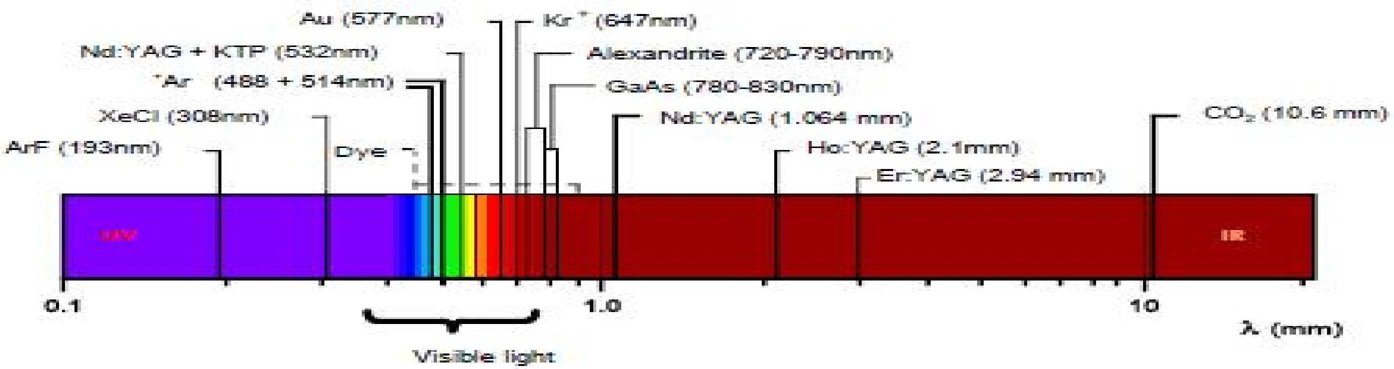
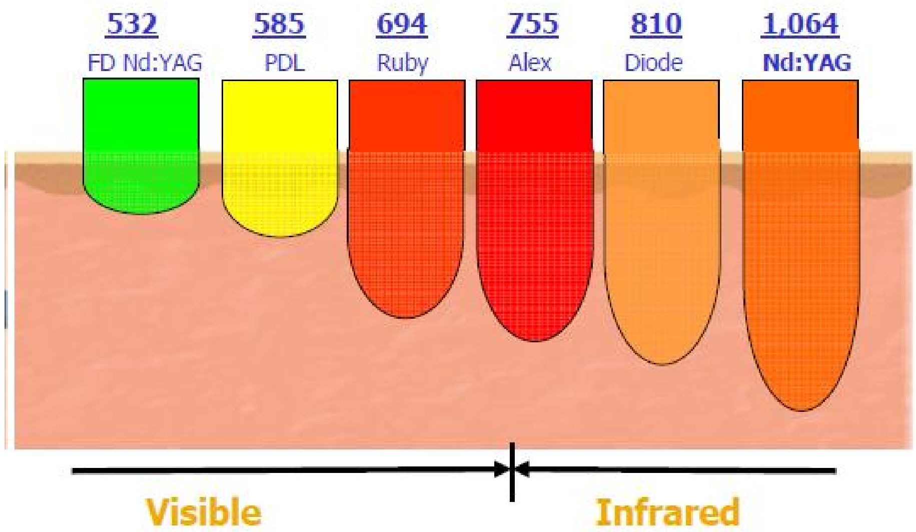
Laser Tissue Interaction:
Photobiological Concepts

Laser Systems



- The fig. shows various laser systems and the position of their radiation in the electromagnetic spectrum.
- It is evident that these laser systems cover the entire range from far-infrared to visible to UV light.
- This is beneficial since each desired application may require specific wavelengths, pulse durations and beam energies. The following types of lasers are most commonly used in medicine: (Nd:YAG laser, Ar^+ laser, CO_2 laser, Excimer laser, Diode laser).

Wavelength: Effect on Depth of Penetration



<u>Wavelength affects depth of penetration:</u>

- Longer wavelengths reach deeper targets.
- Shorter wavelengths experience more scattering.

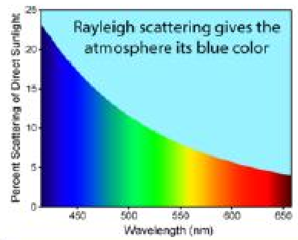
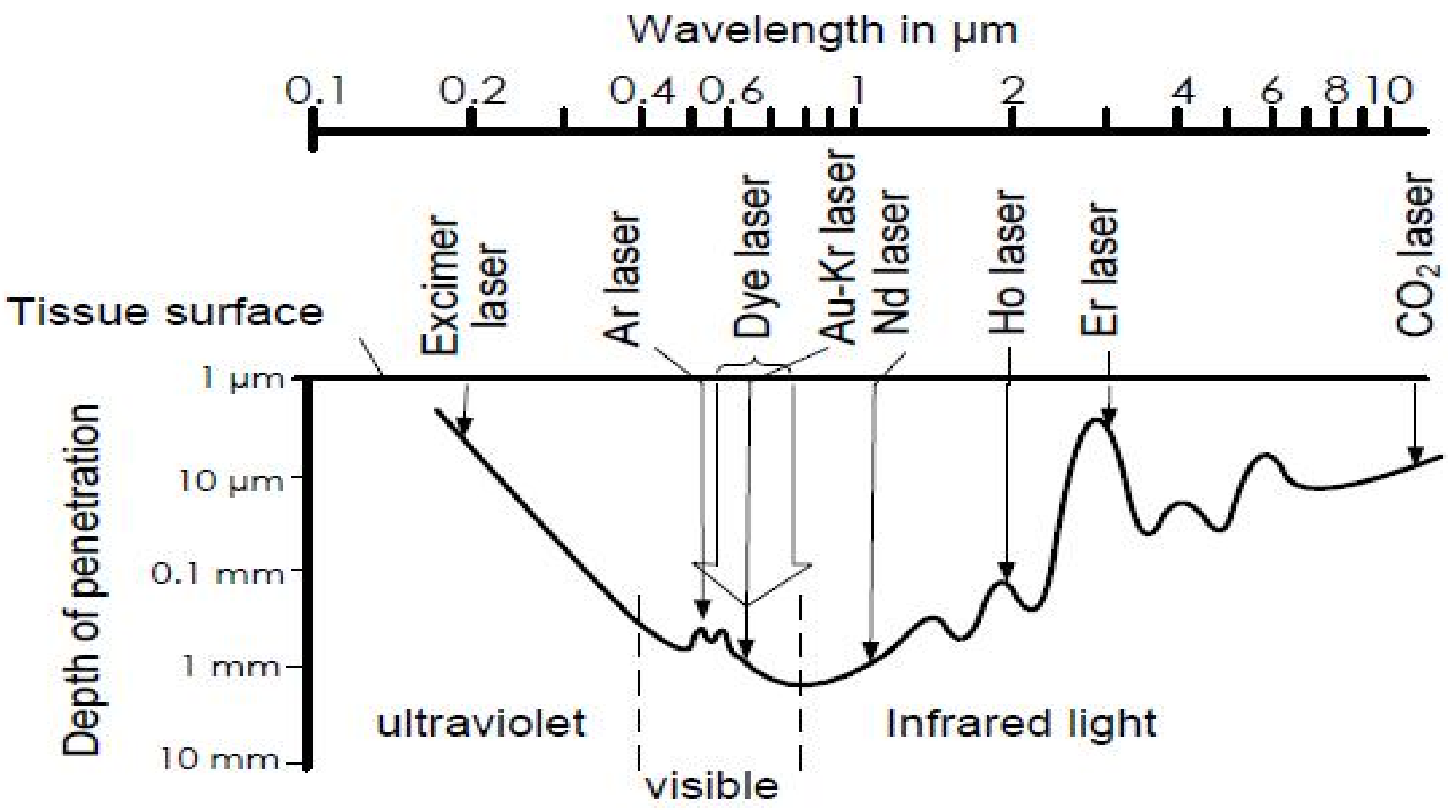


Figure showing the more intense scattering of blue light by the atmosphere relative to red light

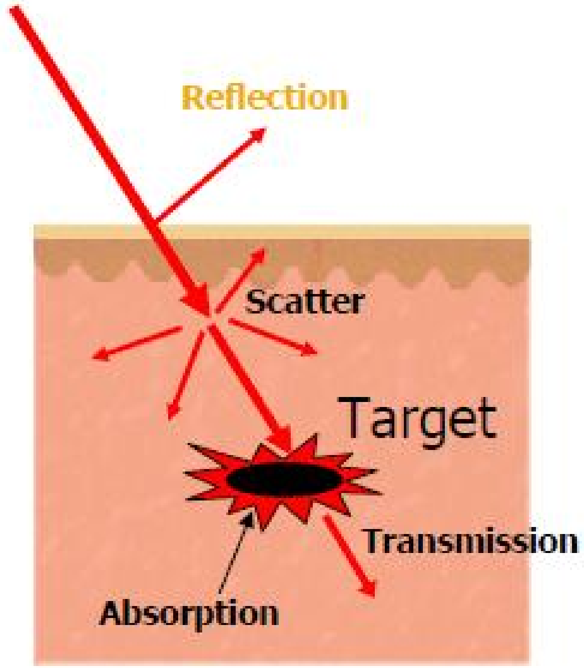
Wavelength of medical lasers and depth of tissue penetration



- The use of medical lasers depends on the penetration power (surface/deep)

Laser Tissue Interaction

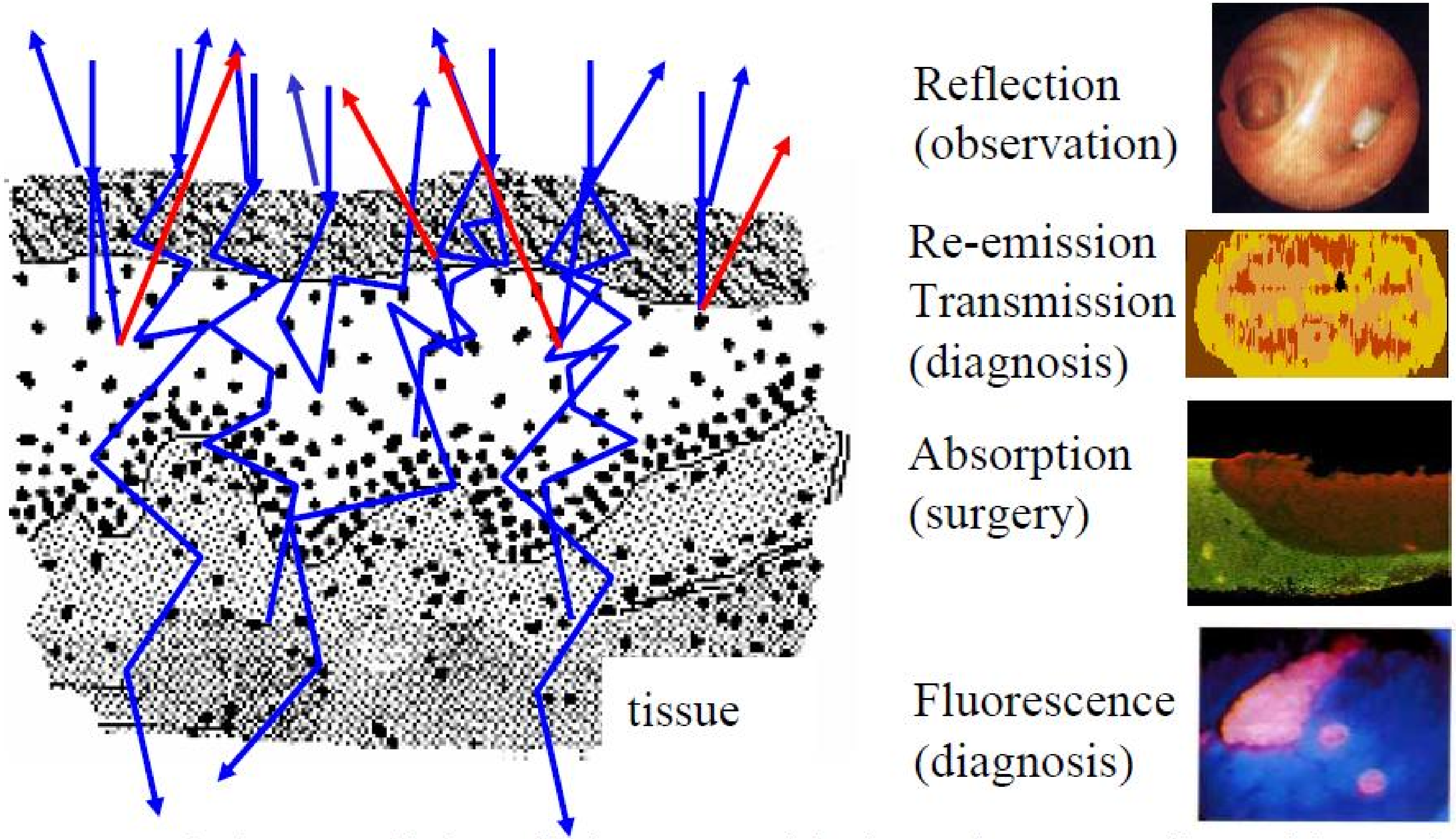
- To get deeper understanding of most laser applications in photobiology/ photomedicine the knowledge of the optical properties of the irradiated tissue is essential.
- The propagation of laser light in biological tissue and the transformation into thermal energy due to absorption of photons is governed by <u>the optical tissue properties</u>.



- Interactions based on:
  - Light source (wavelength, spot size, pulse duration, fluence)
  - Tissue characteristics

<u>P.S. All four interactions occur to a varying degrees with each exposure</u>

Laser Tissue Interaction



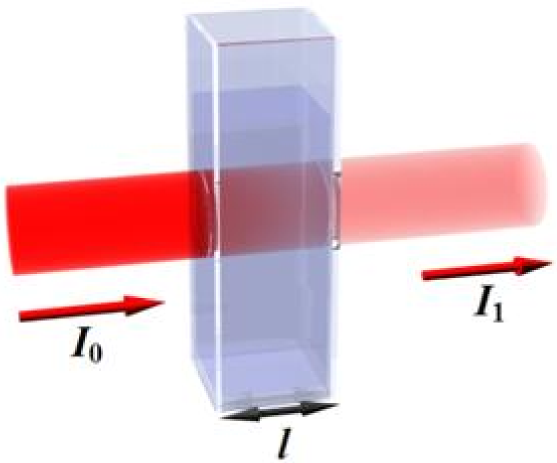
In general, the way light will interact with tissue is a complicated interplay of tissue and light (laser) properties.

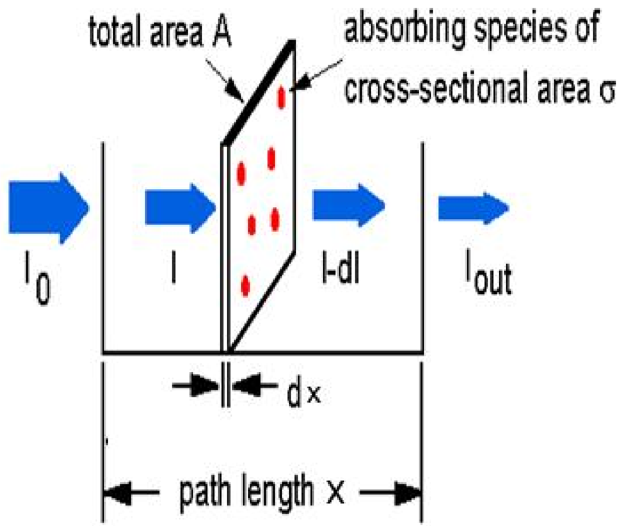
Optical Properties of Tissue

- Absorption coefficient μ_a[cm^{-1}]
- Scattering coefficient μ_s[cm^{-1}]
- Anisotropy factor g
- Refractive index n

Absorption

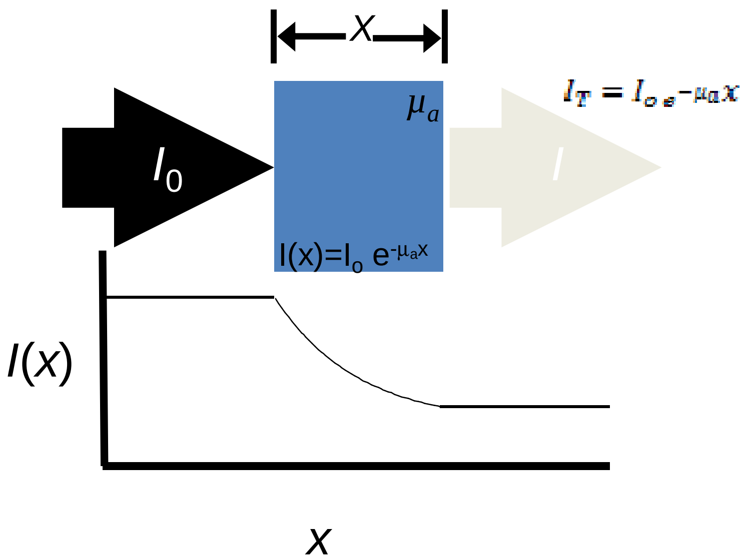
- Absorption occurs from various tissue constituents which depends strongly on the type of tissue and the wavelength of the incident light.
- Absorption → variations in transmission (Beer Law)





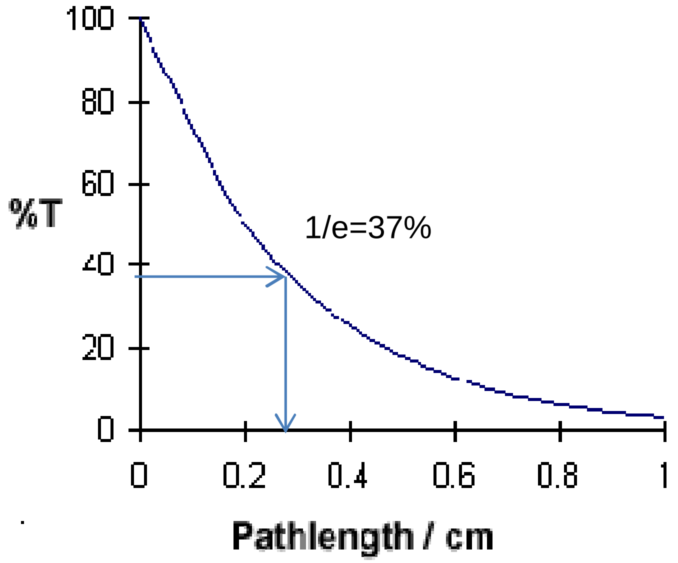
Absorption coefficient μ_a [cm^{-1}]

- The basic idea is based on the assumption of Beer's law where light is attenuated exponentially at its propagation in tissue.
- The measured intensity of transmitted light through a layer of material with thickness x is related to the incident intensity according to the inverse exponential power law that is usually referred to as Beer-Lambert law; where x denotes the path length.
- The decay constant μ_a is a characteristic of the medium (i.e. a property of a material). It defines the extent to which a material absorbs energy.
- Most tissues absorption coefficient is between 0.1-1cm^{-1}

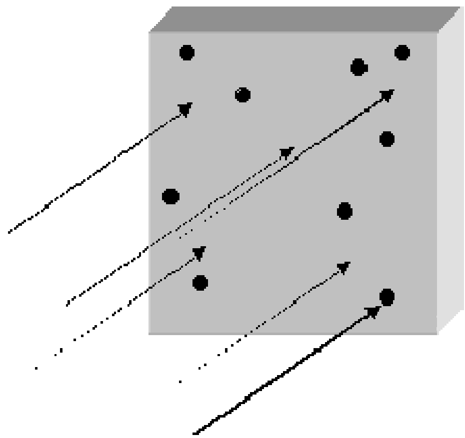


Mean Free Path ($1/\mu_a$)

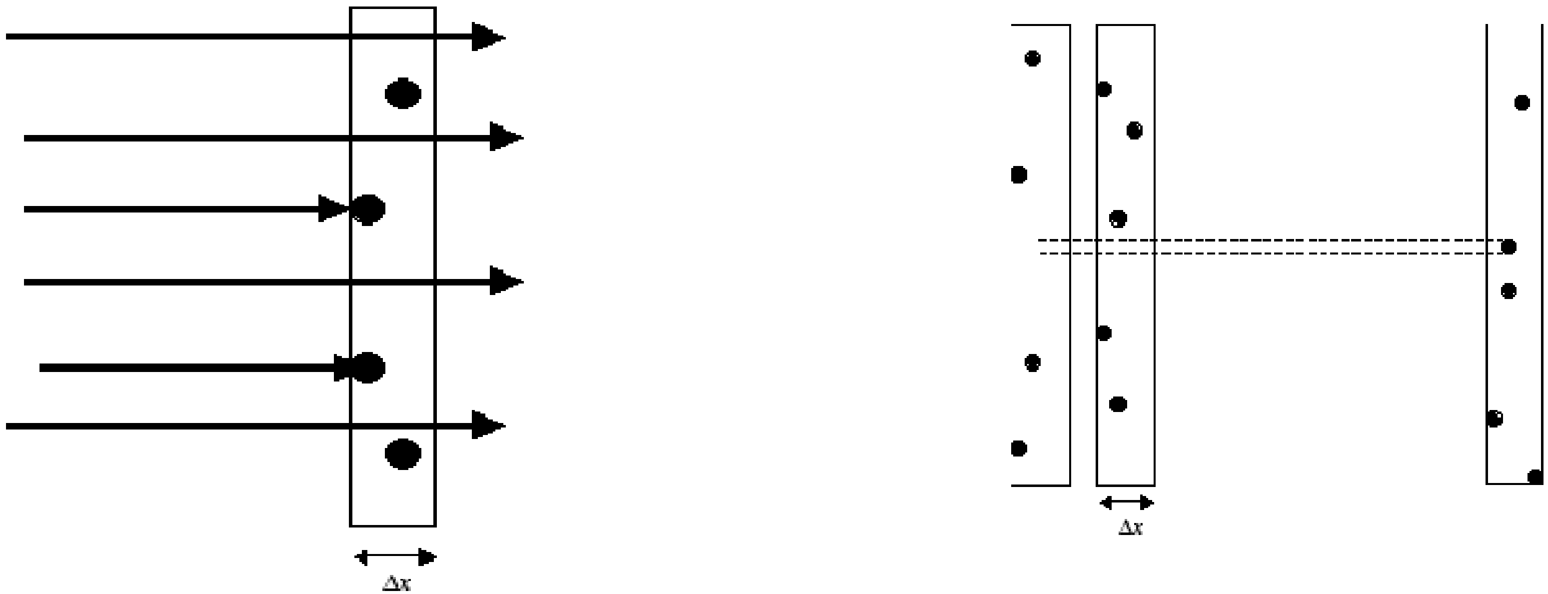
The distance that a photon travels before absorption event is defined by the mean free path (i.e. how far does the photon travel before absorption occurs),
In other words it is defined as the distance after which the intensity drops by1/e (i.e. T=37%) of its initial value.



Why Exponential Decay?

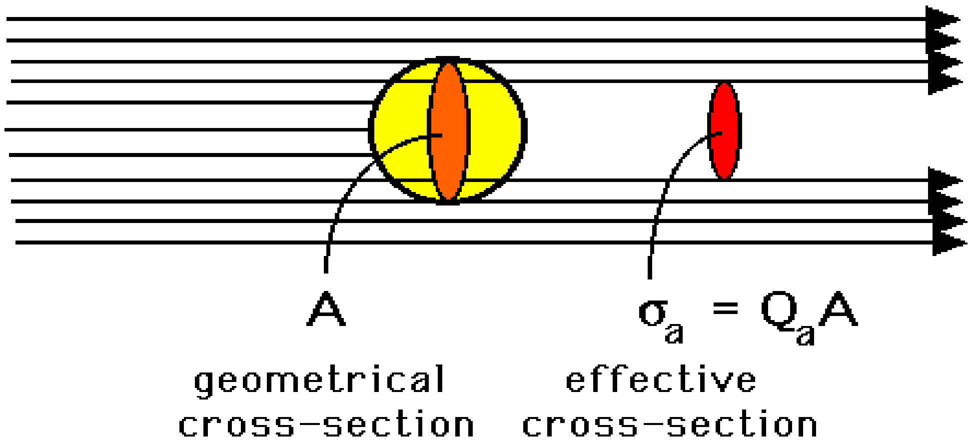


Photons arriving - front view



Photons arriving – side view

Absorption Cross Section σ_a [cm^2]



- When light photons strikes a target, some photons pass directly through the target while others are absorbed. Those that are absorbed are said to *interact* with target particles.
- The effective cross section, which is denoted by σ_a is a measure of the effective area of interaction. (or It is a measure for the probability of an absorption process).

Consider a chromophore idealized as a sphere with a particular geometrical size and consider that this sphere blocks incident light and casts a shadow, which constitutes absorption.

The size of the absorption shadow is called the effective cross-section (σ_a [cm^2]) which is related with the geometrical size of the chromophore (A [cm^2]), by the proportionality constant called the absorption efficiency Q_a [dimensionless]:

$$\sigma_a = Q_a A$$

$$[cm^2] \quad [-] \, [cm^2]$$

The absorption coefficient μ_a [cm^{-1}] is essentially the cross-sectional area per unit volume of medium where it describes a medium containing many chromophores at a concentration described as a volume density ρ_a [cm^{-3}] (i.e. no. of absorbing centres per unit volume).

$$\mu_a = \rho_a \sigma_a$$

$$[cm^{-1}] \quad [cm^{-3}][cm^2]$$

The larger the cross section, the more likely it is that the photons are absorbed.

The cross section depends on the types of target particles involved and depends on the energy of the particles in the beam

Summary

Absorption

The Absorption coefficient (μ_a) describes a medium containing many absorbing particles and is defined as:

$$\mu_a = \rho_a \sigma_a$$

[cm^{-1}] [cm^{-3}] [cm^{2}]

Where,

σ_a is the effective cross-section [cm^2]

ρ_a is a volume density [cm^{-3}] = absorbers per cm^3

$$\mu_a = [c]\varepsilon \ln(10)$$

[cm^{-1}] [moles/cm^3] [cm^2/mole]

Where,

c is molar concentration [moles/cm^3]

ε = molar extinction coefficient [cm^2/mole] [(liter/mole)/cm]

M [mole/liter]

$$T = e^{-\mu_a L}$$

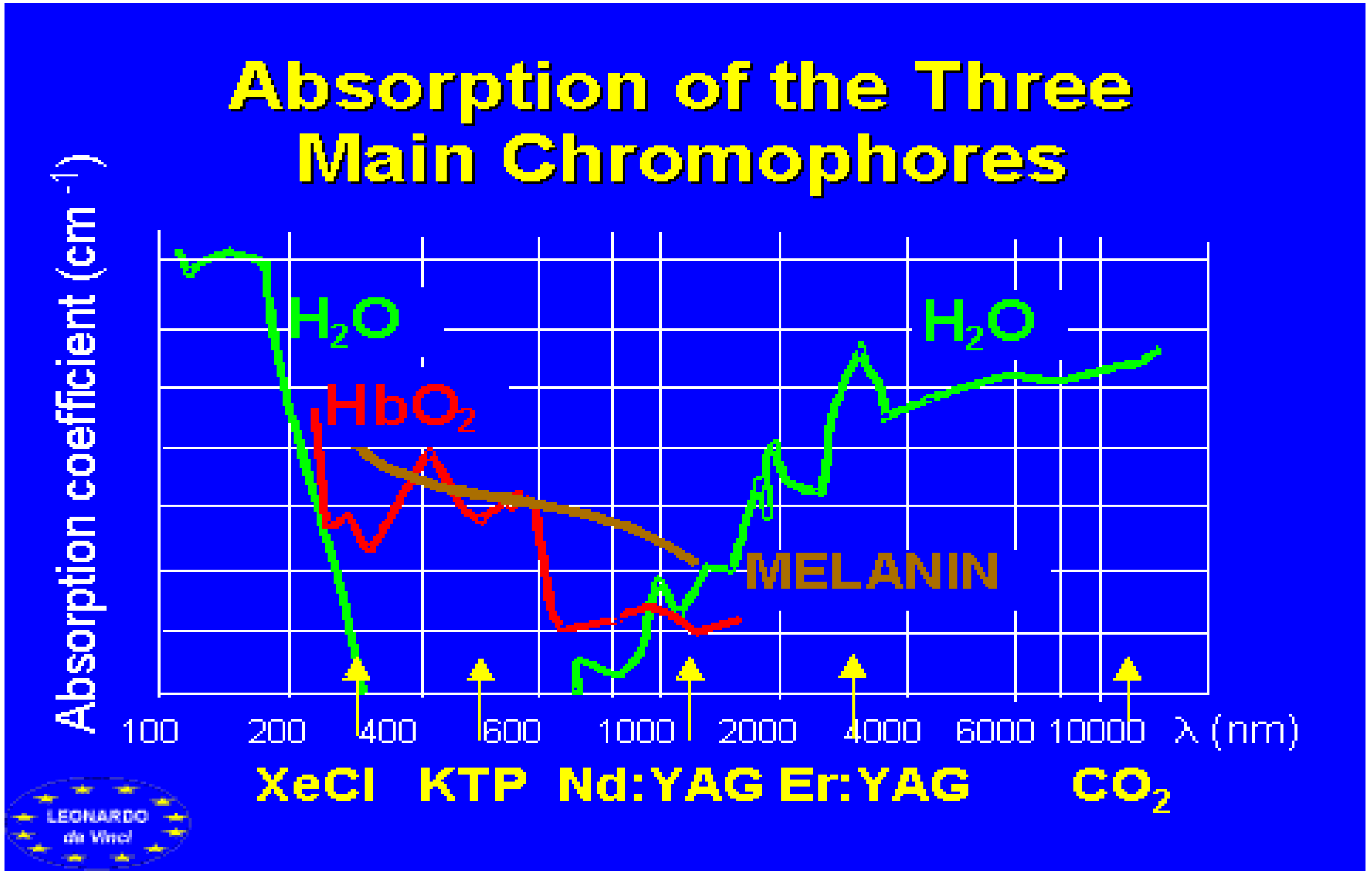
$$T = 10^{-\varepsilon c L}$$

Mean Free Path

$$l_a = \frac{1}{\mu_a}$$

- μ_a ~10 cm^{-1}
- l_a = 1 mm

- Most tissues absorption coefficient is between 0.1-1cm^{-1}



Each tissue has specific absorption characteristics base on its composition and *chromophore* content. The principal chromophores present in mammalian tissue are: Hemoglobin, Melanin , Water, Protein. Infrared light is absorbed primarily by water, while visible and ultraviolet light are absorbed by hemoglobin and melanin, respectively. As wavelength decreases toward the violet and ultraviolet, scatter or absorption from covalent bonds in protein limits penetration depth in this range.

Experimental methods for attenuation due to absorption