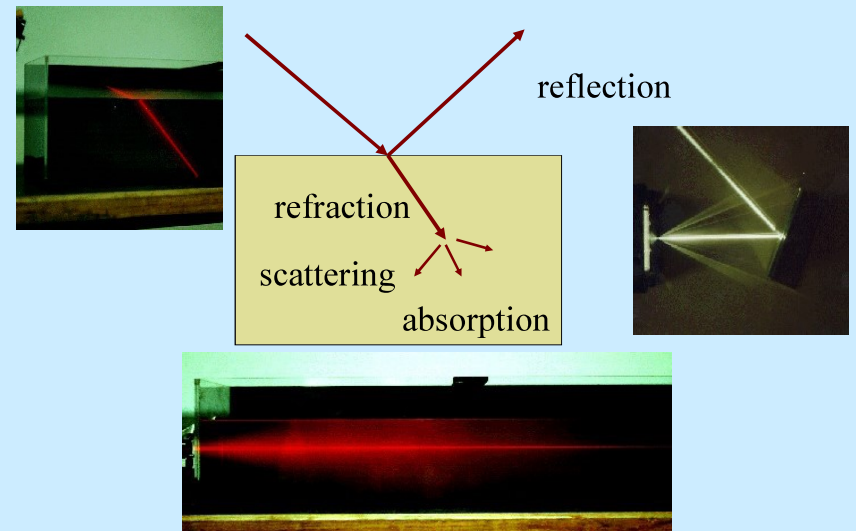
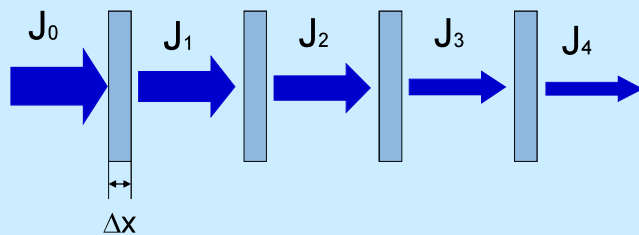


## Interaction of light with matter 2.

## 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**

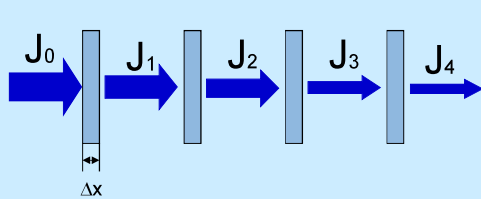
$J$  : incident intensity [ $\text{W/m}^2$ ]

$\Delta J$  : change of intensity after passing through  $\Delta x$  thickness

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

The decrease is proportional to the thickness of absorber  $\Delta x$  and  $J$  what is the initial intensity.

## Law of attenuation



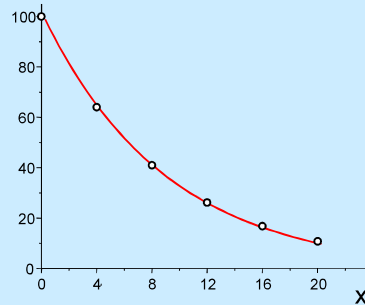
$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

↓ 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<sup>2</sup>]

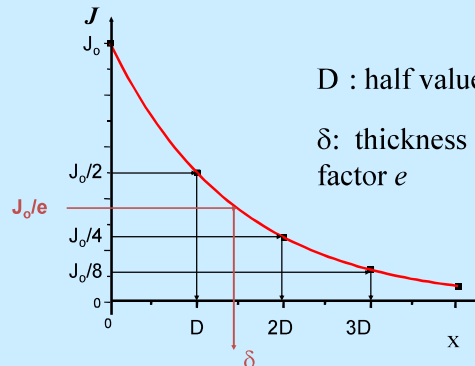
$J$  : intensity after passing through  $x$  thickness

$\mu$  : 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

$\delta$  : thickness decreasing the intensity by a factor  $e$

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

## Definition of attenuation coefficient

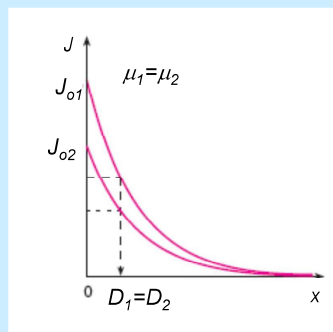
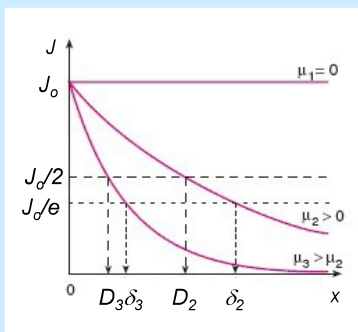
$$J = J_0 e^{-\mu x}$$

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  $800 \text{ cm}^{-1}$  at the wavelength emitted by the  $\text{CO}_2$  laser. Calculate the thickness of the muscle layer that absorbs 90 % of the light energy of these lasers.

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

$$J_0 = 100\%$$

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

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

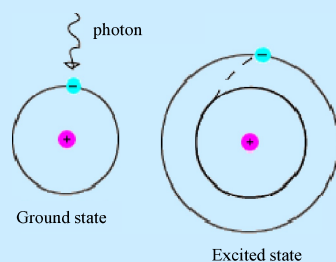
$$10 = 100 e^{-800x}$$

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

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

## Mechanism of light absorption

Repetition: structure of atom

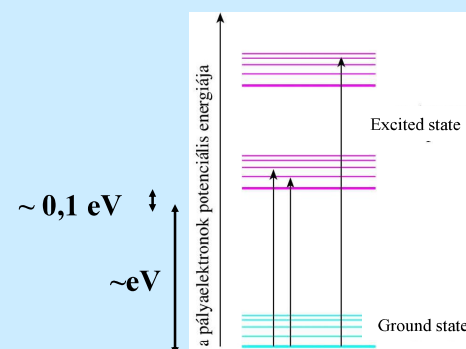


$$hf = \Delta E = E_{n+1} - E_n$$

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

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

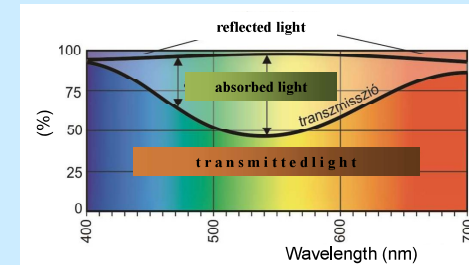
molar concentration

Absorbance  
or  
Optical density

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

Transmittance

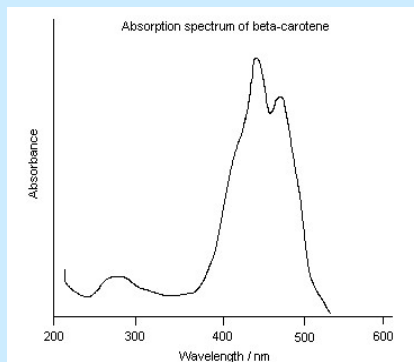
$$\tau = \frac{J_{\text{transmit}}}{J_{\text{incident}}}$$



Spectra of red glass

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

Absorbance – is the function of the wavelength

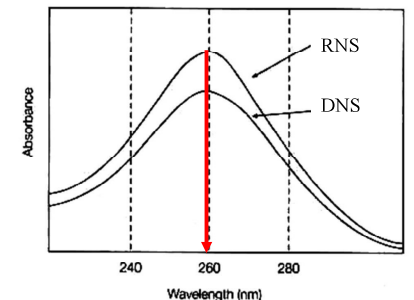
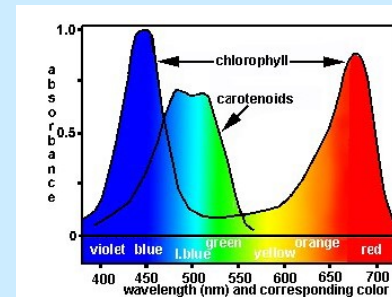


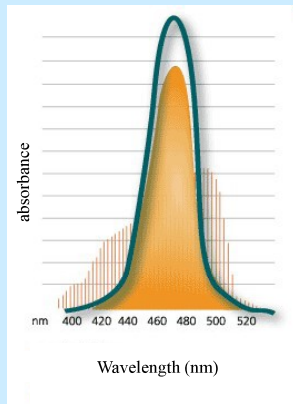
**Absorption spectrum:**

Absorbance as the function of the  
wavelength.

“Band” spektrum

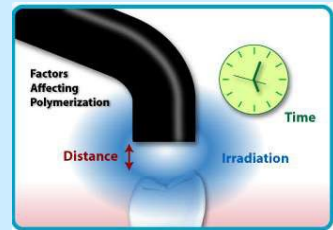
absorption spectrum of some biological macromolecules





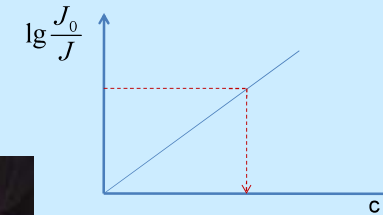
Camphor quinone

Application in dentistry



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

in dilute solutions absorbance is proportional to the concentration



Absorption based determination of concentration



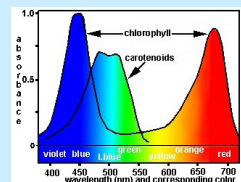
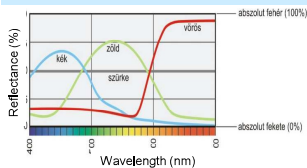
Why do objects appear the color they are?

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

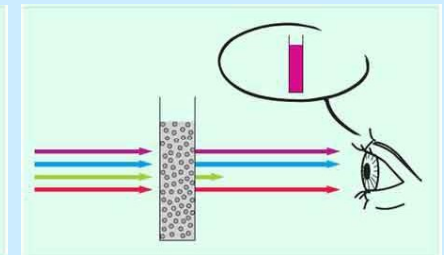
e.g. red absorption

↓  
green in transmitted light

## Absorption

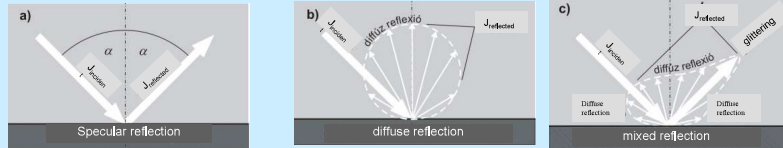
Complementary colors

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



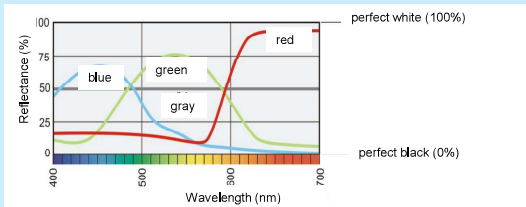
spectral reflectance

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

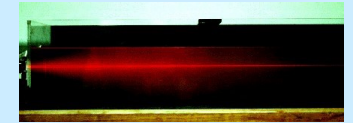
$$\rho = \left( \frac{n_2 - n_1}{n_2 + n_1} \right)^2$$



Spectrum of reflectance



# Light scattering



Scattering coefficient

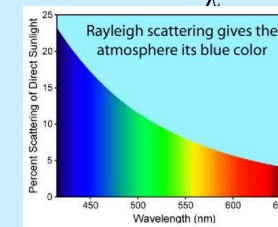
$$\sigma(\lambda) = \frac{J_{\text{scattered}}}{J_{\text{incident}}}$$

Elastic scattering:  $\lambda, f, \epsilon$  are constant

Rayleigh-scattering

$$d \ll \lambda$$

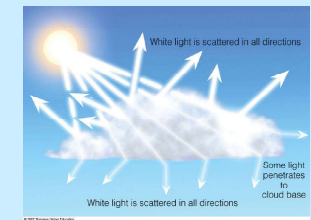
$$\sigma(\lambda) \sim \frac{d^6}{\lambda^4}$$



Mie-scattering

$$d \geq \lambda$$

No strong  $\lambda$  dependency



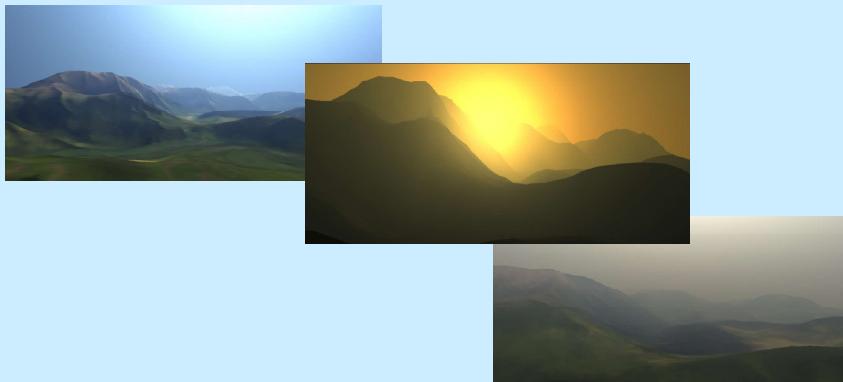
# Light scattering

Rayleigh-scattering

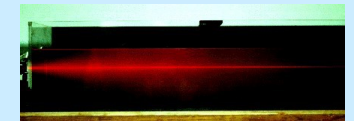
$$d \ll \lambda$$

Mie-scattering

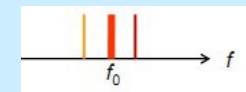
$$d \geq \lambda$$



# Light scattering



Non-Elastic scattering:  $\lambda, f, \epsilon$  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