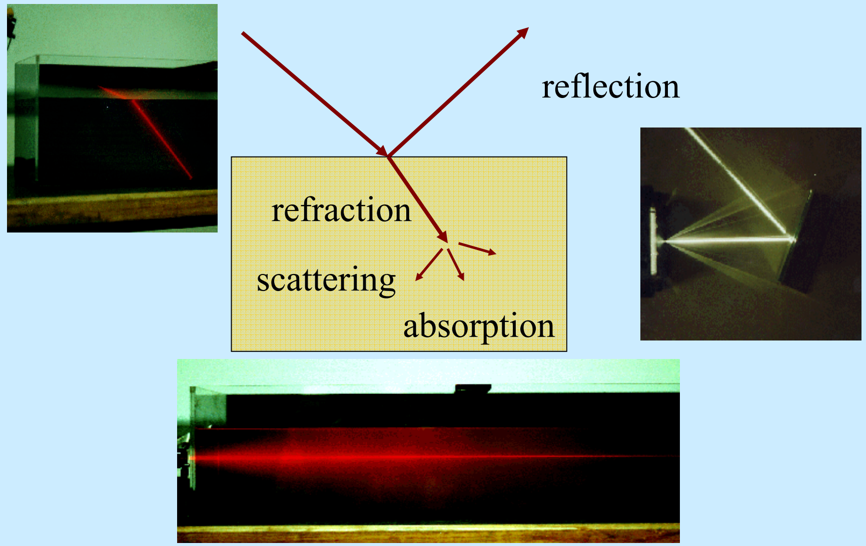
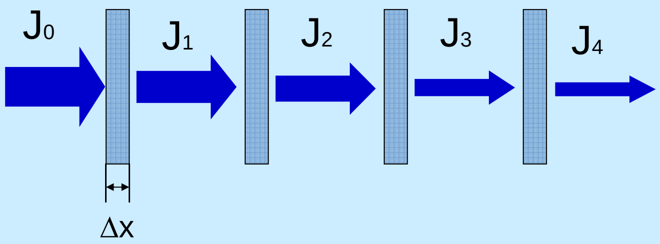
Interaction of light with matter
2.

Interaction of light with matter



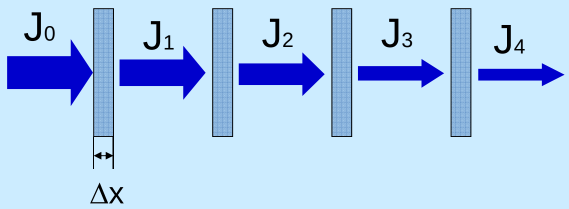
Absorption



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

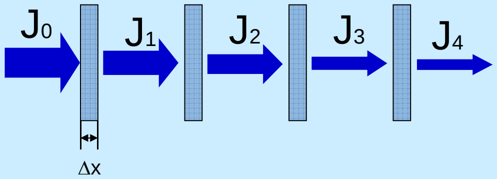
J : incident intensity [W/m^2]

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.

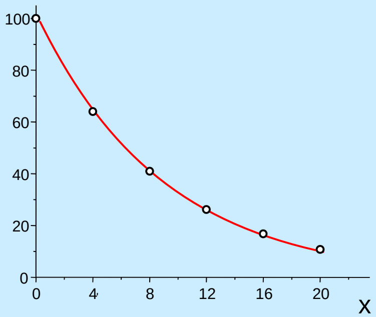
Law of attenuation



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

solution

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



Macroscopic function

Integral form

Exponential law of radiation attenuation

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

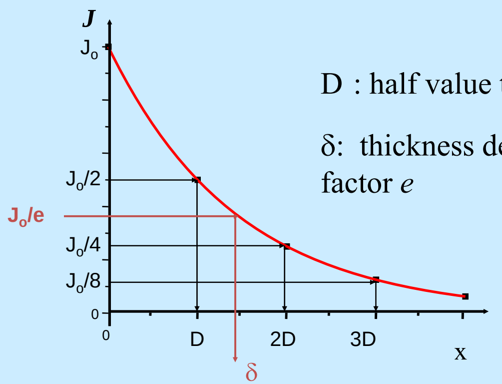
J is exponential function of the thickness of the layer.

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

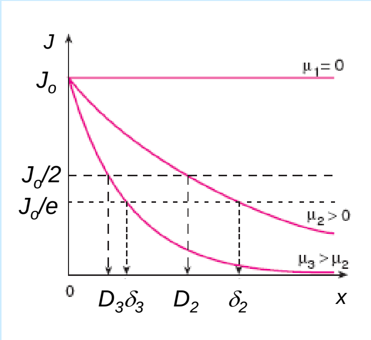
$$J = J_0 e^{-\mu x}$$

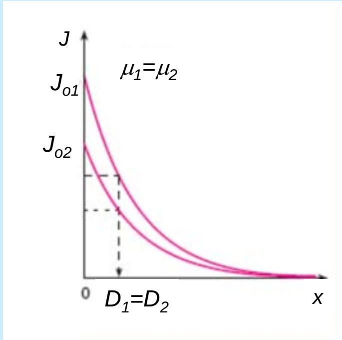
If x = D $\Longrightarrow$ $J_0 / 2 = J_0 e^{-\mu D}$

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

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

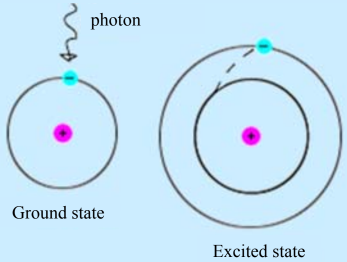
$$\mu = \frac{1}{\delta}$$





Mechanism of light absorption

Repetition: structure of atom

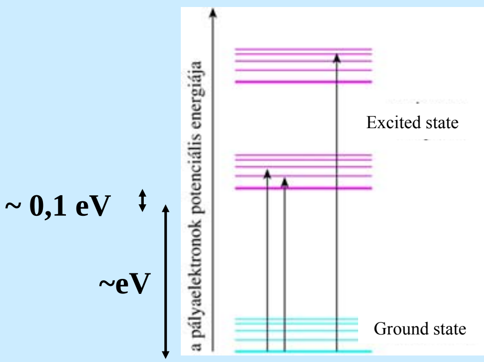


$$hf = \Delta E = E_{n+1} - E_n$$

E_{VIS}= 1.6 – 3.1 *eV*

Excitation of outer shell electrons

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 = ε $_{(\lambda)}$ c

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

Lambert – Beer law

Absorbance or Optical density

decadic molar extinction coefficient

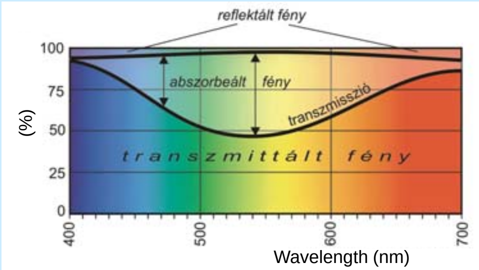
molar concentration

Absorbance
or
Optical density

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

Transmittance

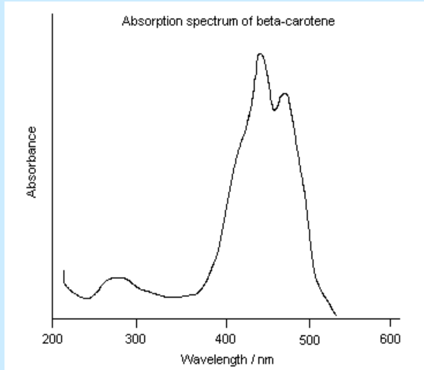
$$\tau = \frac{J_{transmit}}{J_{incident}}$$



Spectra of red glace

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

Absorbance – is the function of the wavelength

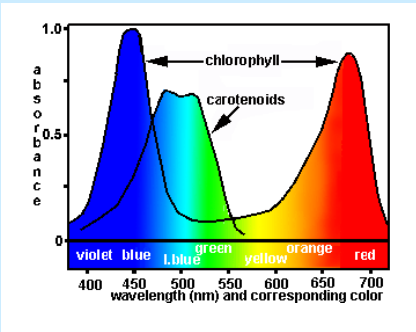


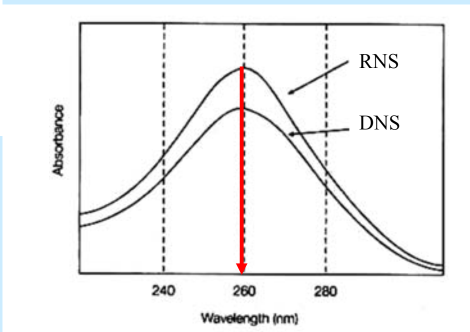
Absorption spectrum:

Absorbance as the function of the wavelength.

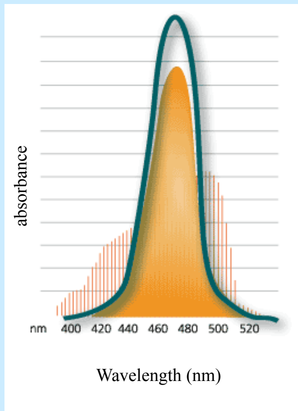
“Band” spektrum

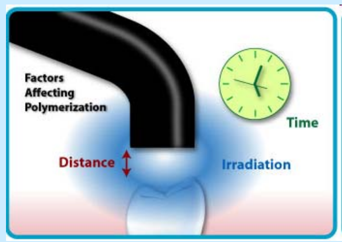
absorption spectrum of some biological macromolecules





Application in dentistry

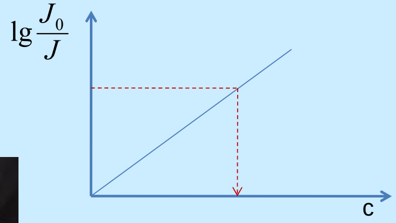




Camphor chinone

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

in dilute solutions absorbance is proportional to the concentration

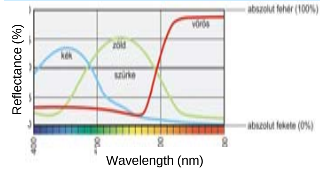


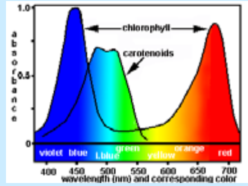
Absorption based determination of concentration

Why do objects appear the color they are?

reflection | scattering | absorption

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





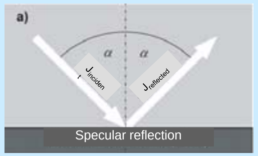
e.g. reflection of red
↓
red

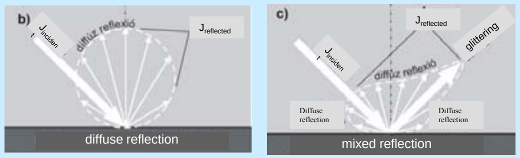
Influenced by the relative position of the light source and observer, size of particles etc

e.g. red absorption
↓
green in transmitted light

Reflection

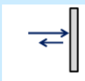
Diffuse reflection





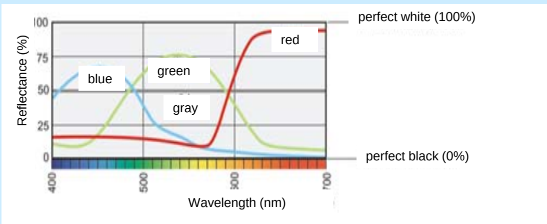
spectral reflectance

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

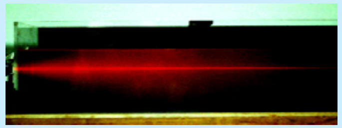


$$\rho = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Spectrum of reflectance



Light scattering



Scattering coefficient

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

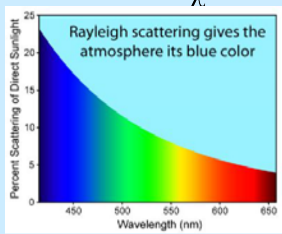
Elastic scattering: λ, f, ε are constant

Rayleigh-scattering $d << \lambda$

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

Mie-scattering $d \geq \lambda$

No strong λ dependency



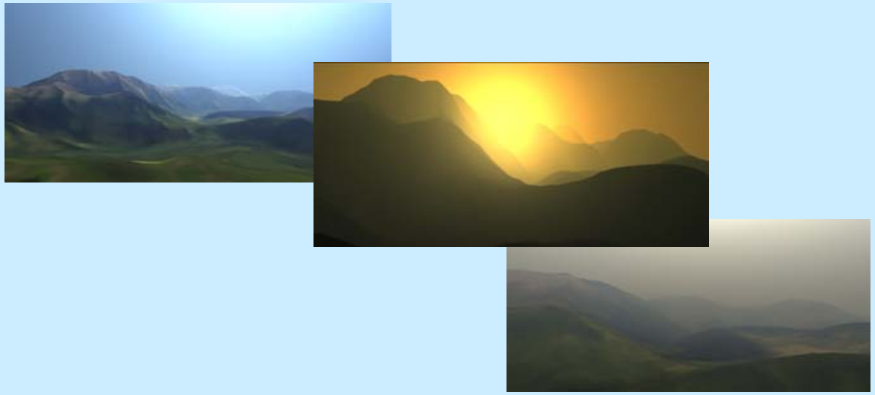
Light scattering

Rayleigh-scattering

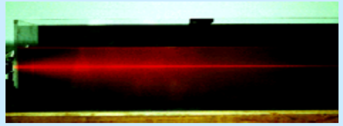
d << λ

Mie-scattering

d ≥ λ



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 shell 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