible (400-780 nm)	Photochemical and Thermal Retinal Injury Color and Night Vision Degradation	Skin Burn Photosensitive Reactions
Infrared A (780-1400 nm)	Retinal Burns Cataract	Skin Burn
Infrared B (1400-3000 nm)	Corneal Burn Aqueous Flare IR Cataract	Skin Burn
Infrared C (3000-1 million nm)	Corneal Burn	Skin Burn

Eye sensitivity



Radiometry vs Photometry

- Radiometry is the science of measuring light in any portion of the electromagnetic spectrum.
- Photometry is the science of measuring visible light in units that are weighted according to the sensitivity of the human eye.

Scoptic vs Photopic

- Rods are sensitive to very low levels of illumination and are responsible for our ability to see in dim light (scotopic vision).
  - They contain a pigment with a maximum sensitivity at about 510 nm, in the green part of the spectrum. The rod pigment is often called visual purple since when it is extracted by chemists in sufficient quantities the pigment has a purple appearance.
  - Scotopic vision is completely lacking in colour; a single spectral sensitivity function is colour-blind and thus scotopic vision is monochromatic.
- Colour vision is provided by the cones, of which there are three distinct classes each containing a different photosensitive pigment. The cones therefore provide us with colour vision (photopic vision).
  - The three pigments have maximum absorptions at about 430, 530, and 560 nm and the cones are often called blue, green, and red. The cones are not named after the appearance of the cone pigments but are named after the colour of light to which the cones are optimally sensitive. This terminology is unfortunate since monochromatic lights at 430, 530, and 560 nm are not blue, green, and red respectively but violet, blue-green, and yellow-green. The use of short-, medium-, and long-wavelength cones is a more logical nomenclature.

Photometric measurements

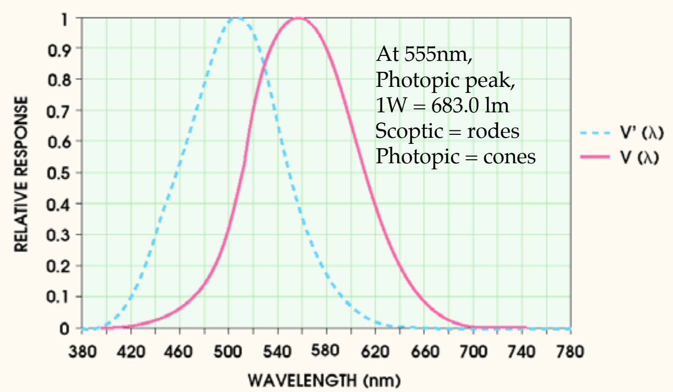


Figure 1. The response of two types of vision can be described by photopic and scotopic response curves.

Radiant Power P

- Power emitted, transferred or received as radiation [W]
- Some examples of radiant sources:
  - sun 4 x 10^{26} W
  - light bulb 100 W
  - medical CO_2 laser 20 W
  - flashlight 0.1 W
  - HeNe laser 1 x 10^{-3} W

Radiant energy Q

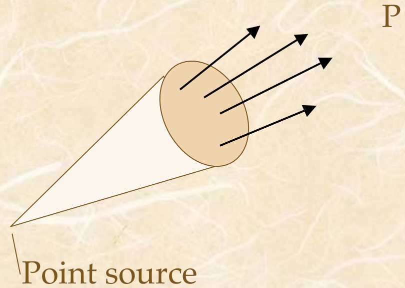
- Energy emitted, transferred or received as radiation [J]
- $Q = P * t$

Experiment: Calibrating a light bulb

Radiant intensity I

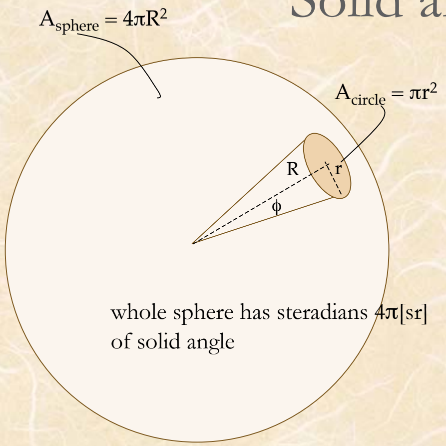
- In a given direction from a source, the radiant energy flux (or power) leaving the source, or an element of the source, in an solid angle containing the given direction, divided by that element of solid angle [W/sr]
- $I = P/\Omega$

Radiant intensity I



$I = P/\Omega$

Solid angle



in limit of small angle ϕ, solid angle of cone, Ω:

$\Omega \approx (4\pi[sr])\pi r^2/4\pi R^2 =$

$\pi r^2/R^2 = \pi\phi^2$

Ex: Flashlight

Irradiance E

- At a point of a surface, the radiant energy flux (or power) incident on an element of the surface, divided by the area of the surface [W/cm^2]
- $E = P/A$
  - Fluence rate
  - Radiant exittance
    - *radiant dose rate*
    - *radiant emittance*

Radiant exposure H

- At a point of a surface, the radiant energy incident on an element of the surface, divided by the area of the surface [J/cm^2]
- H = Q/A = P ∗ t/A = E ∗ t

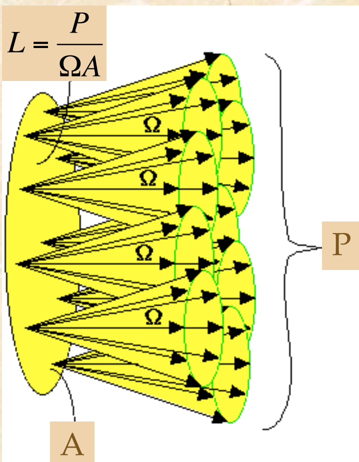
Ex: Irradiance of a flashlight beam on a wall

Radiance L

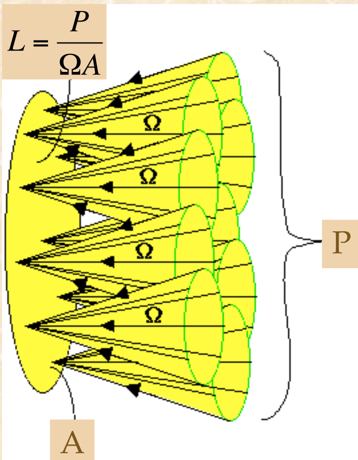
- The power that radiates from a source within a solid angle [sr] and passes through a cross-sectional
  area Acosϕ[W/(sr cm^2)]
- L=P/ ΩAcos

Radiance L

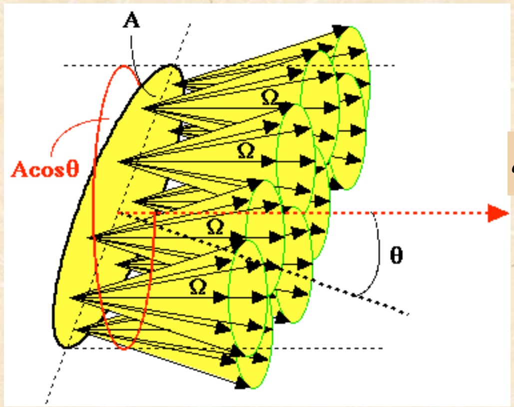
Source



Target



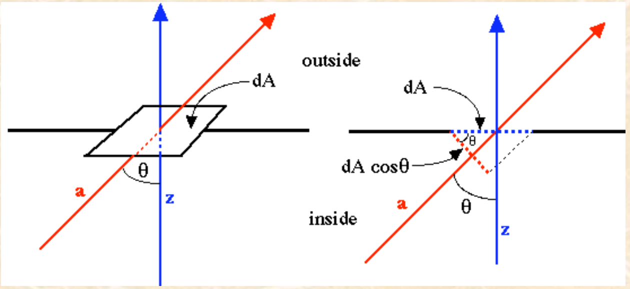
Radiance L



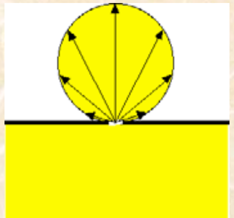
$$dL = \frac{d^2P}{d\Omega dA\cos\Theta} \quad [W/(sr * cm^2)]$$

Ex: radiance of flashlight

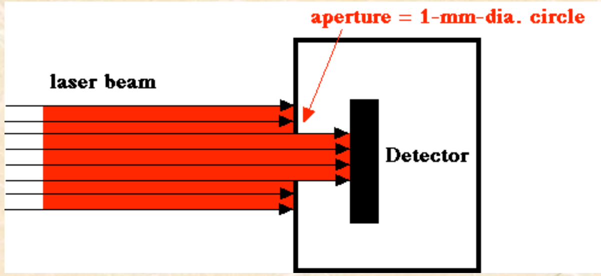
Lambertian pattern and sources



$$I(\theta) = \frac{dP}{d\Omega}\cos\theta$$



Collection of light: by aperture

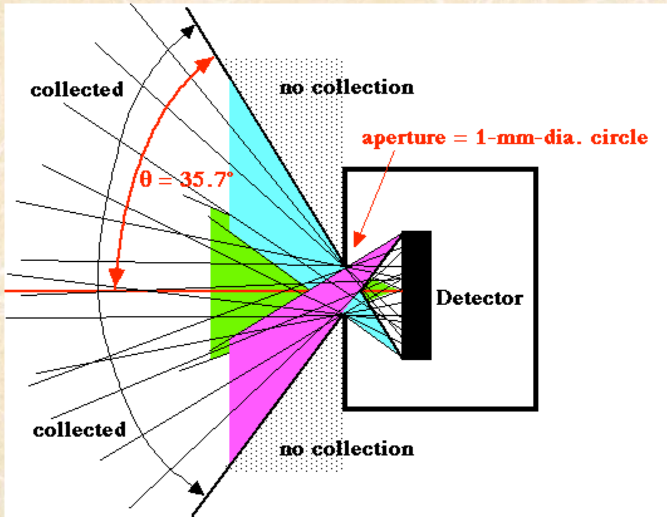


$$E(r) = P\frac{2}{\pi w_0^2}\exp(-2r^2/w_0^2)$$

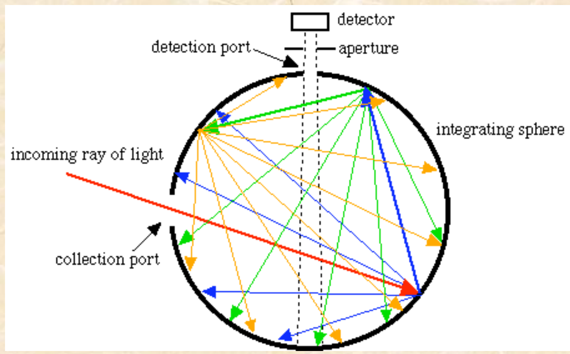
$$P = \int_0^{\infty} E(r)\, 2\pi r\, dr$$

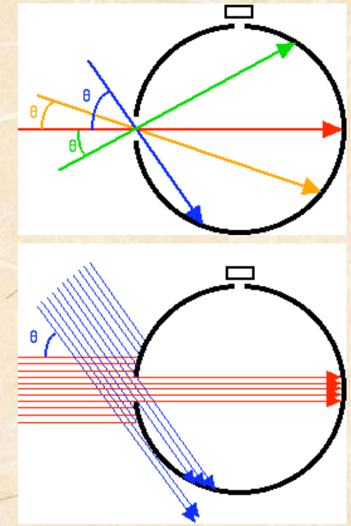
$$P_{collected}(a) = \int_0^{a} E(r)\, 2\pi r\, dr = P(1 - \exp(2a^2/w_o))$$

Collection of light: by aperture at a limited solid angle of light

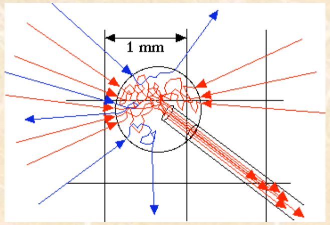


Integrating sphere

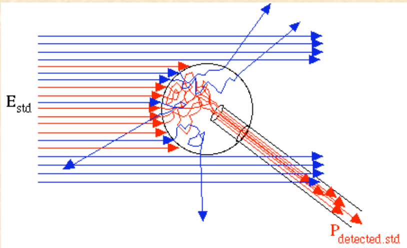


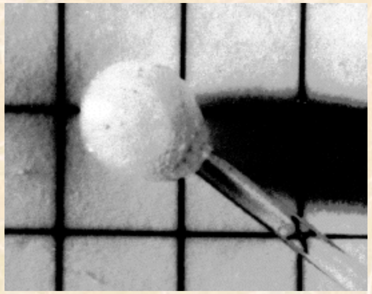


Detector

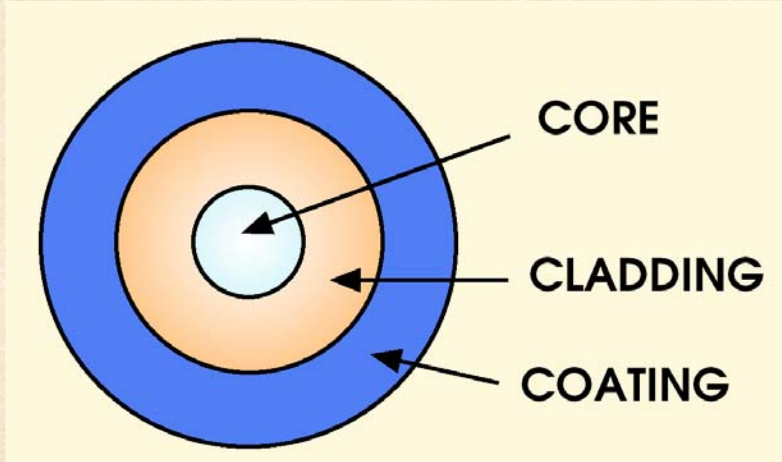


$$E = P_{detected} \frac{E_{std}}{P_{detected.std}}$$

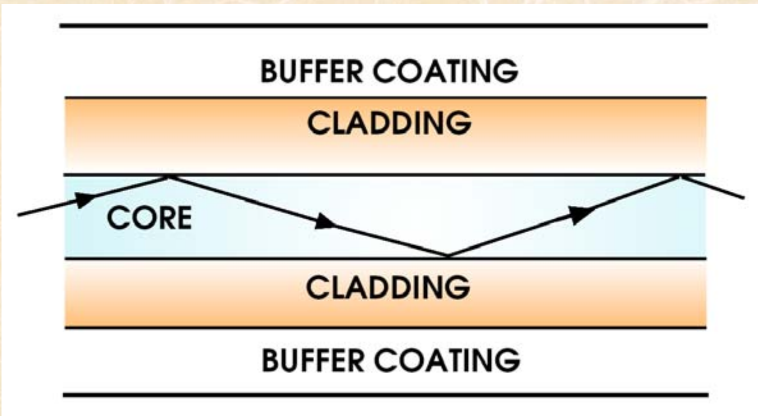




Fibre optics



Total internal reflection



Numerical aperture