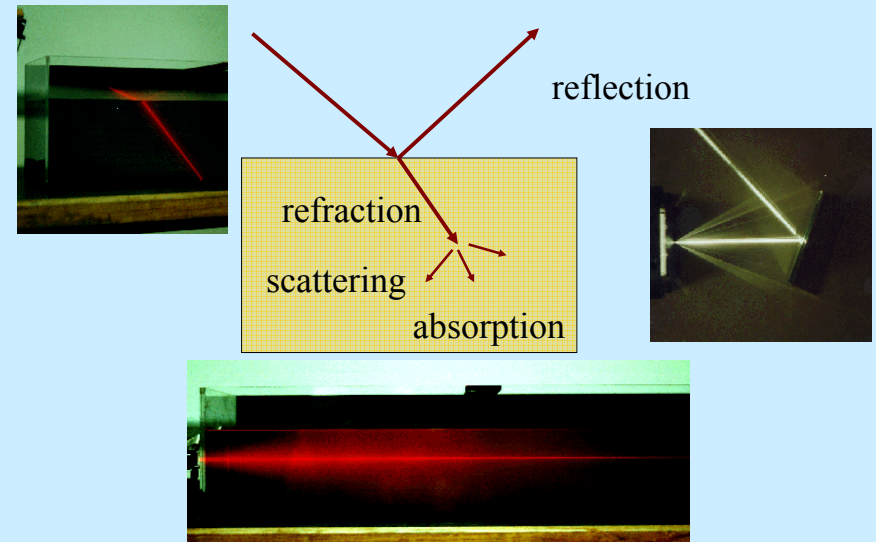
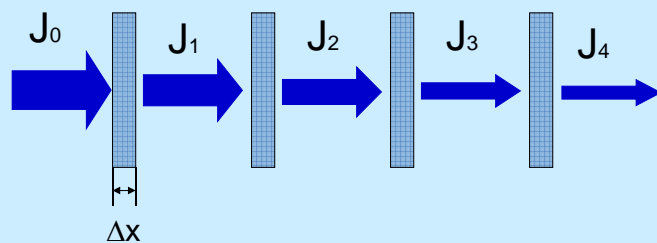


Interaction of light with matter 2.

Interaction of light with matter



Absorption



Intensity of radiation is attenuated when passing through material

Law of attenuation

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

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

Differential form

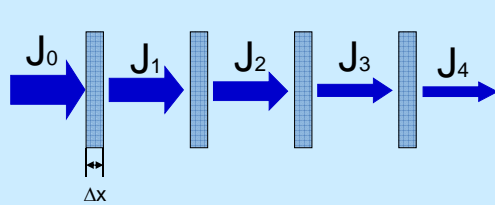
J : incident intensity [W/m^2]

ΔJ : change of intensity after passing through Δx thickness

μ : attenuation coefficient [$1/\text{m}$]

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

Law of attenuation



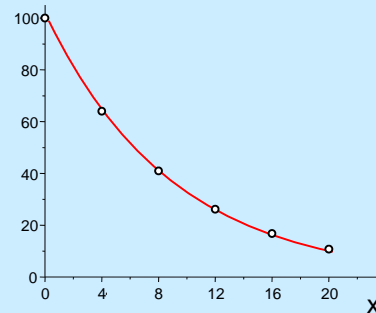
$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

↓ 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]

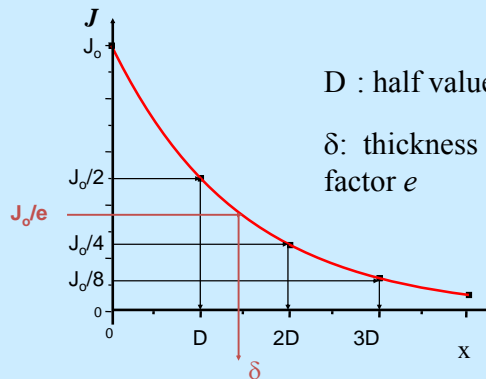
J : intensity after passing through x thickness

μ : attenuation coefficient [$1/\text{m}$]

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

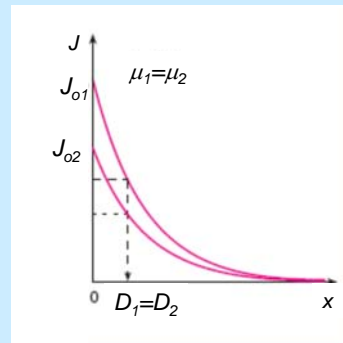
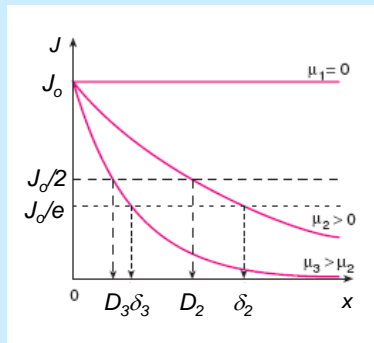
$$J = J_0 e^{-\mu x}$$

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

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

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

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



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.

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

$$J_0 = 100\%$$

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

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

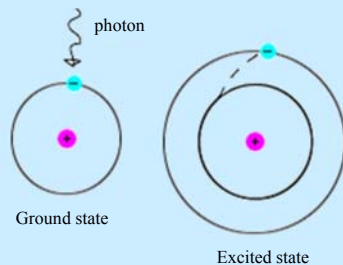
$$10 = 100 e^{-800x}$$

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

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

Mechanism of light absorption

Repetition: structure of atom

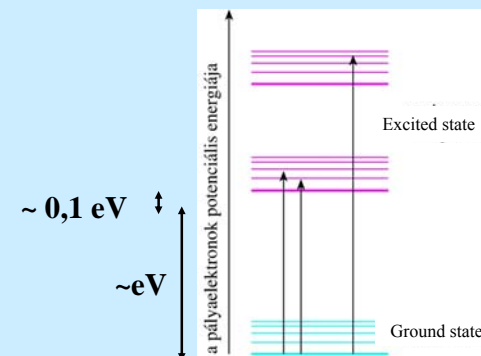


$$hf = \Delta E = E_{n+1} - E_n$$

$$E_{\text{VIS}} = 1.6 - 3.1 \text{ eV}$$

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 :
 $\mu \sim \text{concentration}$

$$\mu \lg e = \varepsilon_{(\lambda)} c$$

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

Lambert – Beer law

Absorbance
or
Optical density

decadic molar
extinction coefficient

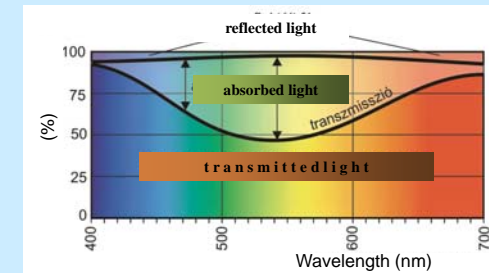
molar concentration

Absorbance
or
Optical density

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

Transmittance

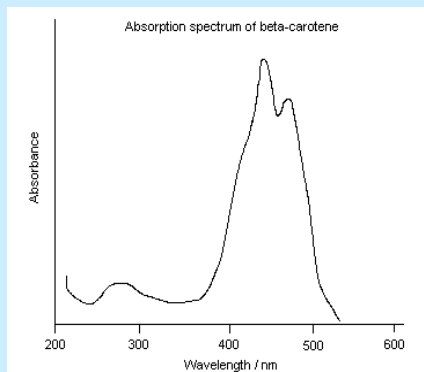
$$\tau = \frac{J_{\text{transmit}}}{J_{\text{incident}}}$$



Spectra of red glass

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

Absorbance – is the function of the wavelength

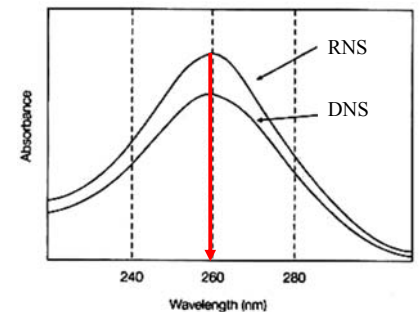
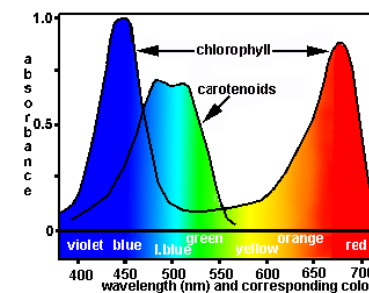


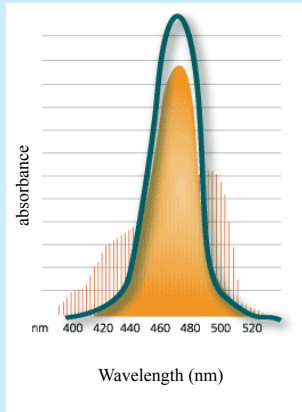
Absorption spectrum:

Absorbance as the function of the
wavelength.

“Band” spektrum

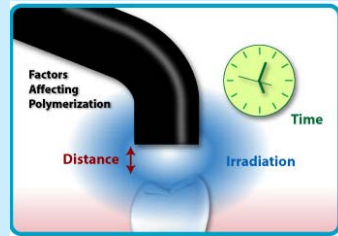
absorption spectrum of some biological macromolecules





Camphor chinone

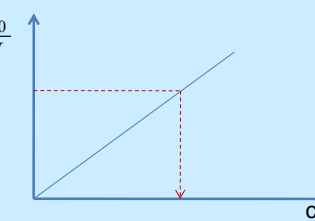
Application in dentistry



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

in dilute solutions absorbance is proportional to the concentration

$$\lg \frac{J_0}{J}$$

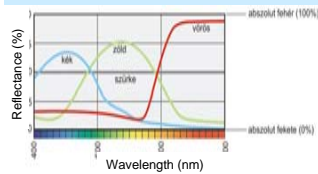


Absorption based determination of concentration



Why do objects appear the color they are?

reflection



e.g. reflection of red

↓
red

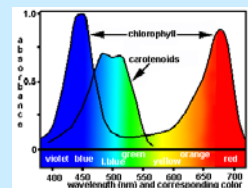
scattering

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



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

absorption



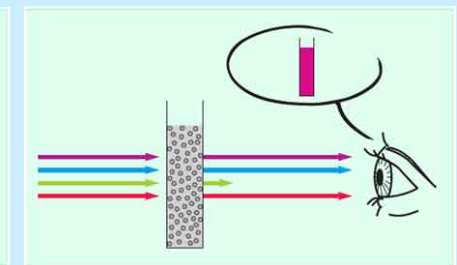
e.g. red absorption

↓
green in transmitted light

Absorption

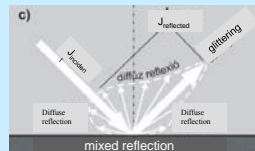
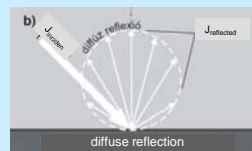
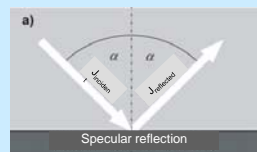
Complementary colors

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

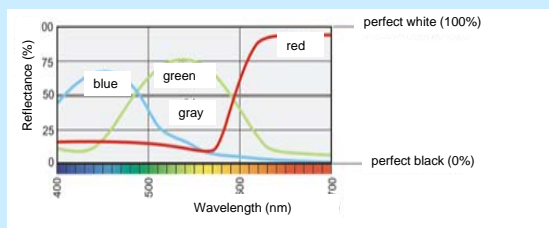
spectral reflectance

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



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

Spectrum of reflectance



Light scattering



Scattering coefficient

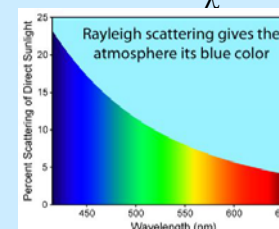
$$\sigma(\lambda) = \frac{J_{\text{scattered}}}{J_{\text{incident}}}$$

Elastic scattering: λ, f, ϵ are constant

Rayleigh-scattering

$$d \ll \lambda$$

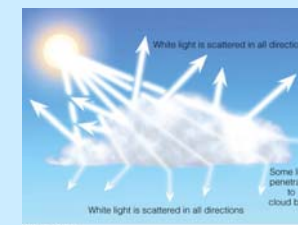
$$\sigma(\lambda) \sim \frac{d^6}{\lambda^4}$$



$$d \geq \lambda$$

Mie-scattering

No strong λ dependency



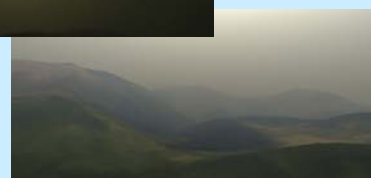
Light scattering

Rayleigh-scattering

$$d \ll \lambda$$

Mie-scattering

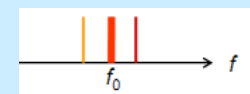
$$d \geq \lambda$$



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"

Question of the week

Attenuation of the light intensity by plastic leafs was shown in an experiment. How many times shall we take the plastic leaf to get the half value thickness? Determine the half value thickness by means of graphical representation.

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