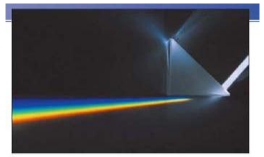
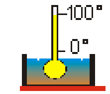




Physical basis of dental material science
10.

Thermal and optical properties

Thermal properties

- **temperature: proportional to the internal energy of the material. (unit: K, °C, in physics K is used mainly)**



- **Heat uptake/loss – exchange between the object and the enviroment.**

Heat capacity (*C*): (energy that increases the temperature by 1 K)

$$C = \frac{\Delta Q}{\Delta T}$$

molar heat capacity (c_ν): (heat capacity for one mol)

$$c_\nu = \frac{C}{\nu}$$

specific heat capacity (*c*): (heat capacity for unit mass)

$$c = \frac{C}{m}$$

ΔQ – exchanged thermal energy
ν – no. of mols
m – mass
ΔT – temperature change

c_p –measured at constant pressure
c_V – measured at constant volume

$$c_p > c_V$$

Specific heat capacity

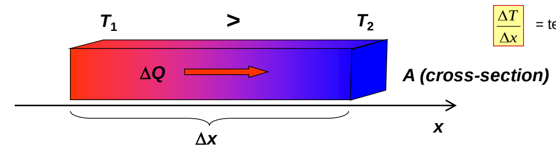
High specific heat of the water is important from the viewpoint of the life! (thermal stability)

specific heat capacity of some dental materials:

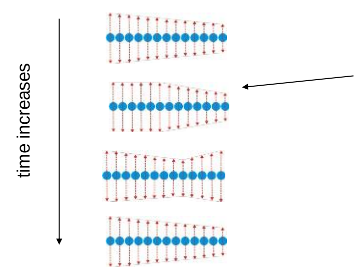
material	*c* (J/(kg·K))
Enamel	750
Dentin	1260
Water	**4190**
Amalgam	210
Gold	126
Porcelain	1100
Glass	800
PMMA	1460
$ZnPO_4$	500

Thermal conduction

$\Delta T = T_2 - T_1$



$\frac{\Delta T}{\Delta x}$ = temperature gradient



How is the energy transported?

lattice oscillation

In metals e.g. motion of the free electrones.

Thermal conductivity

Fourier-law

$$\frac{\Delta Q}{\Delta t} = -\lambda A \frac{\Delta T}{\Delta x}$$

λ — **thermal conductivity**
J/(s·m^2·K/m) = W/(m·K)

Characterizes well the phenomenon in the case of stationary flow!

(stationary – the parameters are constant in time)

Thermal conductivity of some dental material:

material	λ (W/(mK))
Enamel	0.9
Dentin	0.6
Water	0.44
Amalgam	23
Gold	300
Porcelain	1
Glass	0.6-1.4
Acrylate	0.2
PMMA	0.2-0.3
$ZnPO_4$	1.2

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Non-stationary case

$$D = \frac{\lambda}{c_p \rho}$$

D — thermal **diffusivity** (m^2/s)
(may be different at the different points of the material)

ρ — density
c_p – specific heat capacity at constant pressure

Thermal diffusivity of some dental materials:

material	λ (W/(mK))	D (10^{-6} m^2/s)
Enamel	0.9	0.5
Dentin	0.6	0.2
Water	0.44	0.14
Amalgam	23	9.6
Gold	300	118
Porcelain	1	0.4
Glass	0.6-1.4	0.3-0.7
Acrylate	0.2	0.1
PMMA	0.2-0.3	0.12
$ZnPO_4$	1.2	0.3

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Thermal expansion

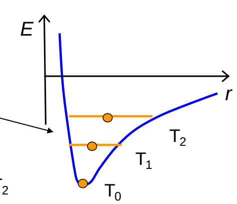
Linear expansion:

$$\frac{\Delta l}{l_0} = \alpha \, \Delta T$$

$$l = l_0 (1 + \alpha) \Delta T$$

α — **coefficient of thermal expansion** (1/K)

Increasing temperature results increasing oscillation of particles.
This may be observed as increasing size.



$T_0 < T_1 < T_2$

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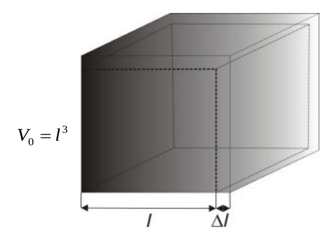
Volumetric thermal expansion

$$\frac{\Delta V}{V_0} = \beta \, \Delta T$$

$$V = V_0 (1 + \beta) \Delta T$$



β — **volumetric thermal expansion coefficient** (1/K)

for isotropic materials:

$$\beta \approx 3\alpha$$

Isotropic: properties are independent from the direction

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The coefficient of thermal expansion of some dental materials :

Material	$\alpha\ (10^{-6}\ 1/K)$
Enamel	11.4
dentin	8.3
Gold	14,2
Gold alloys	11-16
Amalgam	≈ 25
Porcelain	4-16
Acrylate	90
Glass	8
PMMA	90-160
Silicon	100-200
gypsum	15-20
wax	300-500

different expansion → stress!

Conservative dentistry!

Optical properties

What is the light?

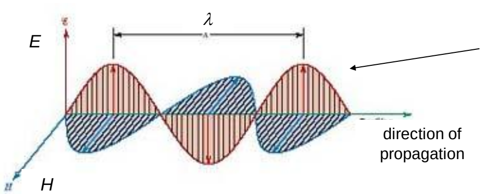
- electromagnetic wave
- propagation of the energy (radiation)
- propagates in straightline
- Interact to the material

Egyptian mythology.
The Sun as the source of the light.

Sources: Sun - thermal radiation
luminescence (cold light)

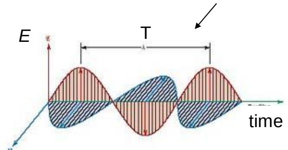
What is the electromagnetic wave?

wave: propagating oscillation.



at a given moment

in a given point



E – strenght of the electric field
H – strength of the magnetic field
λ - wavelength
T - period

Features, characteristic quantities

speed of the wave

$$c = f \cdot \lambda$$

f – frequency = 1/T (T – period)

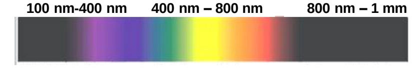
$$c = \frac{c_0}{n}$$

speed in vacuum ~ $3 \cdot 10^8$ m/s

refractive index of the material (absolute)

spectrum: distribution of the energy versus the frequency (or wavelength)

100 nm-400 nm **400 nm – 800 nm** **800 nm – 1 mm** = wavelength



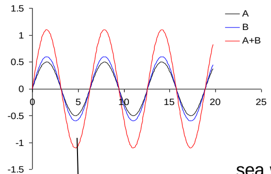
range **ultraviolet (UV)** **visible (VIS)** **infrared (IR)**

• Wave phenomena

superposition of 2 or more waves: the amplitudes are summed.

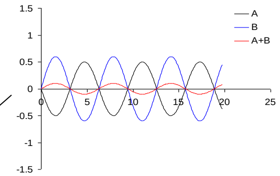
positive (constructive) interference

(same phase: see below)

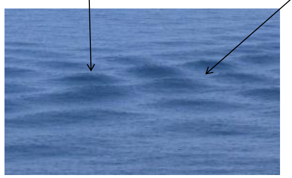


negative (destructive) interference

(opposite phase: see below)



sea waves



Interference pattern
Stable constructive and destructive interference points

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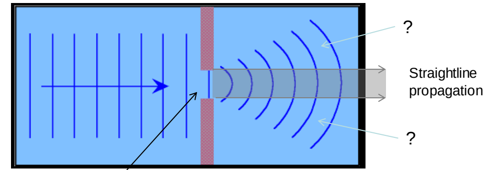
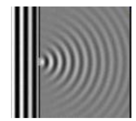
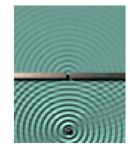
Diffraction

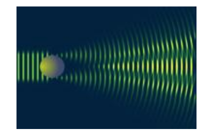


slit (size is close to the wavelength)

may be any barrier







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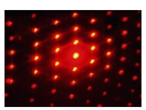
Diffraction and interference

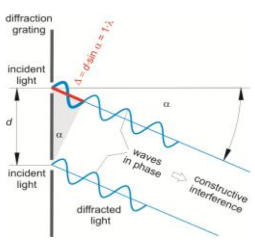
monochromatic light
(practically only 1 wavelength)



Spots are the points produced by constructive interference.

white light
(whole spectrum)

Depends on the wavelength!



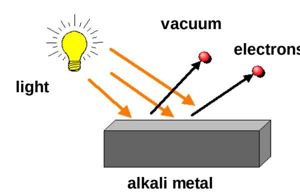
$$d \cdot \sin\alpha = k \cdot \lambda$$

(k =0, 1, 2 …)

The direction of the constructive interference depends ont the wavelength!

Photon

Photoelectric effect



$$\varepsilon = A + E_e$$

A – work function
E_e – kinetic energy of electrons

Planck constant

$$\varepsilon = h \cdot f$$

photonenergy

frequency

Threshold frequency exists.
Below this frequency there are no free electrons.

Energy is quantized and the quantum is the photon.

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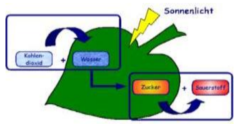
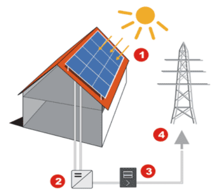
Energy transport

Photosynthesis is the base of the life.



Chloroplast absorbs the light energy and stores in molecules as chemical energy.

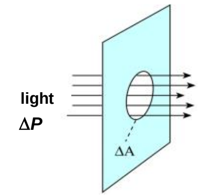


Solar cell converts the light energy into electric one.

Crude oil contains the stored energy of the Sun.

The absorbed energy in the skin results reddening.

Intensity (J)



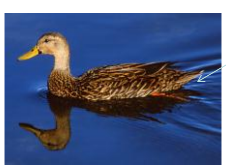
Energy propagates in the radiation.

Intensity characterizes the strength of the radiation.

$$J = \frac{\Delta P}{\Delta A} \quad \left(\frac{\mathrm{W}}{\mathrm{m}^2}\right)$$

ΔA –the area.
ΔP – power of the radiation propagating through the whole.

Power: energy per unit time

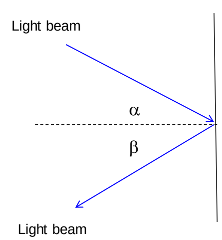


Geometrical optics

- **light propagates in straightline.**

reflection

$$\alpha = \beta$$

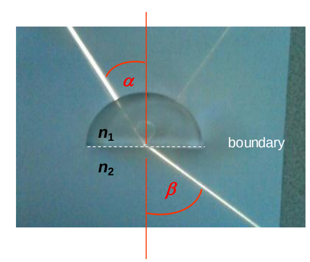


Refraction

Snell's law:

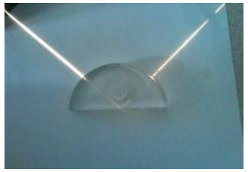
$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

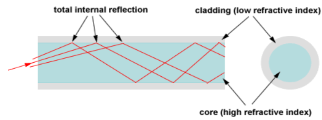
(relative) refractive index



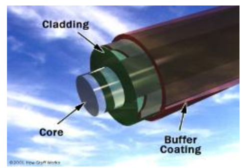
limiting angle

Application of the total internal reflection





optical fiber



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Application of the total internal reflection

mirage:

dentistry

endoscopy

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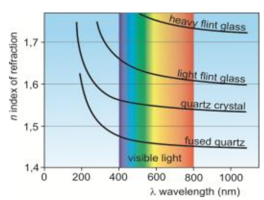
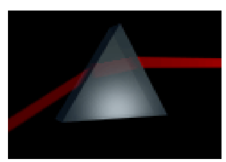
Dispersion of the light
(n depends on the wavelength)

$n(\lambda)$

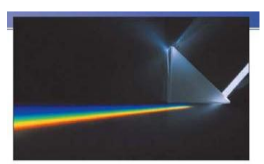


monochromatic light



rainbow

white light



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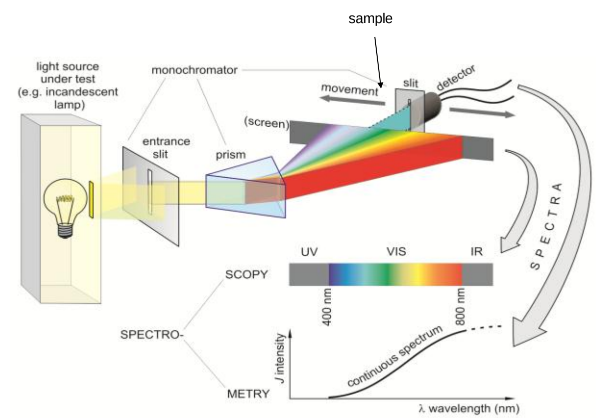
Spectroscopy and spectrometry



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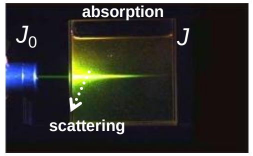
Interaction to the matter

Consequence

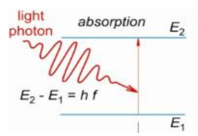
$J < J_0$



Attenuation: decreasing intensity

attenuation = scattering + absorption

Inhomogenity of the refractive index in the material!



Light scattering

elastic scattering
(λ, f, ε are constant)

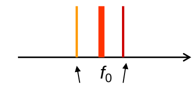
inelastic scattering
(λ, f, ε are not constant)

Rayleigh-scattering
particle size << λ

$$\text{scattered intensity} \sim \frac{1}{\lambda^4}$$

blue sky: blue is scattered better.
(wavelength is shorter)

Raman-scattering



new lines

Mie-scattering
size of the scattering particle ≥ λ
(no strong λ dependency)
(white clouds)

Attenuation law

if the scattering is negligible

attenuation ~ absorption

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

attenuation coefficient

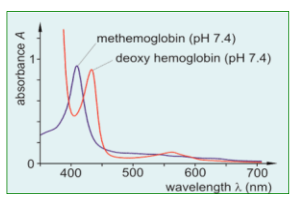
transmission

$$T = \frac{J}{J_0} (\cdot 100\,\%)$$

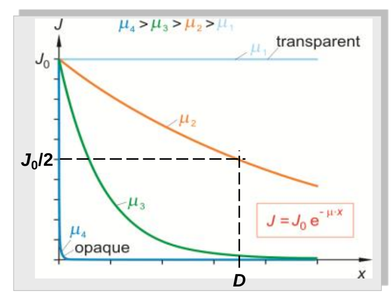
absorbance

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

***absorption spektrum**: A(λ)*



Attenuation law



layer thickness

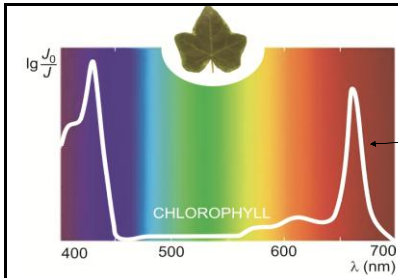
penetration depth (δ):

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

half-value thickness (D):

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

Absorption spectra



Green color of the plants is due to the absorption in red.

The colour of a material depends on the absorption.

Color vision

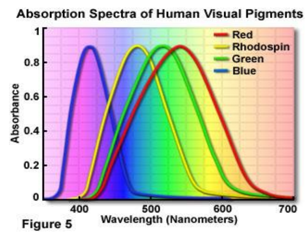
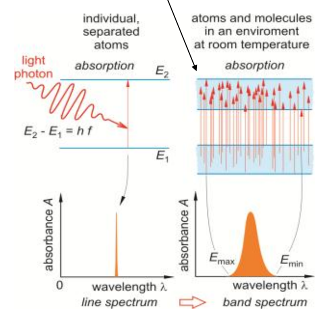


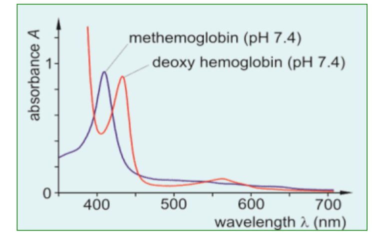
Figure 5

Line and band spectra

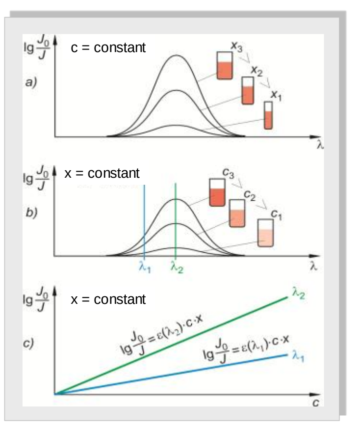
The energy state of the electrons depends on the envireoment a little bit.



Materials in solvent usually have band spectrum.



Application of the attenuation



Lambert-Beer law:

$$A = \varepsilon(\lambda)\cdot c\cdot x$$

Possibility to measure the concentration.