Biophysics

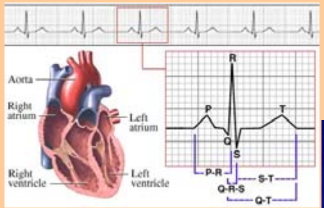
Gabriella Csik

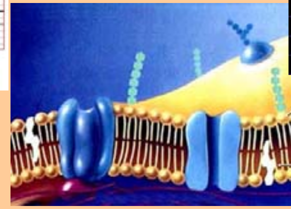
gabriella.csik@eok.sote.hu

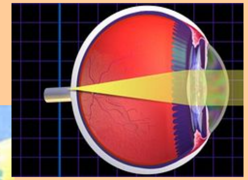
What is the subject of biophysics?

Physical aspects/background of biological processes

E.g., Electrophysiology of heart, structure and functioning of membranes, sensory function stb.



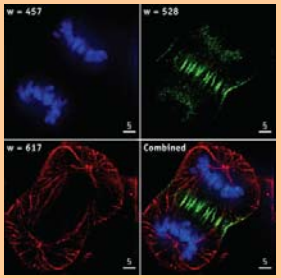




What is the subject of biophysics?

Physical methods in biology and medicine

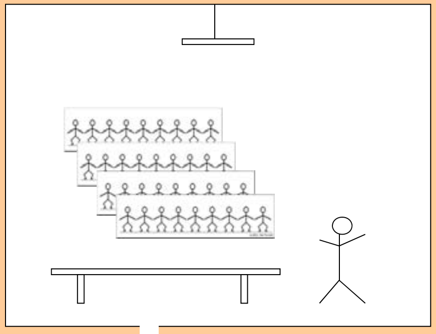
E.g., ECG, X-ray diagnostics, microscopy….



Radiation

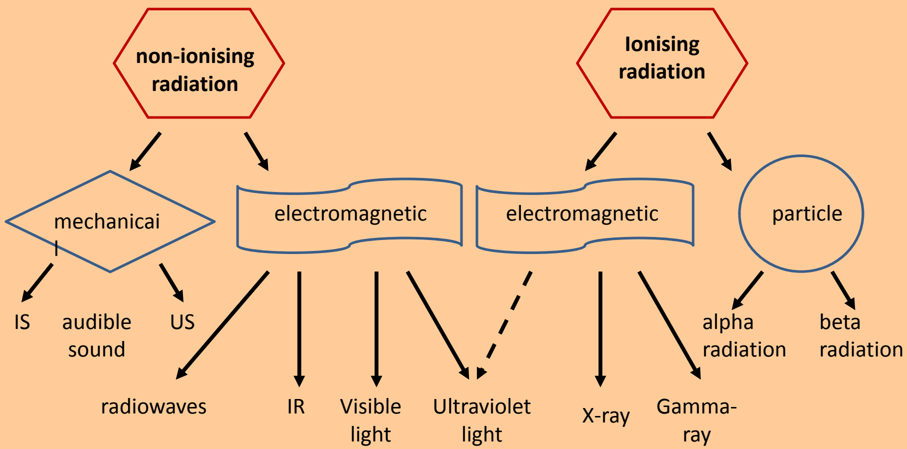
Examples around us

- sound
- light
- radiowaves
- nuclear radiation



Radiation: emission and propagation of energy

Radiation



Nature of light

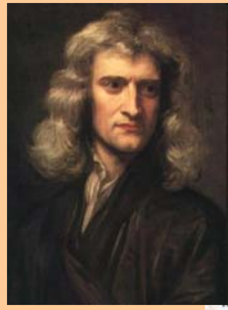
Wave?

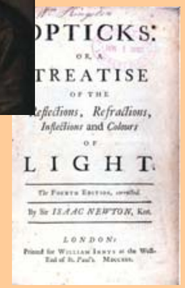
Particle?

Christiaan Huygens

(1629 - 1695)

Traité de la lumière
1690





Isaac Newton

(1642 - 1727)

Opticks
1704

Natur of waves

periodic disturbance in space and time, possibly transferring energy to or through a spacetime region.

Waves differ in
- type of energy
- amplitude
- mechanism of propagation

Characteristic values

Period in space– *wavelength*

λ [m] or [nm]

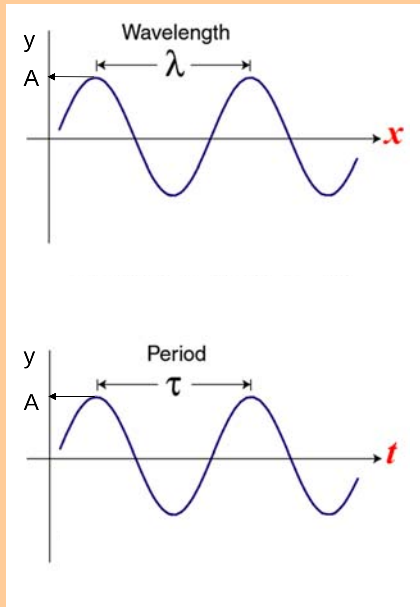
Highest displacement – *amplitude*

$$E \sim A^2$$

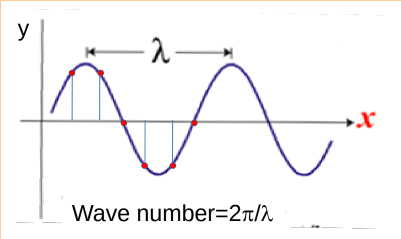
Period in time

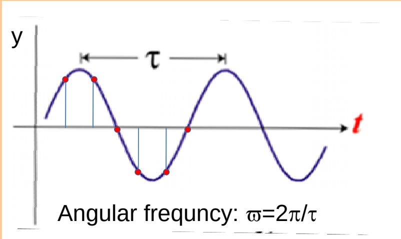
– *period*
– *frequency*

$$f = \frac{1}{\tau}\left[\frac{1}{s}\right]$$



Phase: the initial angle of a sinusoidal function at its origin





$\phi(x)=kx+\phi_o$

$\phi(t)=\varpi t+\phi_o$

$\phi=\varpi t+kx+\phi_o$

Nature of light

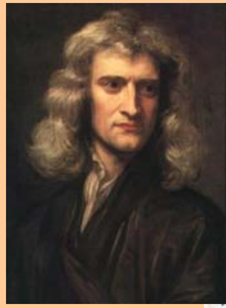
Wave?

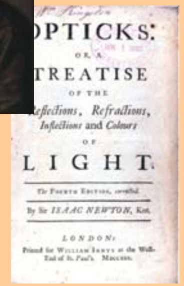
Particle?

Christiaan Huygens

(1629 - 1695)

Traité de la lumière
1690



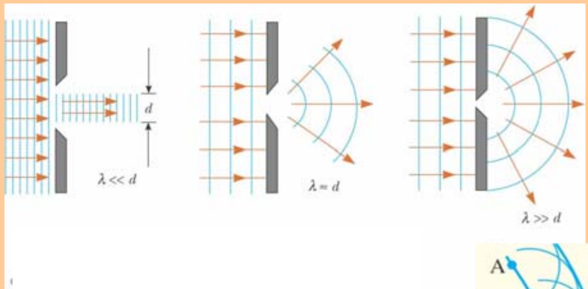


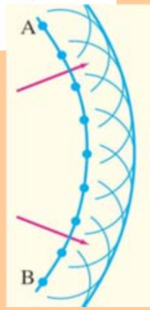
Isaac Newton

(1642 - 1727)

Opticks
1704

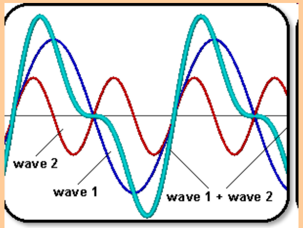
Diffraction



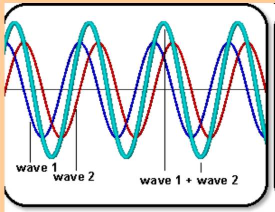


Huygens-principle: every point on a propagating wavefront serves as the source of spherical secondary wavelets, such that the wavefront at some later time is the envelope of these wavelets.

Superposition: The principle of superposition may be applied to waves whenever two (or more) waves travelling through the same medium at the same time. The net displacement of the medium at any point in space or time, is simply the sum of the individual wave displacements.



Un-equal frequencies



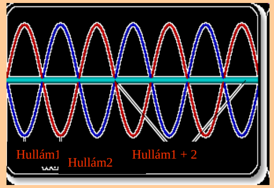
Equal frequencies

Interference: superposition of coherent waves

Similar phase

Constructive interference

$\Phi = 0^\circ$



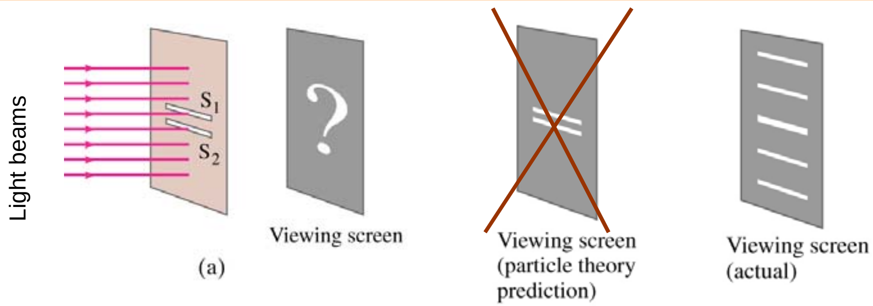
Opposite waves

Destructive interference

$\Phi = 180^\circ$

Thomas Young
(1773-1829)

Thomas Young's
double-slit experiment



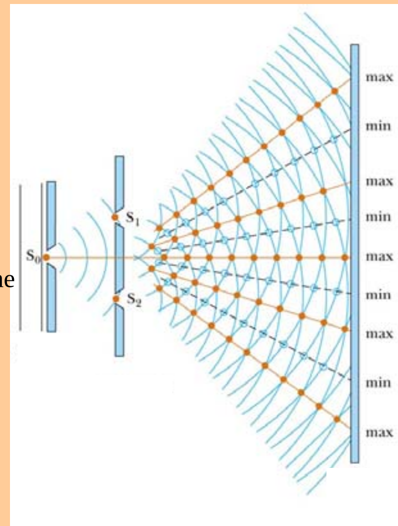
Interpretation of Thomas Young's double-slit experiment

S_1 and S_2 slits are wave sources

Two waves from S_1 and S_2 originates from the same wave front that is they are in the same phase.

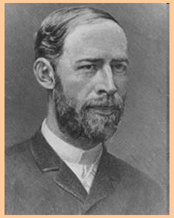
↓↓

interference

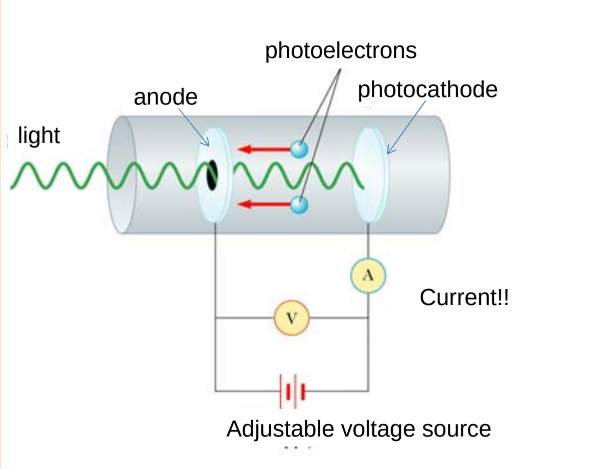


Interference fringes on a screen

Photoelectric effect



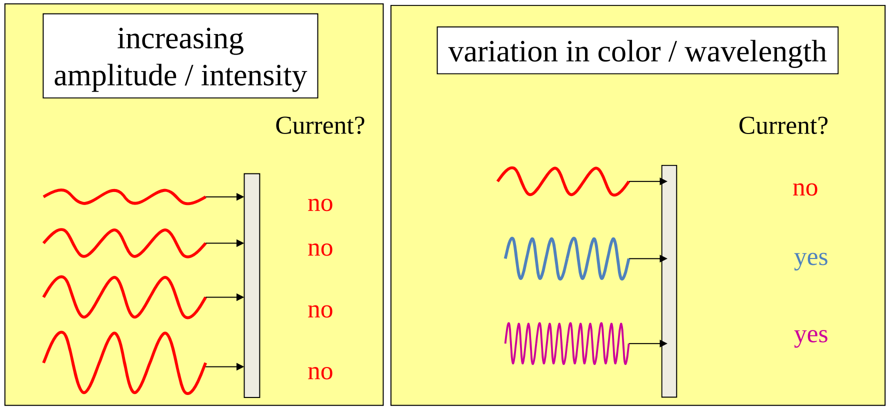
Heinrich Hertz
1887



Light irradiation

Similar color / wavelength

Similar amplitude



No current up to a critical value of frequency

Interpretation of photoelectric effect

- Based on the wave character it is not possible.

- Planck – foundation of quantum physics

$$E = hf$$

- Einstein's concept is based on the quantum theory

Max Planck

Albert Einstein

Nobel Prize in physics 1918

"in recognition of the services he rendered to the advancement of Physics by his ***discovery of energy quanta****"*.

Nobel Prize in physics 1921

for his services to Theoretical Physics, and especially for his ***discovery of the law of the photoelectric effect****"*.

Einstein interpretation

- Light consists of a finite number of energy quanta - photons
- The energy of photon: $E = hf$
- Photon can be absorbed or generated only as complete units.
- A photon transfer its energy to one electron if the photon energy is equal or higher than the work function (A).
- No interaction, if the photon energy is smaller than the work function.
- 1 photon– 1 electron interaction
- Kinetic energy of the electron: $E_{kin} = hf - A$

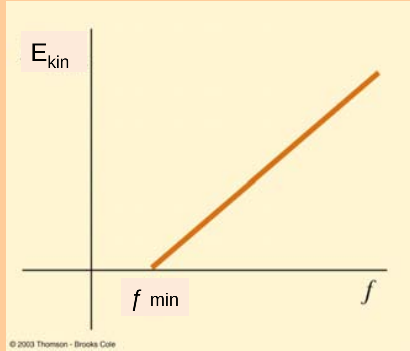
Einstein interpretation and the frequency limit

Kinetic energy of electron proportional to the frequency.

Intercept with the *x* axis is the smallest frequency inducing photoelectric effect

F_{min} depends on the cathode material:

$$A = hf_{min}$$



Dual nature of light

Particle – its energy is quantised; a photon is an elementary particle, the quantum of the electromagnetic interaction

Energy of photon: $E = hf = h\dfrac{c}{\lambda}$

Planck constant: $h = 6.62 \cdot 10^{-34}\, Joule \cdot s$

It has no resting mass

Propagates in vacuum

Calculation of photon energy

$$E = h \times \frac{c}{\lambda}$$

If λ=400 nm

$$E = 6.6\times10^{-34}\, Js \times \frac{3\times10^{8}\,\frac{m}{s}}{4\times10^{-7}\, m} = 4.95\times10^{-19}\, J$$

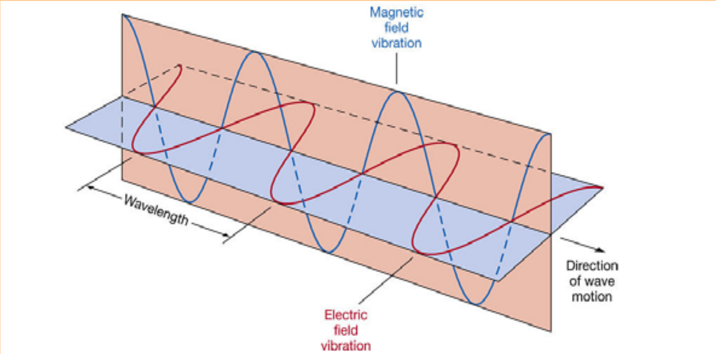
$$E = \frac{4.95\times10^{-19}\, J}{1.6\times10^{-19}} = 3.1 eV$$

E_{VIS}= 1.6 – 3.1 *eV*

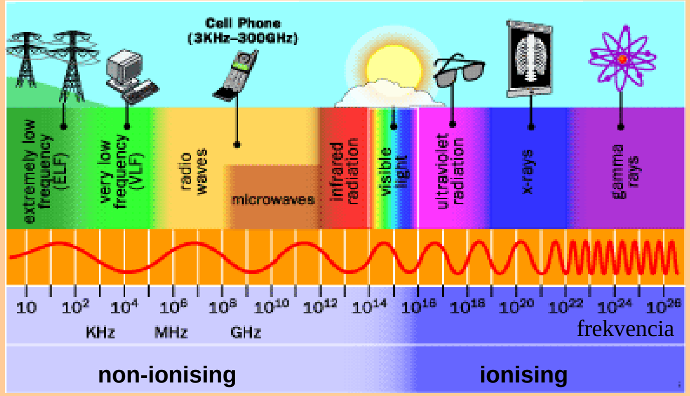
Dual nature of light

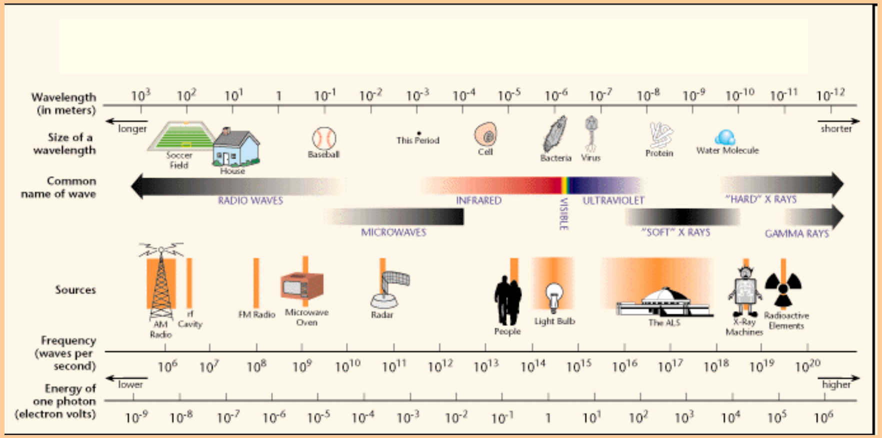
Wave – electric and magnetic fields vary sinusoidally

Electromagnetic radiation

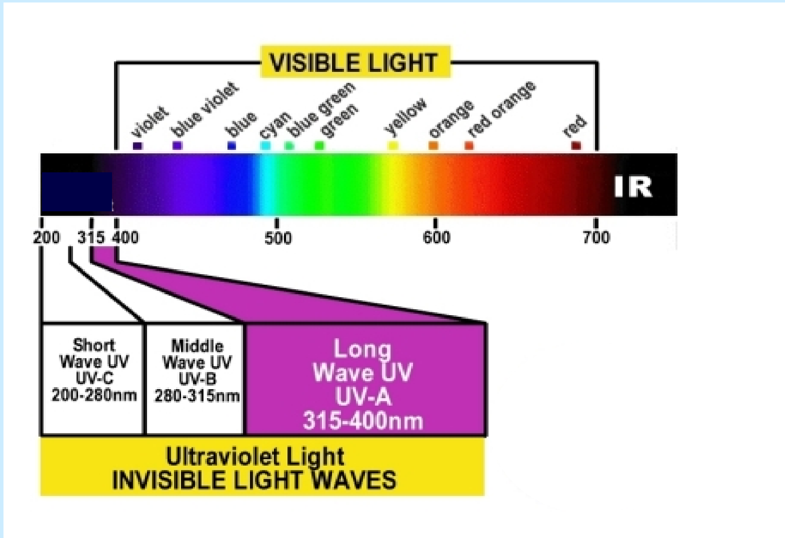


Ranges of electromagnetic radiation



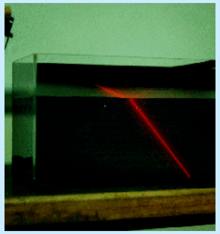


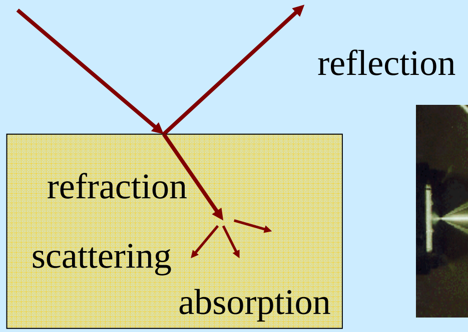
Optical range

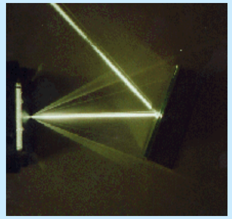


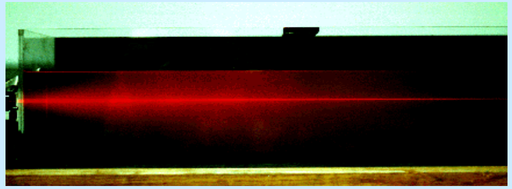
Interaction of light with matter

Interaction of light with matter



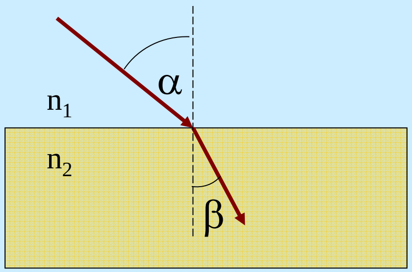






Refraction of light

Fermat's Principle: Light follows the path of least time



$n_1 < n_2$

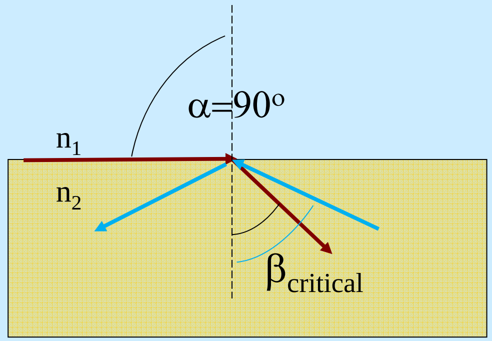
$\alpha > \beta$

Snell's Law

$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

The index of refraction

Critical angle – total reflection



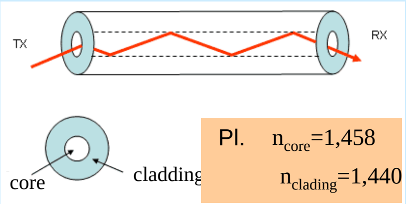
$\beta > \beta_{critical}$

Medical application

Determination of concentration – refractometry

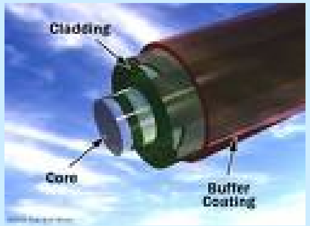
Concentration of solutions is proportional with their index of refraction .

Optical fibers

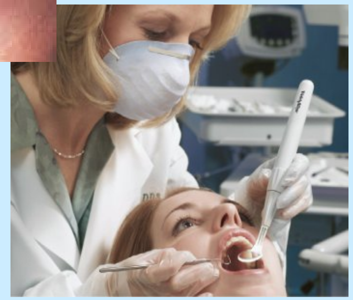


Pl. $n_{core}=1{,}458$

$n_{clading}=1{,}440$



Application in dentistry



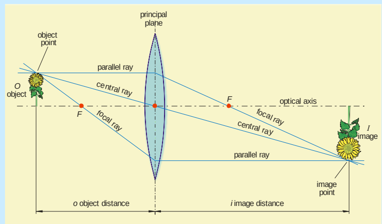
Other medical applications

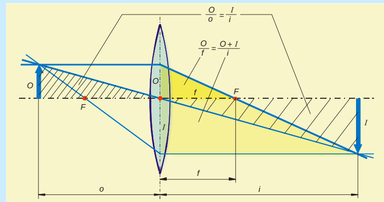
Bronchoscopy

Colonoscopy

Image formation (thin lens approximation)

Image construction by principal rays

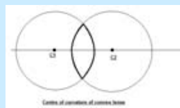




lensmaker's formula.

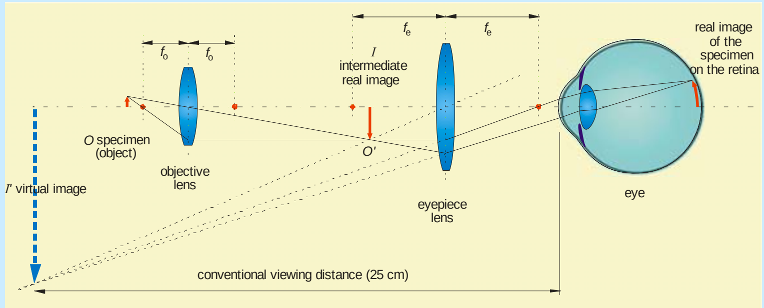
$$D=\frac{1}{f}=\frac{1}{o}+\frac{1}{i}=(n-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

the radii of curvature



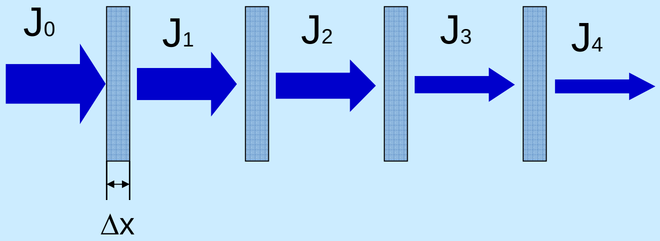
D - diopter: measure of the optical power of a lens, which is equal to the reciprocal of the focal length measured in meters

Image formation – compound microscope



The image is magnified
reversed
virtual

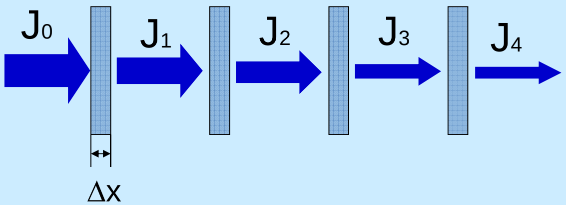
Absorption



Intensity of radiation is attenuated when passing through material

Law of attenuation

$$\Delta J = J_0 - J_1 = J_1 - J_2 = ...$$



$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

Differential form

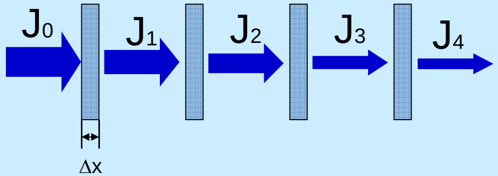
J : incident intensity [W/m^2]

ΔJ : change of intesity after passing trough Δx thickness

μ: attenuation coefficient [1/m]

The decrease is proportional to the thickness of absorber Δx and J what is the initial intensity.

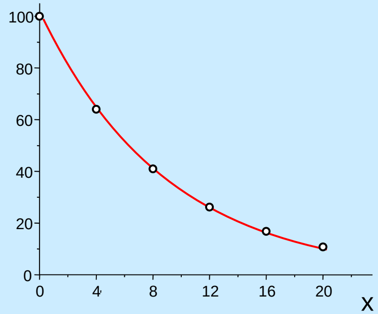
Law of attenuation



$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

solution

$$J = J_0 e^{-\mu x}$$



Macroscopic function

Integral form

Exponential law of radiation attenuation

$$J = J_0 e^{-\mu x}$$

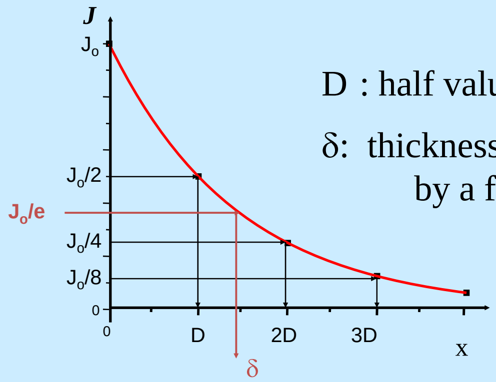
J is exponential function of the thickness of the layer.

J_0 : incident intensity [W/m^2]
J : intesity after passing trough *x* thickness
μ: attenuation coefficient [1/m]

Linear attenuation (absorption) coefficient depends on
- photon energy
- quality (atomic number) of absorber
- density of absorber

Graphical representation

$$J = J_0 e^{-\mu x}$$



D : half value thickness

δ: thickness decreasing the intensity by a factor *e*

Both D and δ depend on photon energy, quality (atomic number) of absorber, density of absorber

Definition of attenuation coefficient

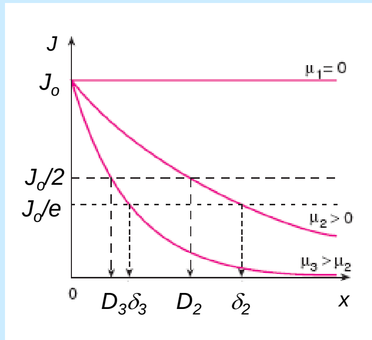
$$J = J_0 e^{-\mu x}$$

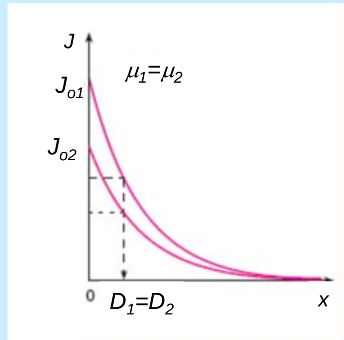
If x = D ⟹ $J_0 / 2 = J_0 e^{-\mu D}$

$$\mu = \frac{\ln 2}{D} = \frac{0.693}{D}$$

If x = δ ⟹ $J_0 / e = J_0 e^{-\mu \delta}$

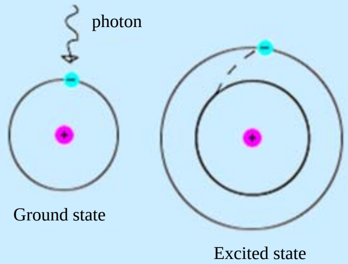
$$\mu = \frac{1}{\delta}$$





Mechanism of light absorption

Repetition: structure of atom



$$hf = \Delta E = E_{n+1} - E_n$$

E_{VIS}= 1.6 – 3.1 *eV*

Excitation of outer shell electrons

Laboratory application of light absorption

$$J = J_0 \cdot e^{-\mu x}$$

$$\lg \frac{J_0}{J} = \mu \cdot x \cdot \lg e$$

in dilute solutions :
μ ~ concentration

μ lge = $\varepsilon_{(\lambda)}$ c

$$\lg \frac{J_0}{J} = \varepsilon_{(\lambda)} \cdot c \cdot x$$

Lambert – Beer law

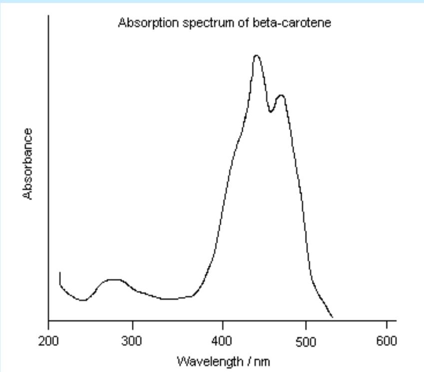
Absorbance or Optical density

decadic molar extinction coefficient

molar concentration

$$\lg \frac{J_0}{J} = \varepsilon_{(\lambda)} \cdot c \cdot x$$

Absorbance – is the function of the wavelength

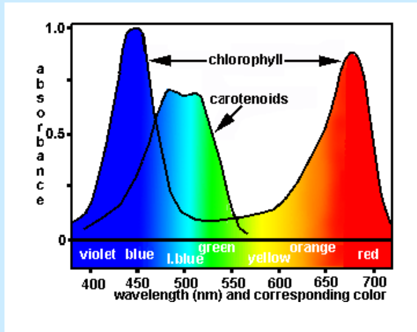


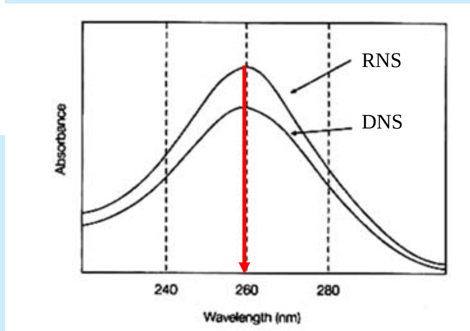
Absorption spectrum:

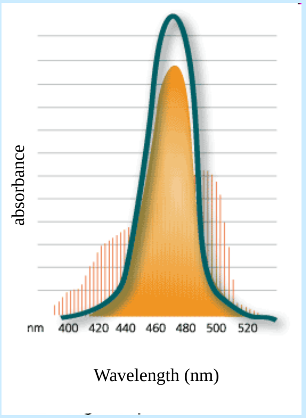
Absorbance as the function of the wavelength.

“Band” spektrum

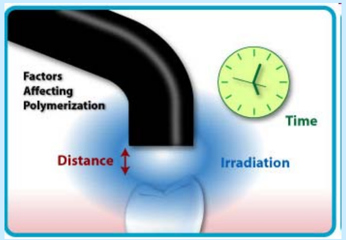
absorption spectrum of some biological macromolecules







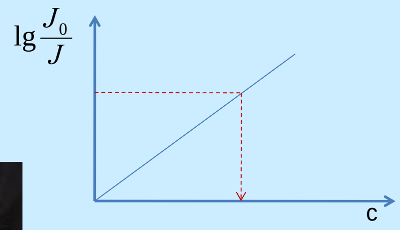
Application in dentistry



Camphor chinone

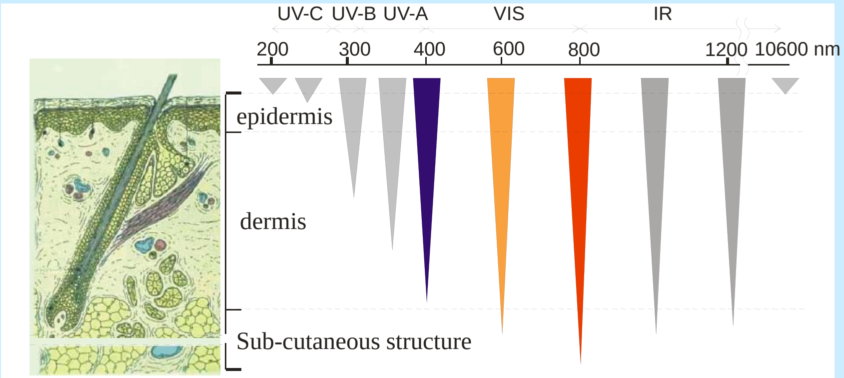
$$\lg \frac{J_0}{J} = \varepsilon_{(\lambda)} \cdot c \cdot x$$

in dilute solutions absorbance is proportional to the concentration



Absorption based determination of concentration

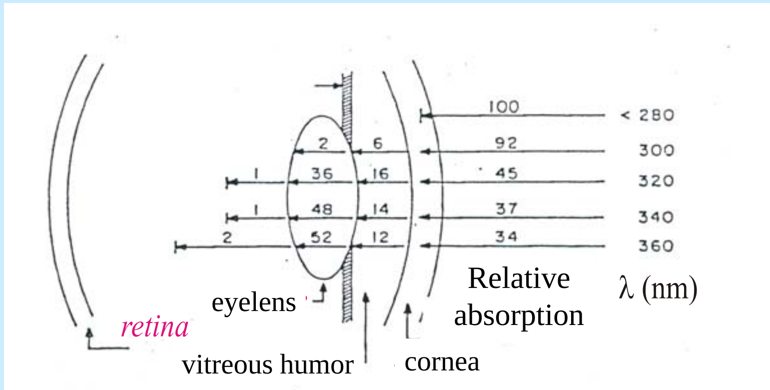
Penetration of light into the skin



Light intensity is attenuated due to absorption, reflection, refraction.

Penetration depth depends on the wavelength.

Penetration of light into the skin



Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 1.1.
- 1.1.1
- 1.1.3

II. 2. 1.
- 2.1.1
- 2.1.2
- 2.1.3
- 2.1.4
- 2.1.5
- 2.1.8

VI.3
- 3.1.1
- 3.1.2