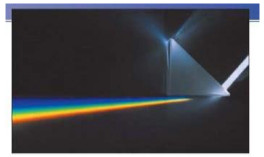


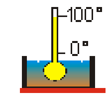
Physical basis of dental material science 10.

Thermal and optical properties

1

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

$$c_p > c_V$$

2

Specific heat capacity

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

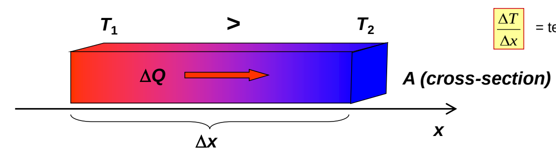
specific heat capacity of some dental materials:

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

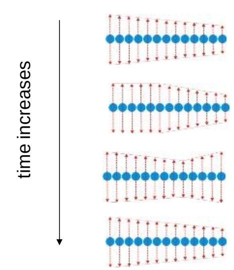
3

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.

4

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

5

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

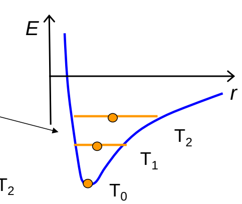
Linear expansion:

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

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

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

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



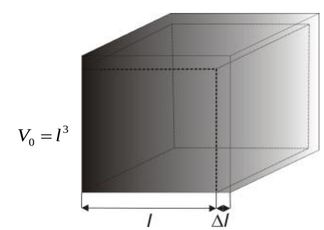
$T_0 < T_1 < T_2$

7

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

8

Effect of thermal expansion

Larger expansion

(compressiom)

Smaller expansion

(tension)

Cave is formed

9

The coefficient of thermal expansion of some dental materials :

Material	α (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!

Implants, braces.

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Optical properties

Color of the teeth

Color of the amalgam

Optical phanomena

Absorption
Emission
Reflection
Scattering

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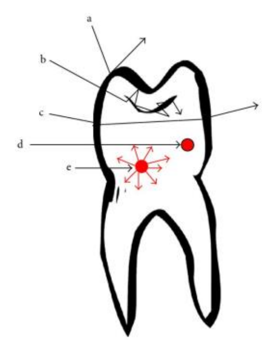
Light and the tooth



a - reflection
b - scattering
c - transmission and refraction
d - absorption
e - absorption and fluroscence

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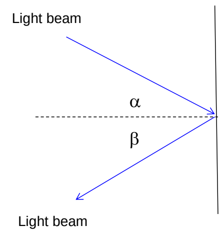
Geometrical optics

- light propagates in straightline.

reflection

$\alpha = \beta$



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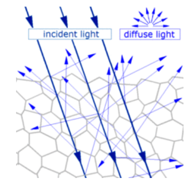
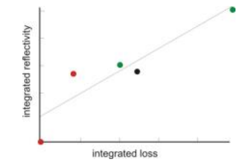
Reflection

Determination
of mineral loss

Diffuse reflection





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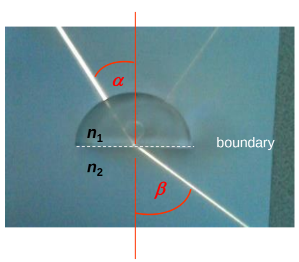
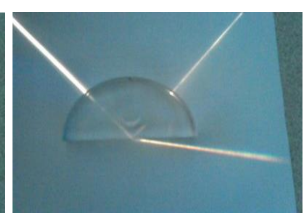
Refraction

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

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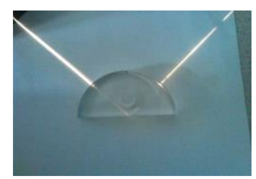
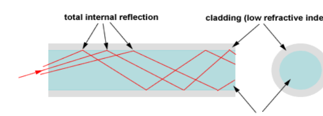
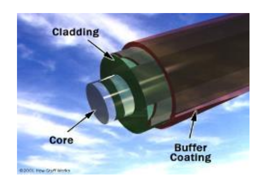
Application of the total internal reflection





optical fiber



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Application of the total internal reflection

mirage:

dentistry

endoscopy

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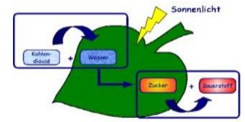
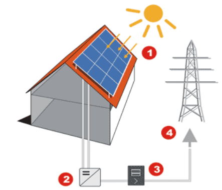
Energy transport

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.

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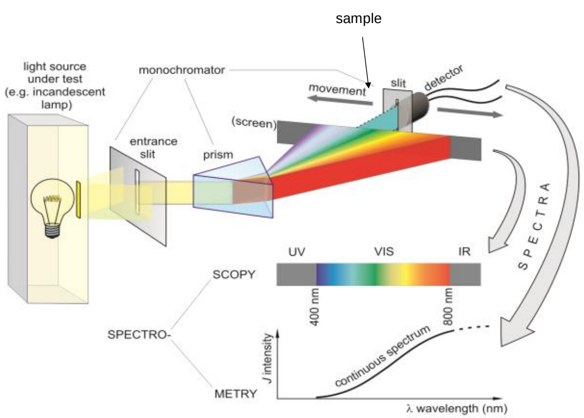
Spectroscopy and spectrometry



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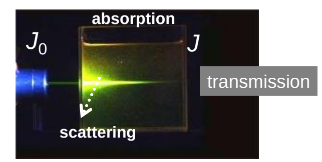
Interaction to the matter

<u>*Consequence*</u>

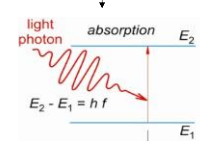
$J < J_0$



Attenuation: decreasing intensity

attenuation = scattering + absorption

Inhomogenity of the refractive index in the material!



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Light scattering

elastic scattering
(λ, f, ε are constant)

Rayleigh-scattering
particle size << λ

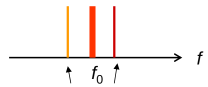
$$\text{scattered intensity} \sim \frac{1}{\lambda^4}$$

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

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

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

Raman-scattering



new lines

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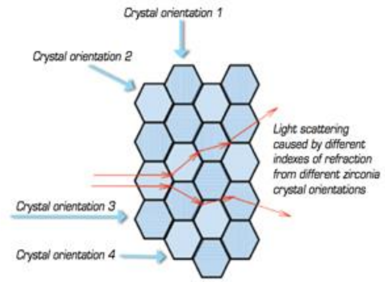
Light scattering



Scattering on crystals.

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Attenuation law

if the scattering is negligible

↓

attenuation ~ absorption

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

attenuation coefficient

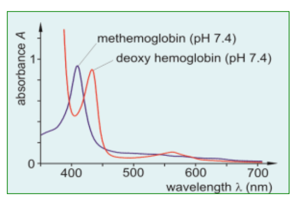
transmission

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

absorbance

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

***absorption spektrum*: $A(\lambda)$**



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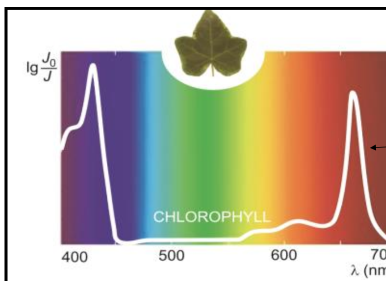
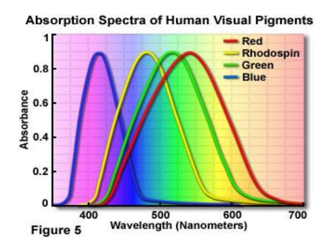
Absorption spectra



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

The colour of a material depends on the absorption.

Color vision



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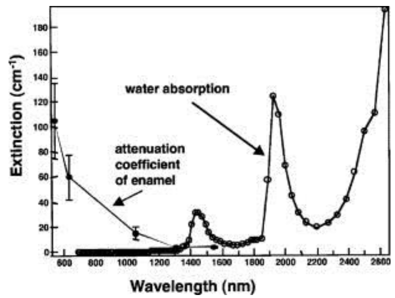
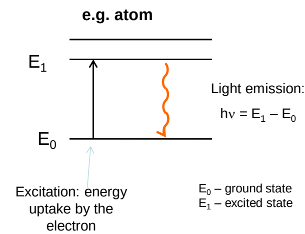
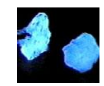
Absorption of the natural materials

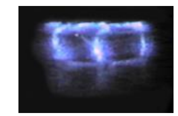


Luminescence

Light emission over the thermal radiation.
Light emission after excitation.







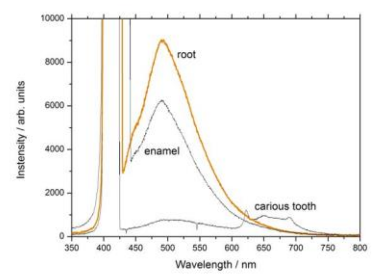
Application of luminescence

excitation	name: -luminescence	example
light	photo-	quinine-sulphate, phosphor, …
X-ray	X-ray	NaI(Tl)
radioactive radiation	radio-	NaI(Tl)
electric field	electro-	mercury-lamps
mechanical effect	tribo-	sugarcube
chemical raction	chemo- (bio-)	firebug
heat	thermo-	$CaSO_4$(Dy)

+ materials analysis, structure of biological macromolecules, fluorescence microscopy, sensors, monitors, radiation detectors, ...

Luminescence spectrum

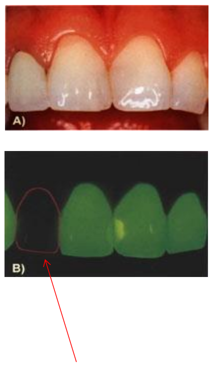
Blue light excitation (405 nm)

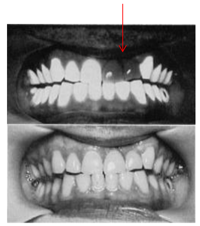


less intensity

higher intensity

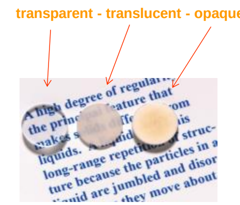
Dental application





Intensity: depends on the thickness of the palque.

Transparency



transparent: light passes through the material without being scattered.

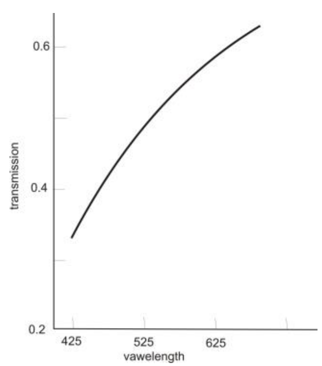
translucent: diffuse transparency, the light is scattered.

opaque: not transparent, diffuse reflection

Examples:

transparent: plate glass, water ….
translucent: oil paper, ice, some plastics…

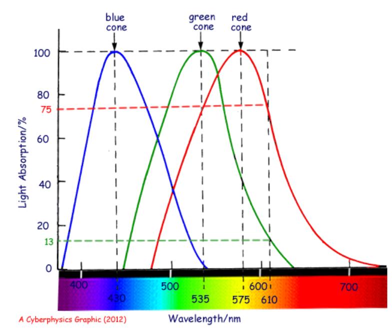
Transparency of the enamel



Transmission:

$T = J/J_0$

Why can we see colors?



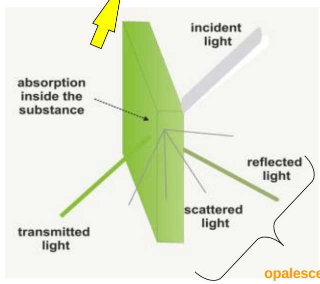
Color therory:

Every color may be produced mixing appropriate 3 colors.

Colors

color 3

fluorescence after absorption



Depends on the spectrum of the incident light!

opalescence

color 2

color 1

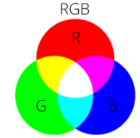
Color theory

- color
  - chromatic color
    - primary color
      - additive — 1, 3, 5
      - substractive — 2, 4, 6
    - mixed color
  - achromatic color — white, gray, black

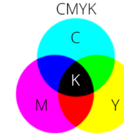
additive

substractive

RGB



CMYK

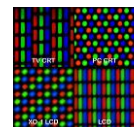


- 1 – red
- 2 – yellow
- 3 – green
- 4 – cyan
- 5 – blue
- 6 – magenta

primary color: sets of colors that can be combined to make a color.

additive color model: involves light emitted directly from a source.

substractive color model : mixing of paints, dyes, inks, and natural colorants.



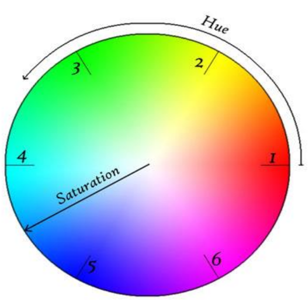
Color properties

„**color space**": **3 coordinates to describe the color**

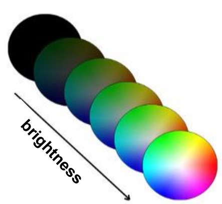
Hue: refers to a *pure* color.
An element in the color wheel (down).

Saturation: perceived intensity of a specific color.

Brightness: the perception elicited by the luminescence of a visual target.



regular units:
hue: °
saturation: %



Color of teeth

sickness or antibiotics during the development.

necroses

filling