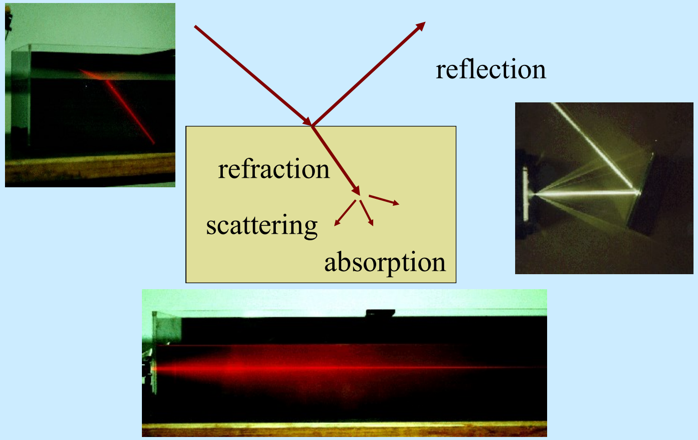
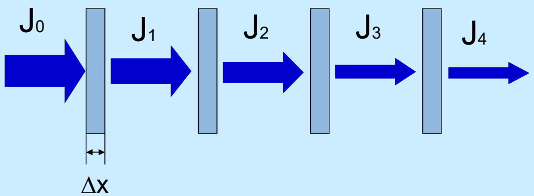
Interaction of light with matter 2.

Interaction of light with matter



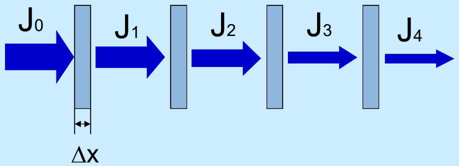
Absorption



Intensity of radiation is attenuated when passing through material

Law of attenuation

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



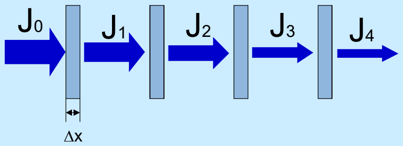
$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

Differential form

J : incident intensity [W/m^2]
ΔJ : change of intesity after passing trough Δx thickness
μ: attenuation coefficient [1/m]

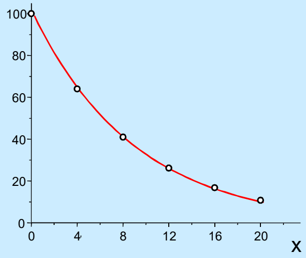
The decrease is proportional to the thickness of absorber Δx and J what is the initial intensity.

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

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

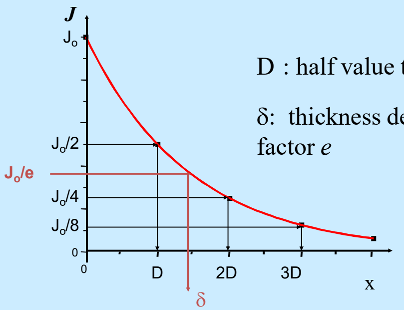
J is exponential function of the thickness of the layer.

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

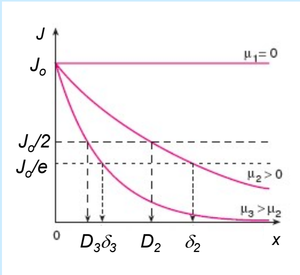
$$J = J_0 e^{-\mu x}$$

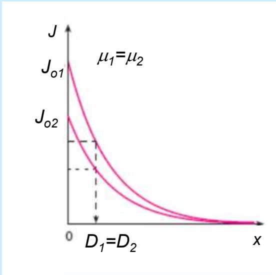
If x = D ⟶ $J_0 / 2 = J_0 e^{-\mu D}$

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

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

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





The attenuation coefficient of the muscle is 800 cm^{-1} at the wavelength emitted by the CO_2 laser. Calculate the thickness of the muscle layer that absorbs 90 % of the light energy of these lasers.

$$\mu = 800 cm^{-1}$$

$$J_0 = 100\%$$

$$J = 100\% - 90\% = 10\%$$

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

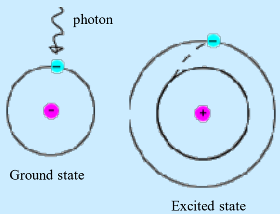
$$10 = 100 e^{-800x}$$

$$\lg 10 = 800 * x * \lg e$$

$$x = 2.9 * 10^{-3} cm$$

Mechanism of light absorption

Repetition: structure of atom

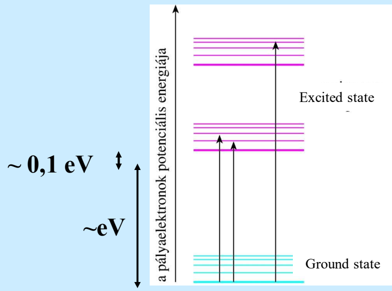


$$hf = \Delta E = E_{n+1} - E_n$$

E_{VIS}= 1.6 – 3.1 *eV*

Excitation of outer shell electrons

Electronic and vibronic energy levels



Molecules can absorb photons in a certain energy range

Fate of excited electron will be discussed later

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

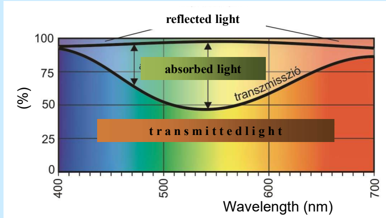
Absorbance or Optical density

decadic molar extinction coefficient

molar concentration

Absorbance or Optical density $\qquad \lg \frac{J_0}{J} = \varepsilon_{(\lambda)} \cdot c \cdot x$

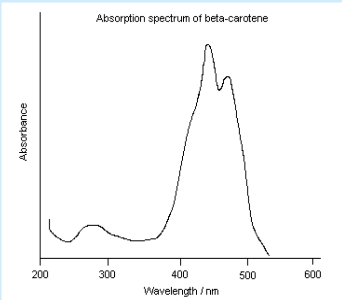
Transmittance $\qquad \tau = \frac{J_{transmit}}{J_{incident}}$



Spectra of red glace

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

Absorbance – is the function of the wavelength



Absorption spectrum:

Absorbance as the function of the wavelength.

"Band" spektrum

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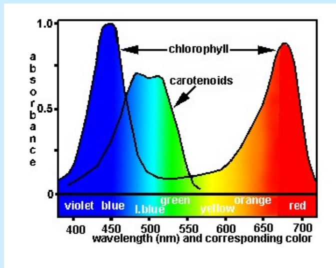
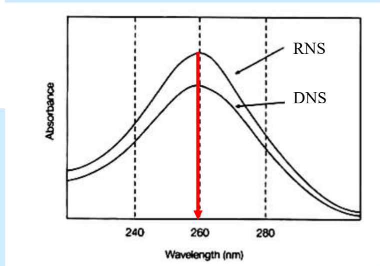
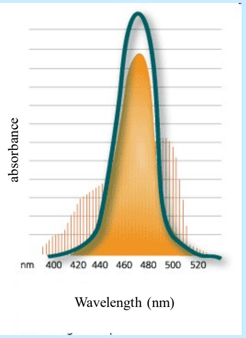
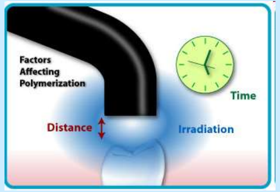
absorption spectrum of some biological macromolecules







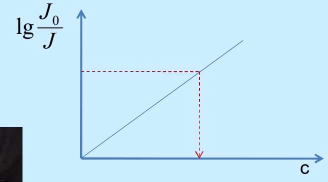
Application in dentistry



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

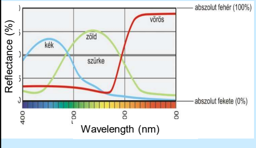
Why do objects appear the color they are?

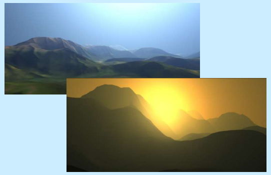
reflection

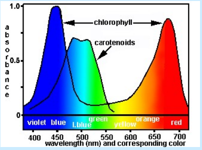
scattering

absorption

$$\rho(\lambda) + \sigma(\lambda) + \alpha(\lambda) = 1$$







e.g. reflection of red
↓
red

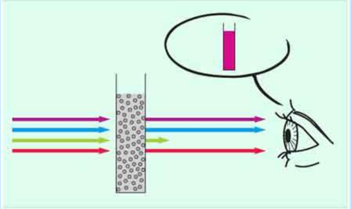
Influenced by the relative position of the light source and observer, size of particles etc

e.g. red absorption
↓
green in transmitted light

Absorption

Complementary colors

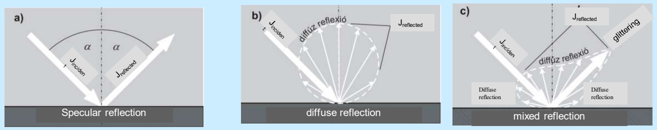
Wavelength [nm]	Absorbed color	Complementary color
650-780	red	blue-green
595-650	orange	greenish blue
560-595	yellow-green	purple
500-560	green	red-purple
490-500	bluish green	red
480-490	greenish blue	orange
435-480	blue	yellow
380-435	violet	yellow-green



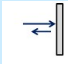
The color of matter is related to its **absorptivity**, reflectivity and light scattering. The human eye sees the complementary color to that which is absorbed

Reflection

Diffuse reflection

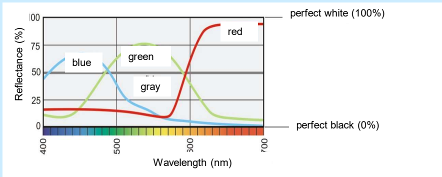


spectral reflectance $\rho(\lambda) = \frac{J_{reflected}}{J_{incident}}$

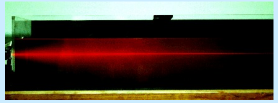


$$\rho = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Spectrum of reflectance



Light scattering



Scattering coefficient $\sigma(\lambda) = \frac{J_{scattered}}{J_{incident}}$

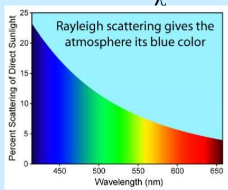
Elastic scattering: λ, f, ε are constant

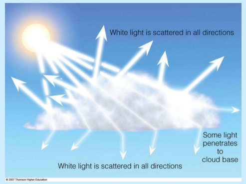
Rayleigh-scattering $d << \lambda$

$$\sigma(\lambda) \sim \frac{d^6}{\lambda^4}$$

Mie-scattering $d \geq \lambda$

No strong λ dependency





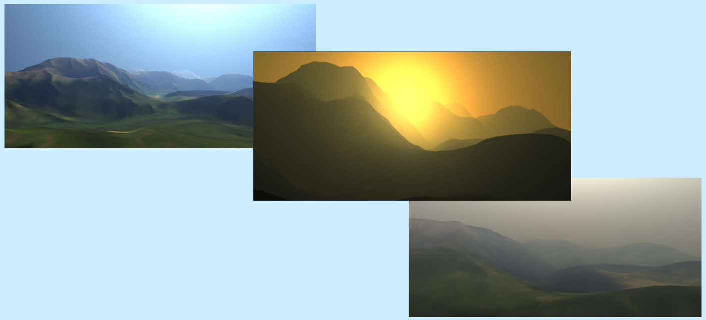
Light scattering

Rayleigh-scattering

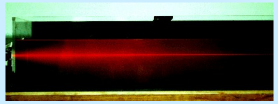
$d << \lambda$

Mie-scattering

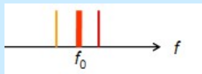
$d \geq \lambda$



Light scattering

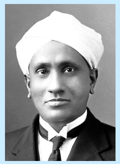


Non-Elastic scattering: λ, f, ε are not constant



Energy transition between light and material

Raman-scattering



Sir Chandrasekhara Venkata Raman

Nobel Prize in physics, 1930

"for his work on the scattering of light and for the discovery of the effect named after him"

Checklist

•law of attenuation – integral for, differential form

•attenuation coefficient – definition, unit, factors influencing it's value

mechanism of light absorption

Beer's law

absorbance

absorption spectrum

measuring technics

reflection of light

types of light scattering

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