Biophysics I

4. Light absorption, reflection, scattering, color vision

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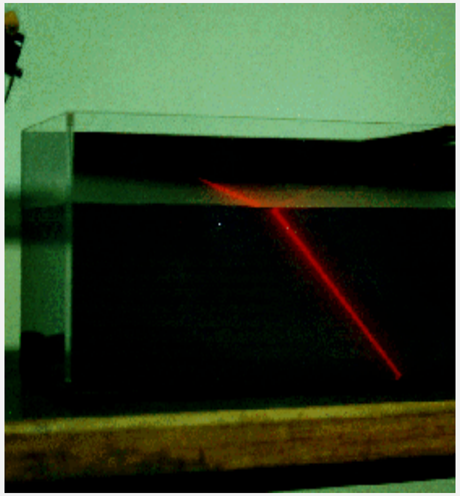
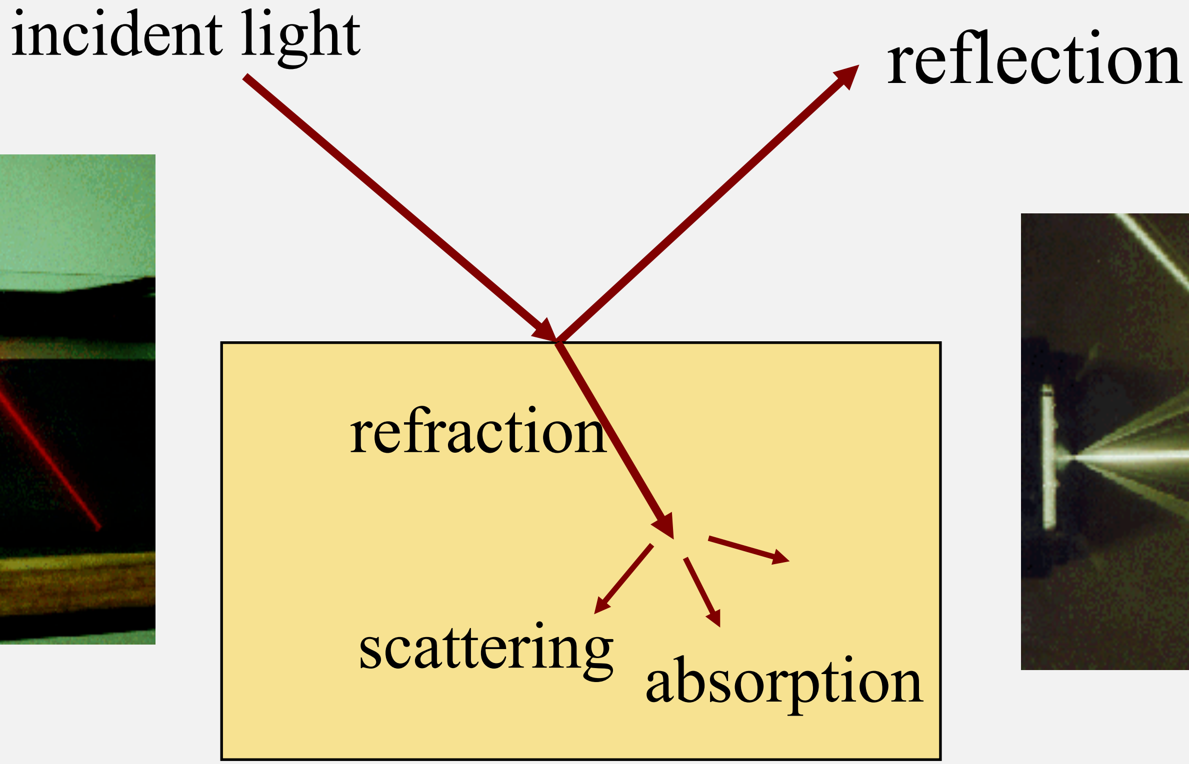
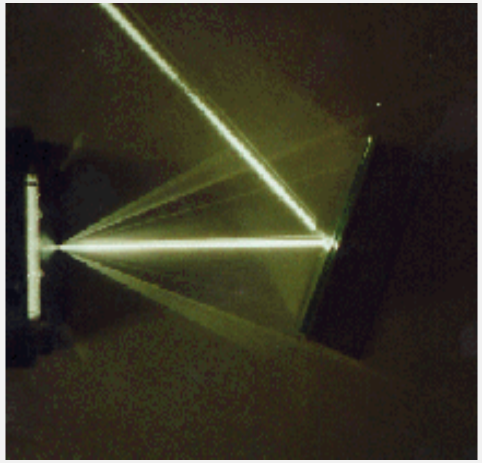
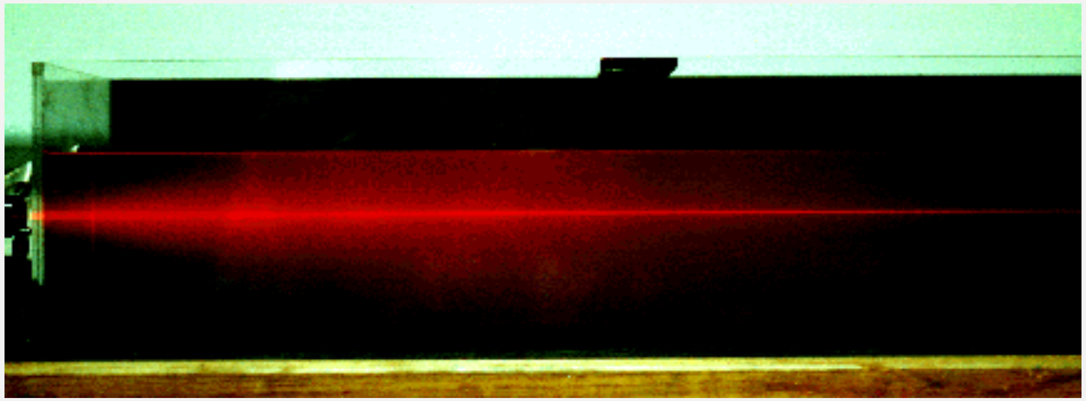
Interactions of light and matter

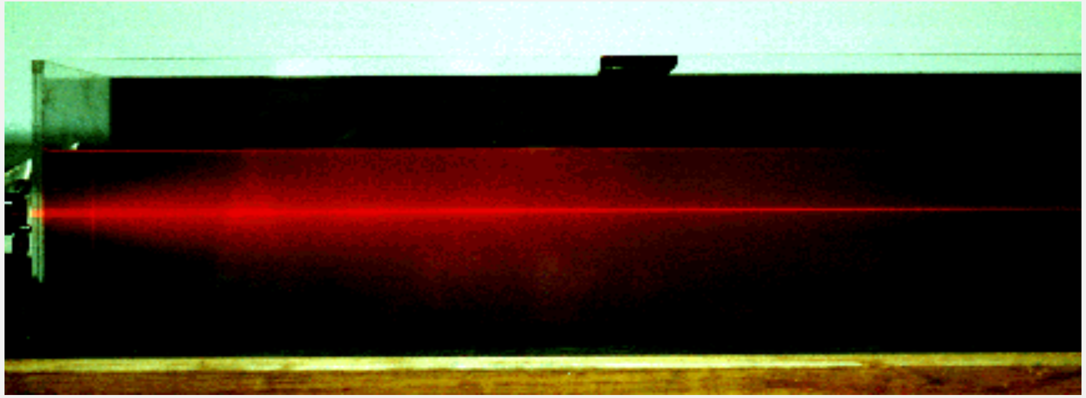


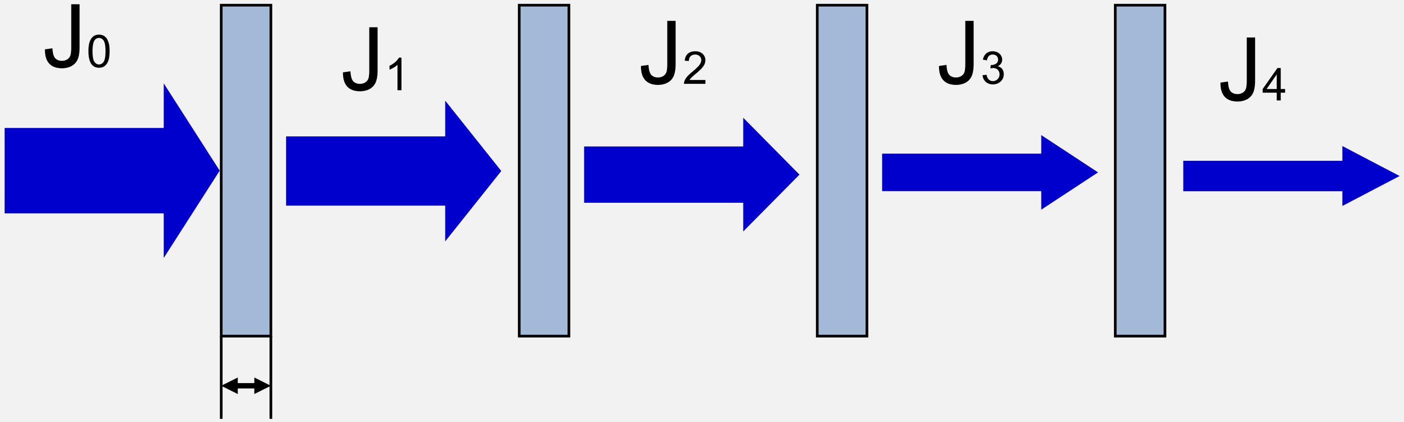






Absorption of light





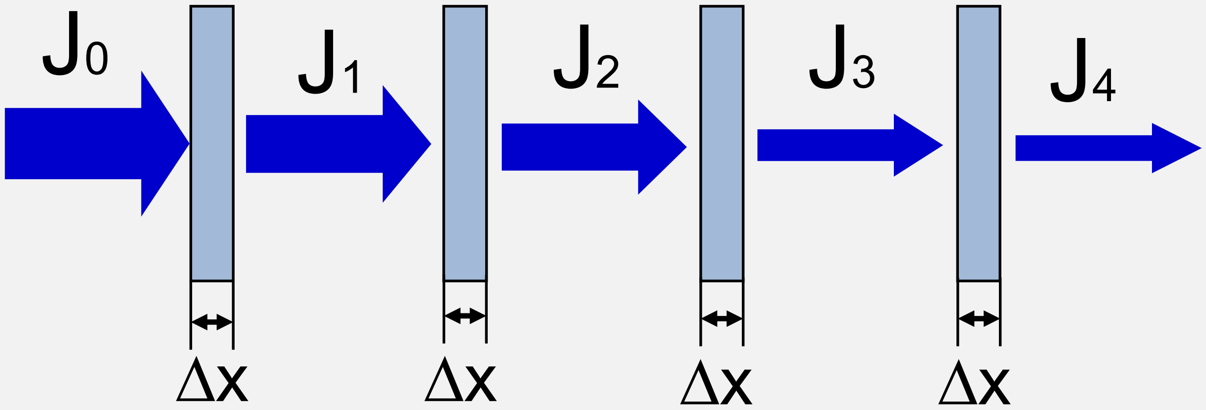
Δx $\Delta J = J_0 - J_1 \ldots$ $\Delta J / \Delta x \sim J$

Intensity of radiations passing through matter is attenuated.

[Intensity] = [energy / unit area / unit time] = $J/(m^2 * s) = W/m^2$

Law of attenuation

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



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

Differential form

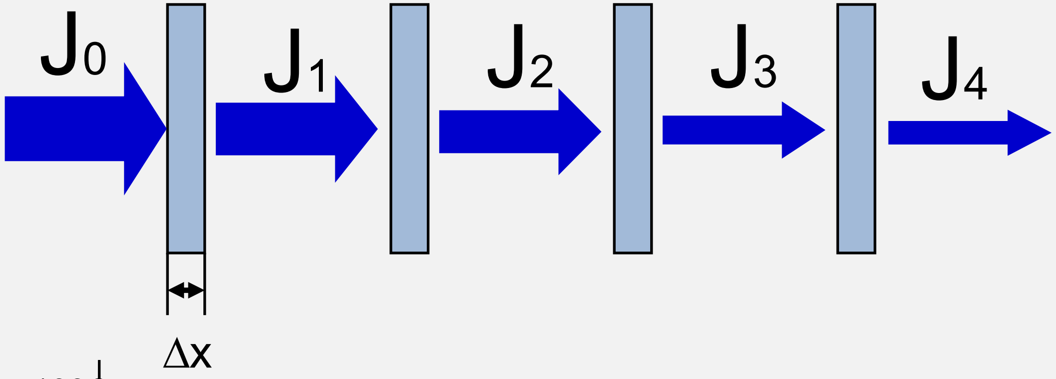
J_i: incident intensities [W/m^2]

ΔJ: change of intesity when passing through Δx thin layer

μ: attenuation coefficient [1/m]

The decrease of intensity over a thin layer of the absorber is proportional to the intensity entering into that layer.

Law of attenuation



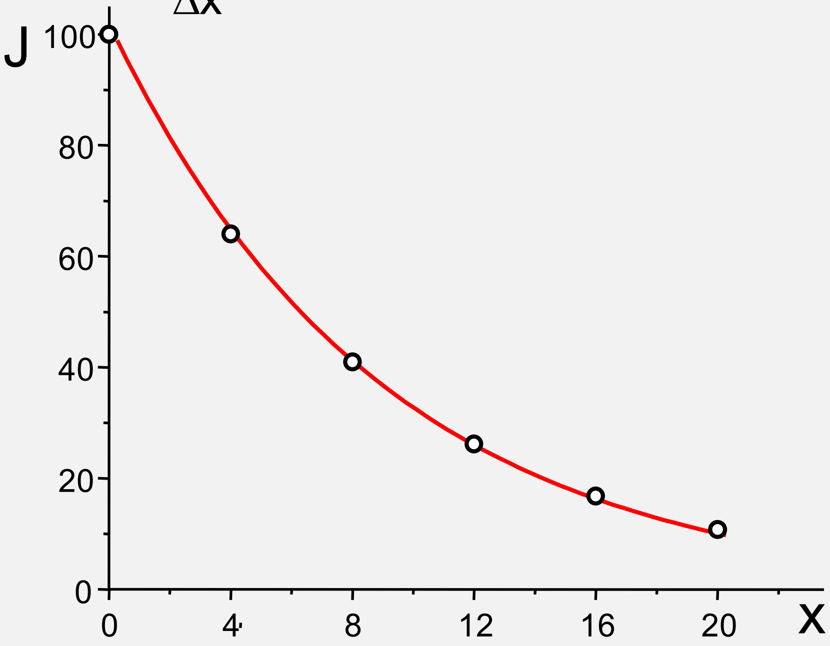
$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

math solution

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

Integral form

e = Euler's number = 2,71828...



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

J is an exponential decay function of the layer thickness.

J_0: incoming intensity [W/m^2]

J: intensity at x [m] layer thickness

μ: attenuation coefficient [1/m]

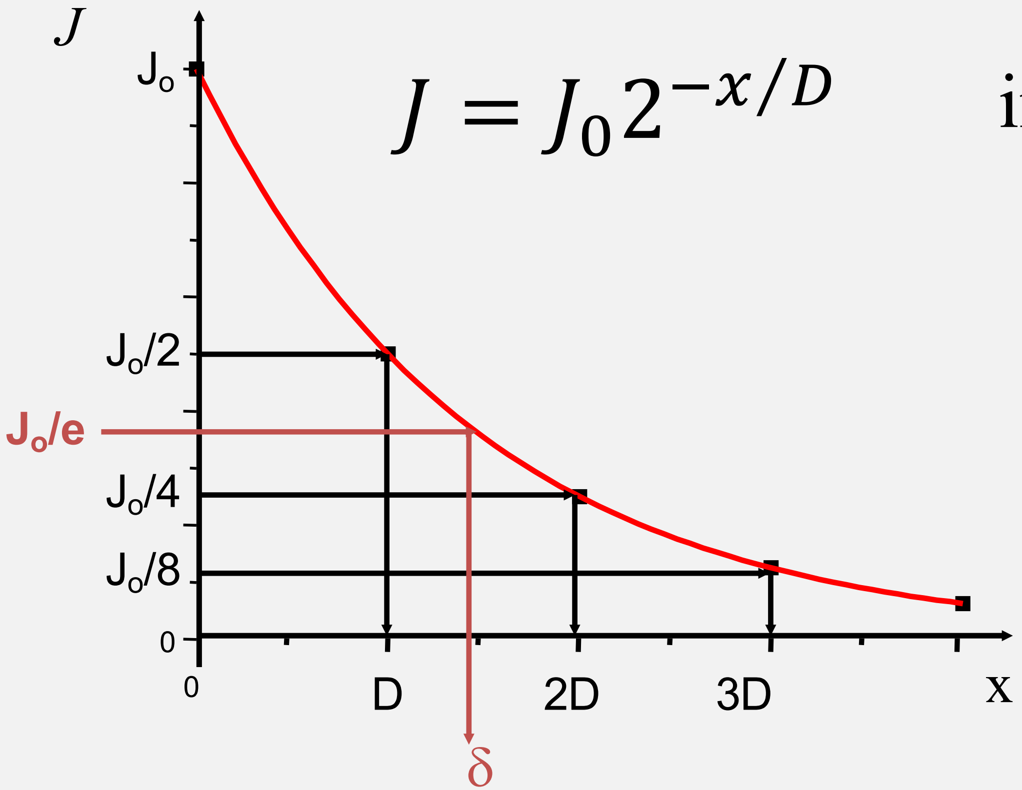
The attenuation coefficient depends on:

- photon energy,
- material composition
- density of the absorber

Half-value thickness

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

$$J = J_0 2^{-x/D}$$



D: half-value thickness

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

both D and δ
– characteristic for the absorption of light by matter
– depend on the photon energy, the material composition, and the density of absorbers

Relationships of D, δ and μ

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

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

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

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

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

Analytical applications of light absorption

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

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

In diluted solutions μ is proportional with the concentration:

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

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

Beer's law

Absorbance

molar extinction coefficient [$mol^{-1}cm^{-1}$]

molar concentration [mol/l]

layer thickness *(usually set to 1 cm)*

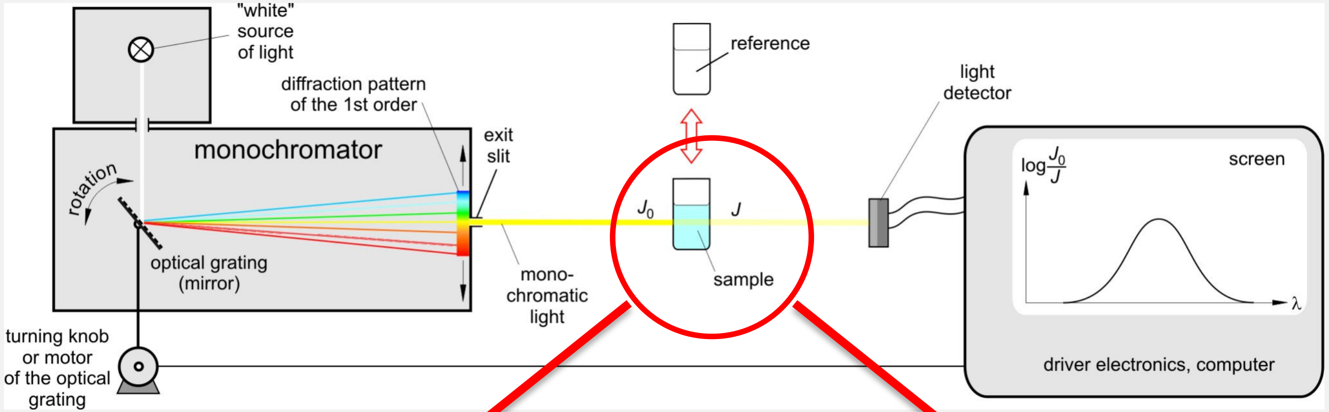
Transmittance, $T = J/J_0 * 100$ (%)

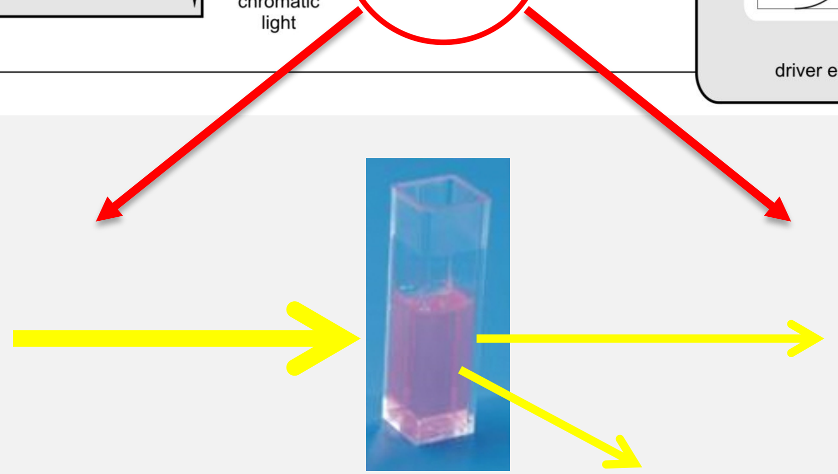
Absorbance (A) = optical density, (OD)

Extinction of light?

$$A = \varepsilon_{(\lambda)} \bullet c \bullet x$$

$\varepsilon_{(\lambda)}$: molar **extinction** coefficient

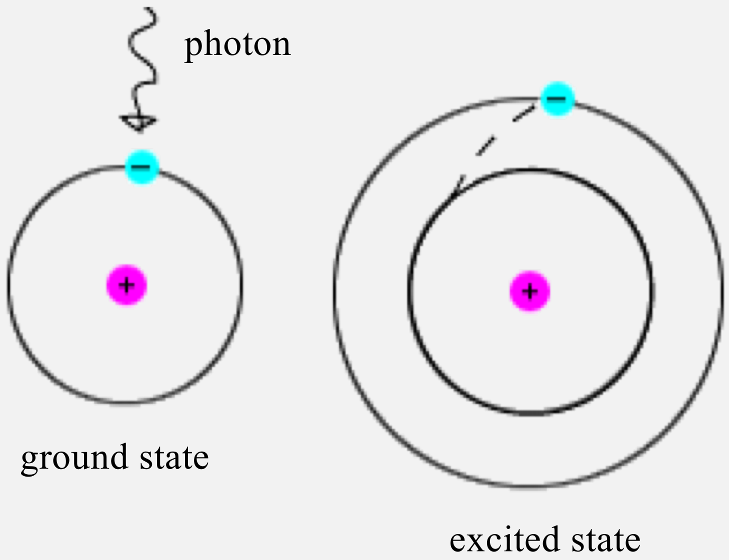




Extinction: attenuation by absorption and scattering together

Mechanism of light absorption

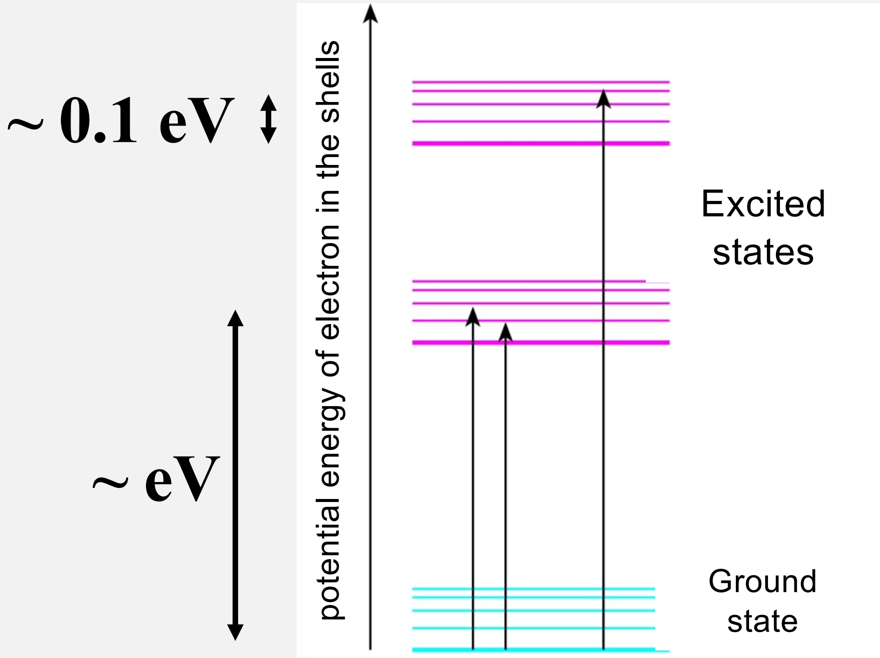
The potential energy of electrons is quantized in atoms and molecules

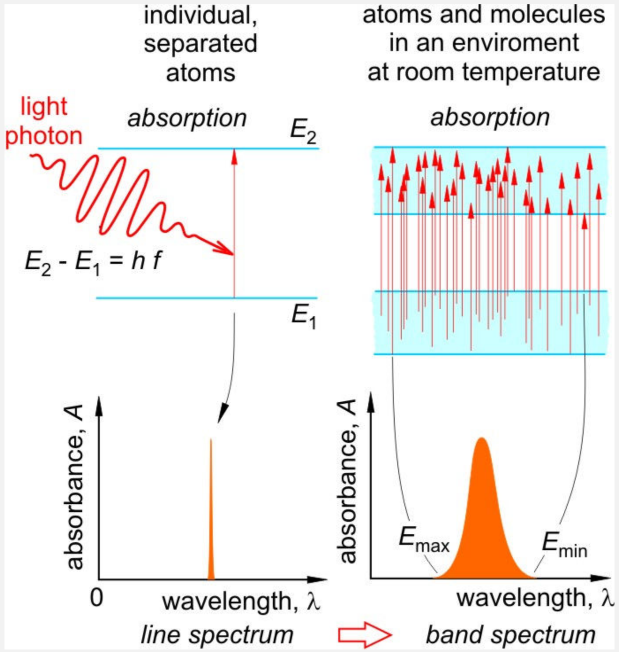


$$hf = \Delta E = E_{n+1} - E_n$$

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

Mechanism of light absorption



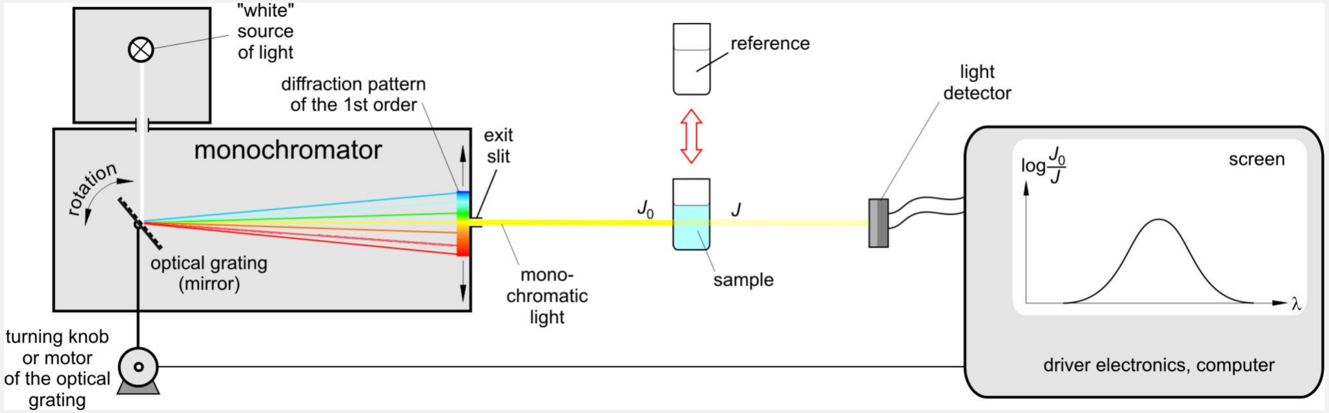


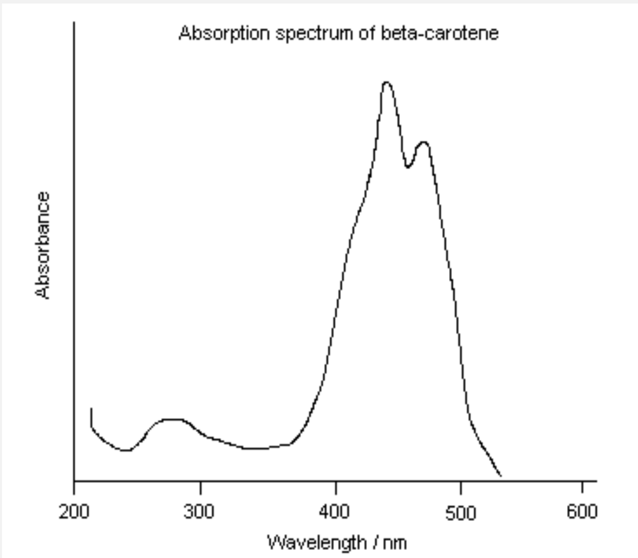
Molecules can absorb photons in a certain energy range

➔ band spectrum

Absorption spectrum

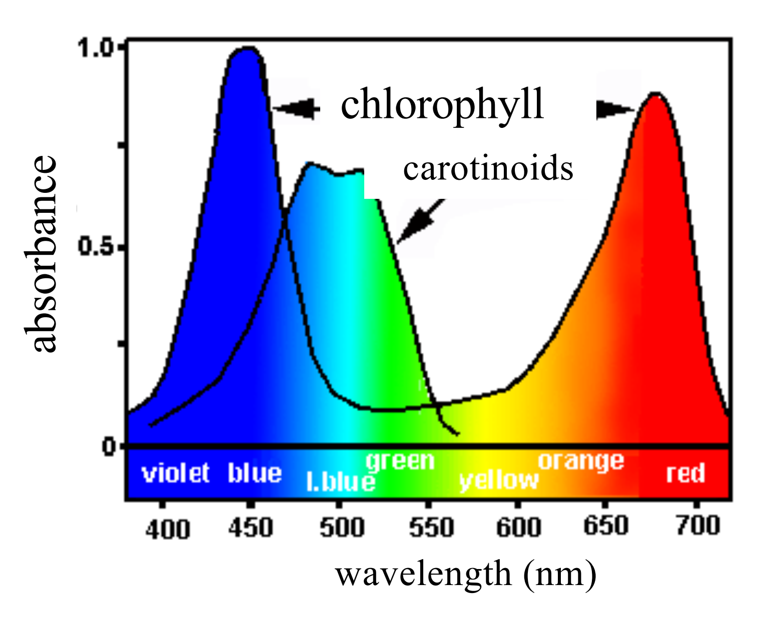
Absorbance depends on the wavelength: $A = \varepsilon_{(\lambda)} \cdot c \cdot x$

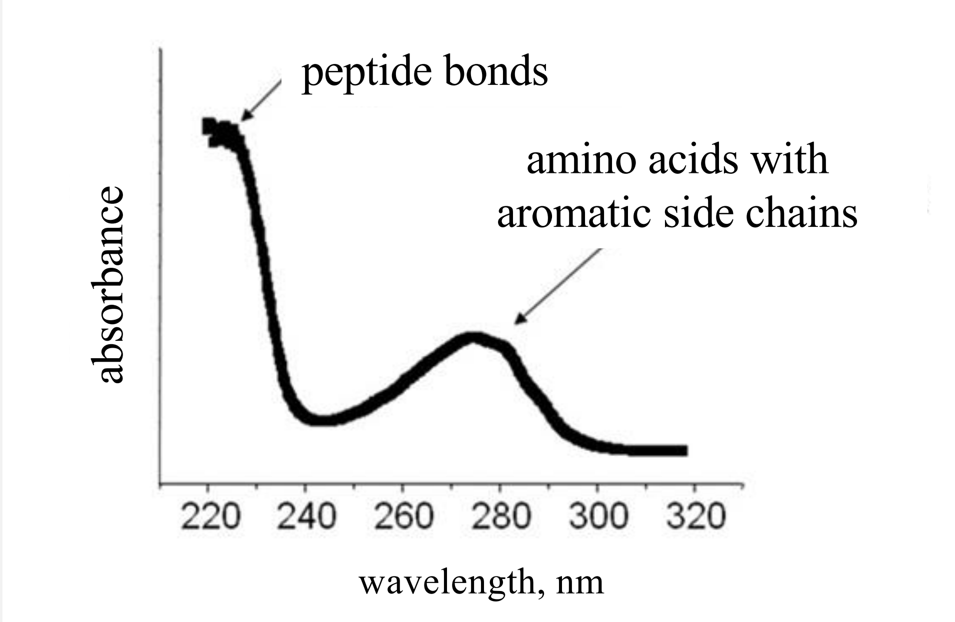


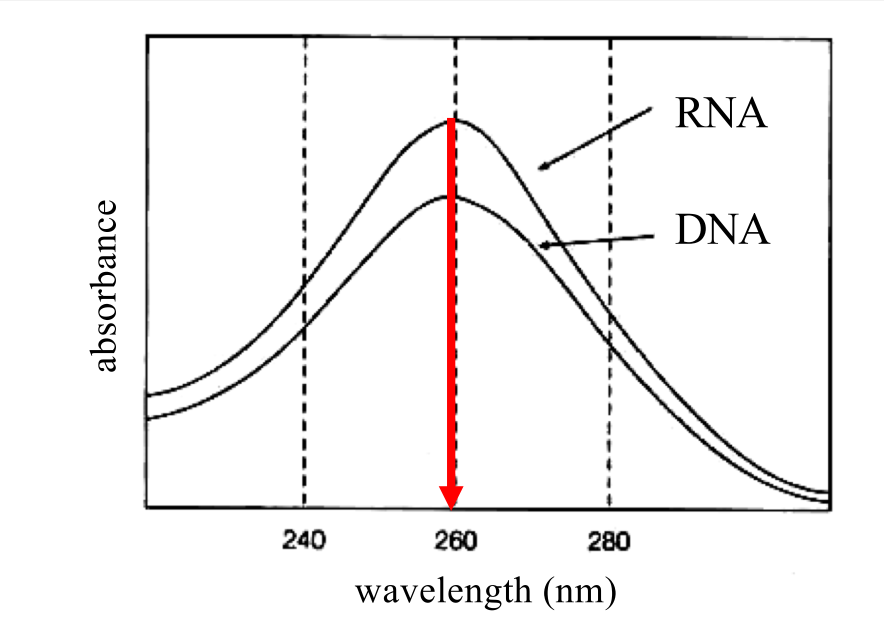


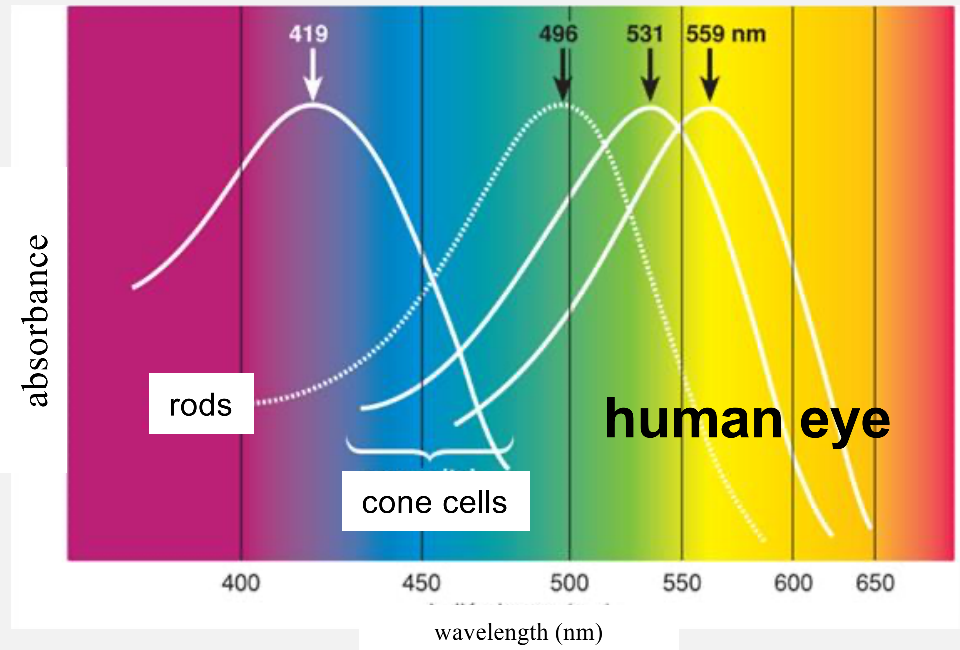
Absorbance as a function of wavelength is characteristic to the absorber (depends on the electronic structure of the material).

Absorption spectrums of several biomolecules

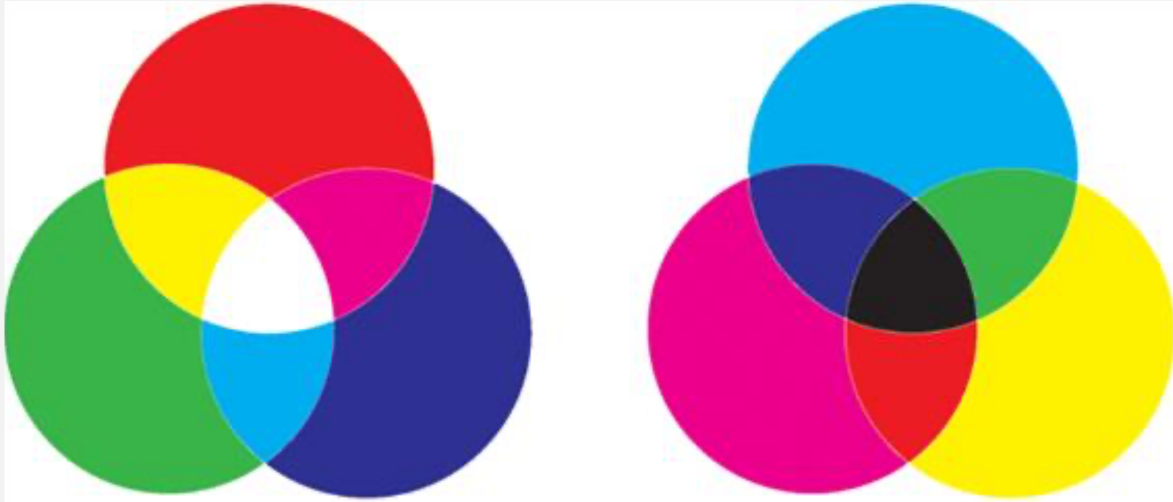




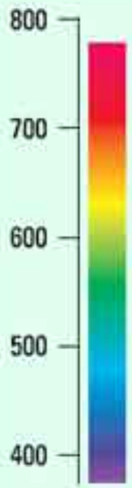




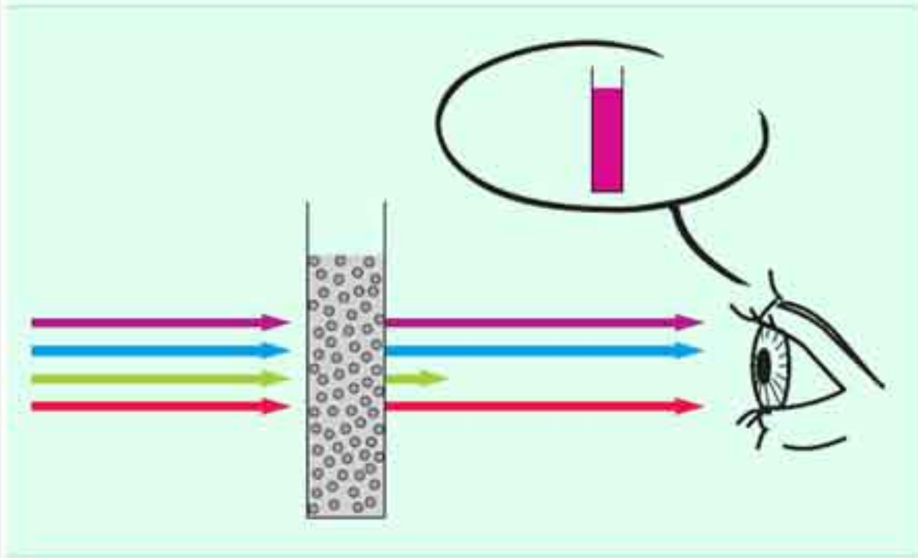
Absorption and colors – complementary colors

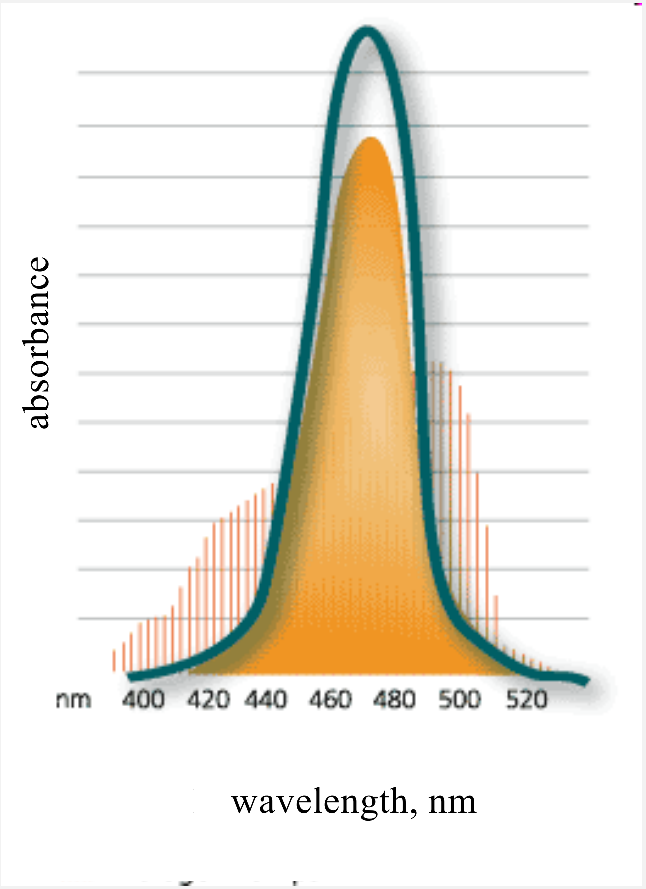


additive color mixing   substractive color mixing

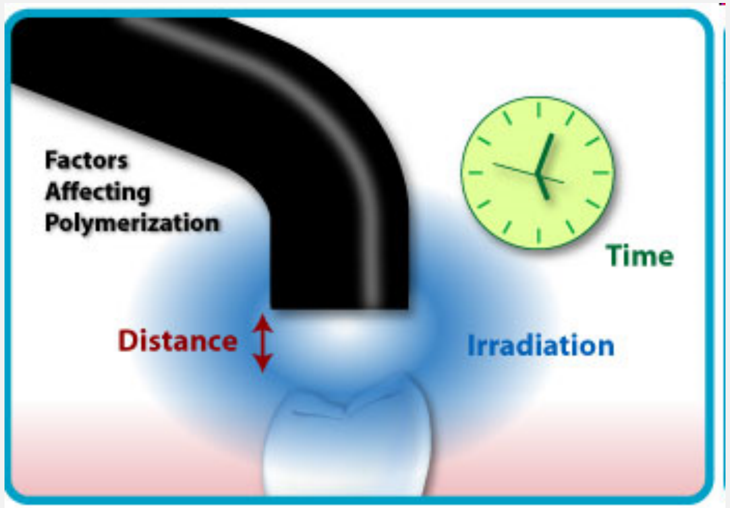


Wavelength [nm]	Absorbed color	Complementary color
650-780	red	blue-green
595-650	orange	greenish blue
560-595	yellow-green	purple
500-560	green	red-purple
490-500	bluish green	red
480-490	greenish blue	orange
435-480	blue	yellow
380-435	violet	yellow-green



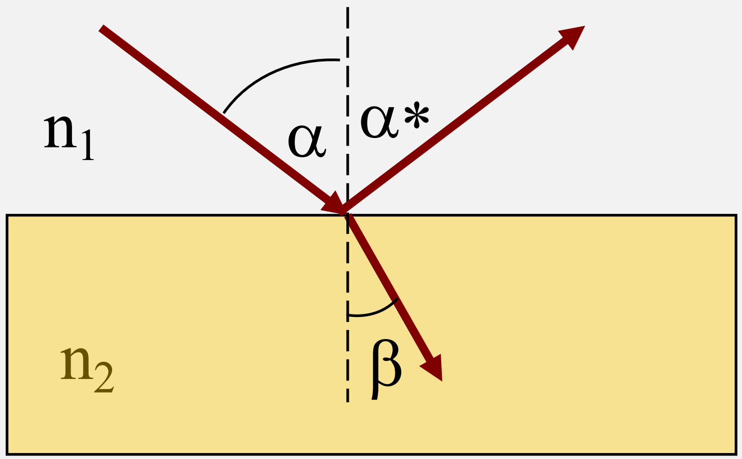


Application in Dentistry



Camphor chinone
dental composite polimerizes due to light absorption

Refraction and reflection



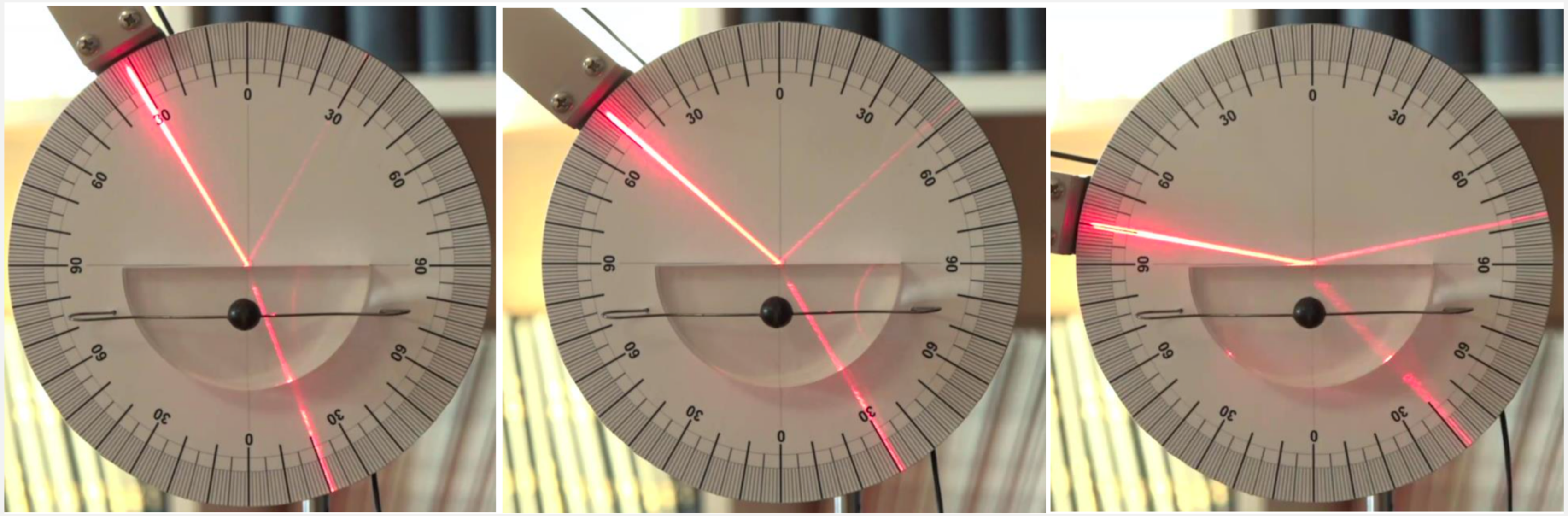
$n_1 < n_2$

$\alpha > \beta$

$\alpha > \alpha^*$

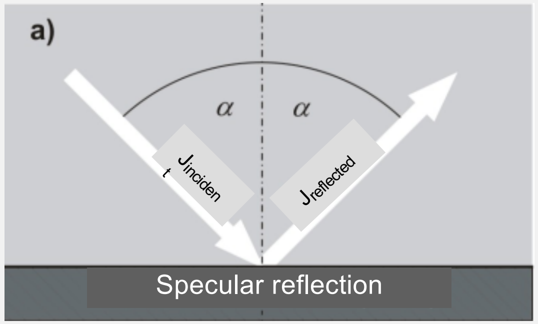
Snell's law:

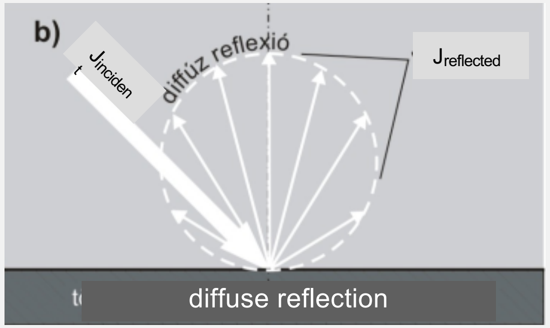
$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

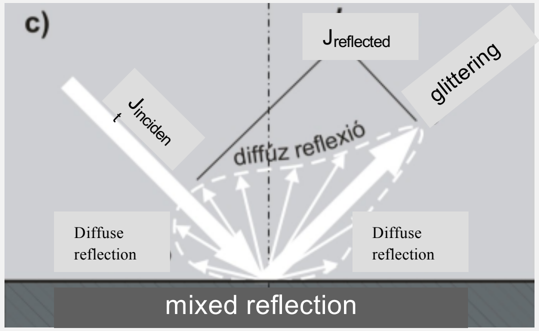


Reflection of light

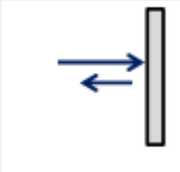
Diffuse reflection





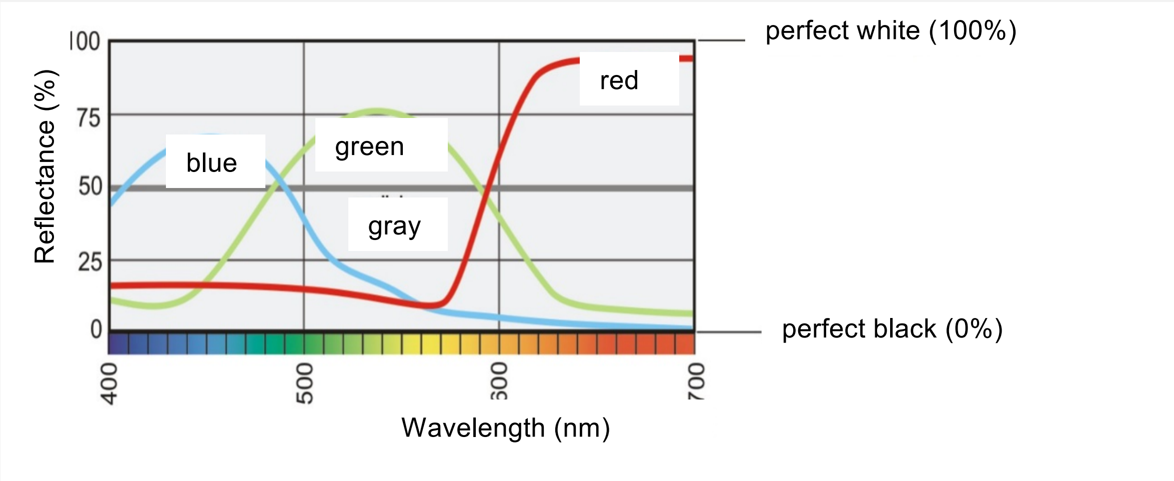


spectral reflectance

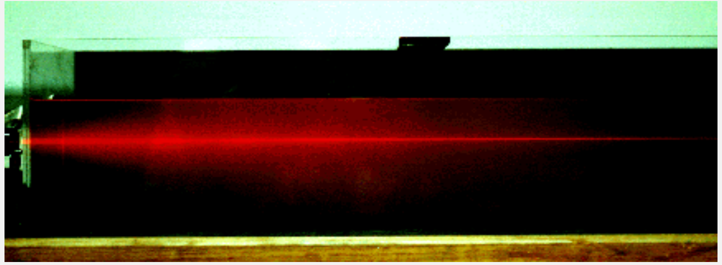


$$\rho(\lambda) = \frac{J_{reflected}}{J_{incident}} \qquad \rho = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Spectra of reflectance curves of basic colors



Scattering of light



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

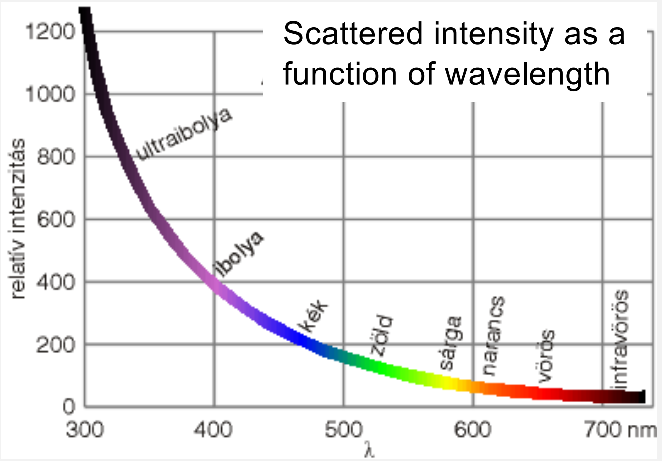
Elastic scattering: no energy change ➔ f, λ are constant

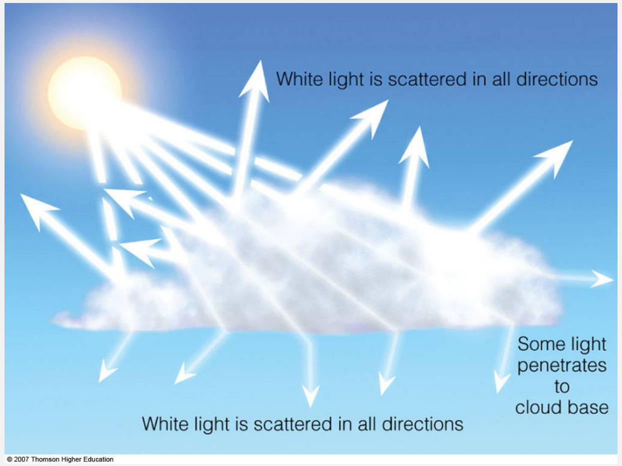
Rayleigh scattering $d << \lambda$

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

Mie scattering $d \geq \lambda$

σ weakly depends on λ

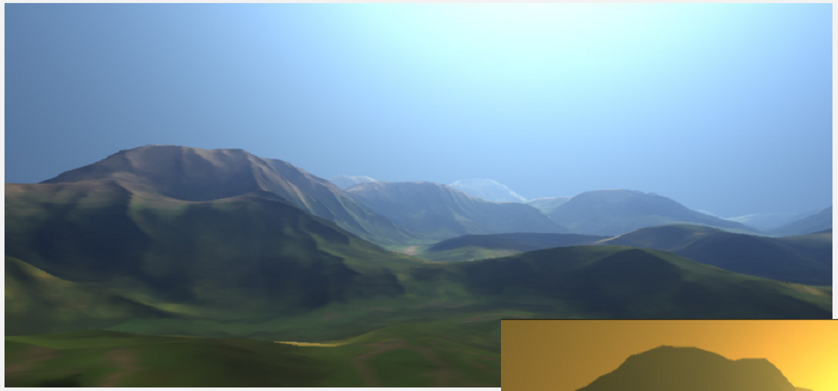




Light scattering

Rayleigh-scattering

d << λ



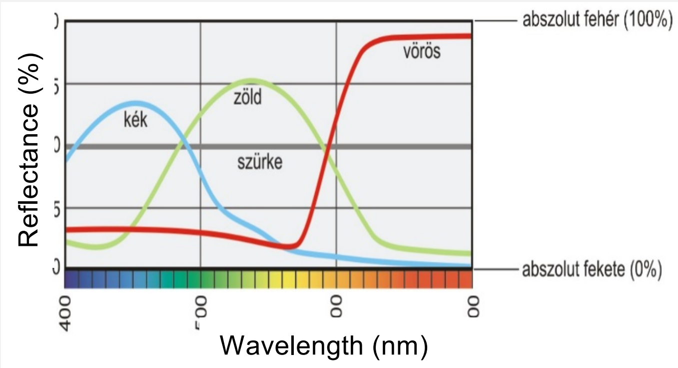
Mie-scattering

d ≥ λ

Factors affecting the color of objects

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

reflection

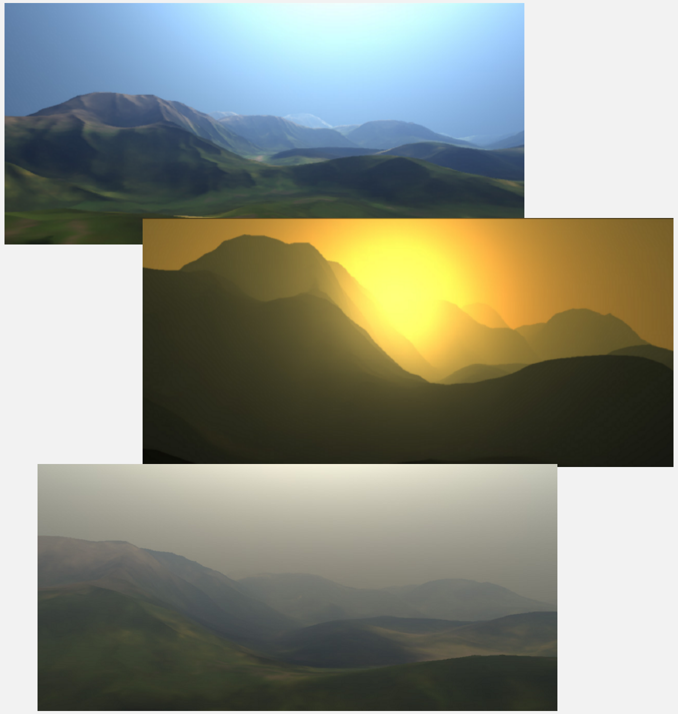


reflection of red

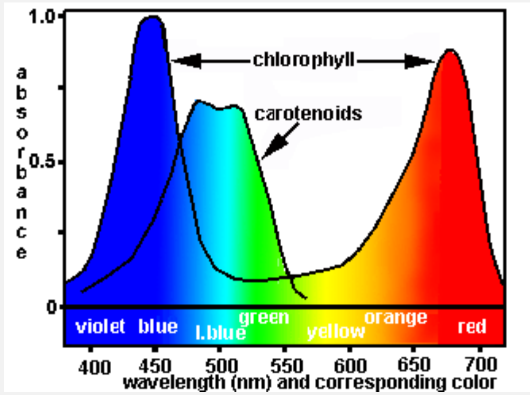
↓

red

scattering



absorption



absorption of red

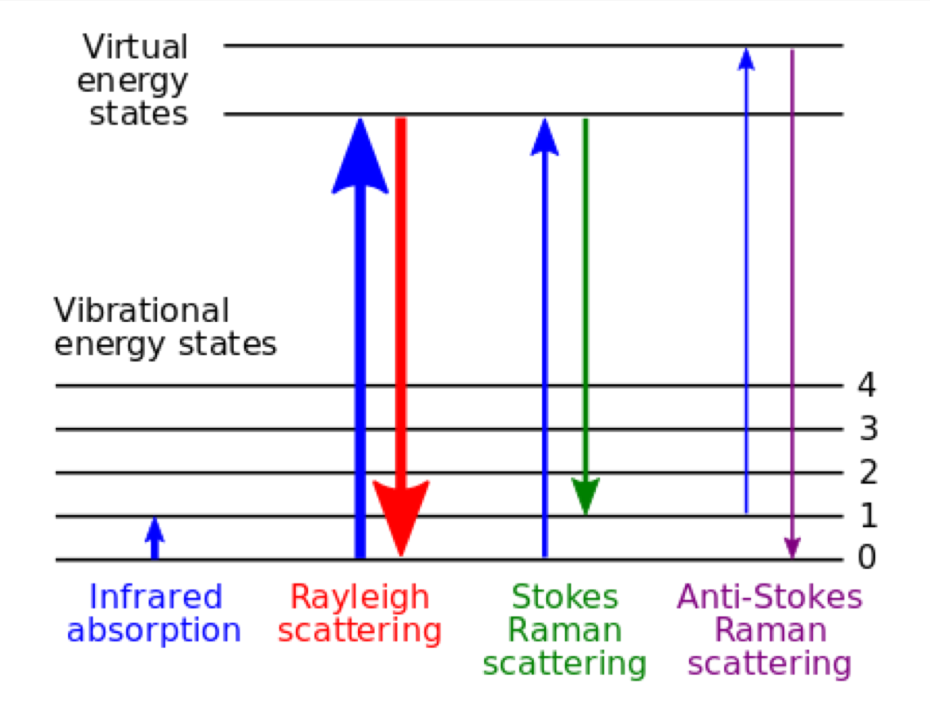
↓

green

Raman scattering

Energy transition between light and matter:

➔ inelastic scattering: λ, f are not constant



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 fom, 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

Related chapters in

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