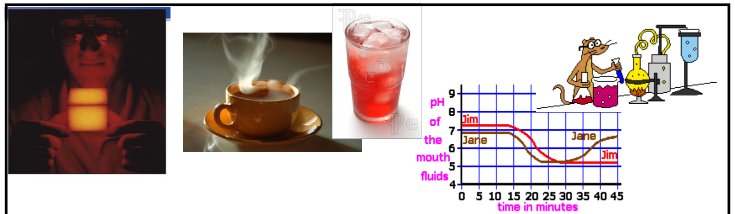


Physical bases of dental materials
10.

Thermal and electric properties

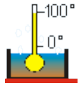
e-book chapter.: 19

1

1

Thermal properties

- temperature
- heat uptake/release



heat capacity (*C*): $C = \frac{\Delta Q}{\Delta T}$

molar heat capacity (c_v): $c_v = \frac{C}{\nu}$

specific heat capacity (*c*): $c = \frac{C}{m}$

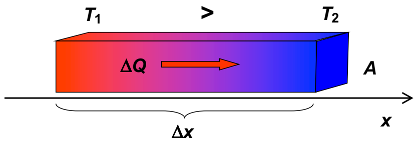
specific heat of dental materials:

material	c (J/(kg·K))
enamel	750
dentine	1260
water	4190
amalgam	210
gold	126
porcelain	1100
glass	800
PMMA	1460
zinc-phosphate	500

2

2

- **heat conduction**
  - lattice vibrations
  - free electrons



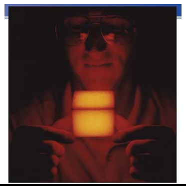
$$\frac{\Delta Q}{\Delta t} = -\lambda A \frac{\Delta T}{\Delta x}$$ **Fourier's law**

λ — **thermal conductivity**
J/(s·m²·K/m) = W/(m·K)

used in case of stationary conditions

thermal conductivity of dental materials

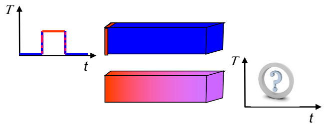
material	λ (W/(mK))
enamel	0,9
dentine	0,6
water	0,44
amalgam	23
gold	300
porcelain	1
water	0,6-1,4
acrylate	0,2
PMMA	0,2-0,3
zinc-phosphate	1,2



3

3

non-stationary conditions:



$$D = \frac{\lambda}{c \cdot \rho}$$

D — **thermal diffusivity** (m²/s)

thermal diffusivity of dental materials

material	λ (W/(mK))	D (10^{-6} m²/s)
enamel	0,9	0,5
dentine	0,6	0,2
water	0,44	0,14
amalgam	23	9,6
gold	300	118
porcelain	1	0,4
water	0,6-1,4	0,3-0,7
acrylate	0,2	0,1
PMMA	0,2-0,3	0,12
zinc-phosphate	1,2	0,3

4

4

• thermal expansion

Linear thermal expansion:

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

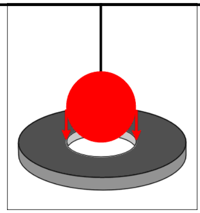
α — **coefficient of thermal expansion** (1/K)

Volumetric thermal expansion

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

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

$$\beta = 3\alpha$$



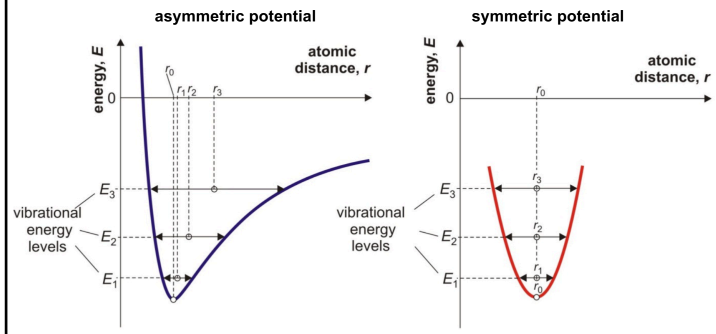
thermal expansion coefficient of dental materials:

anyag	α (10^{-6} 1/K)
enamel	11,4
dentine	8,3
gold	14,2
gold alloys	11-16
amalgam	≈ 25
porcelain	4-16
acrylate	90
glass	8
PMMA	90-160
silicone	100-200
gypsum	15-20
wax	300-500

5

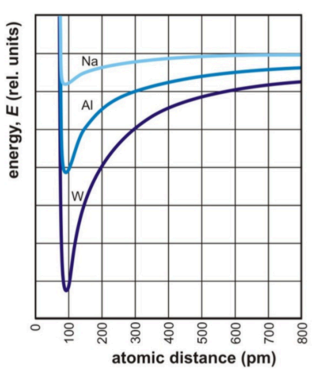
5

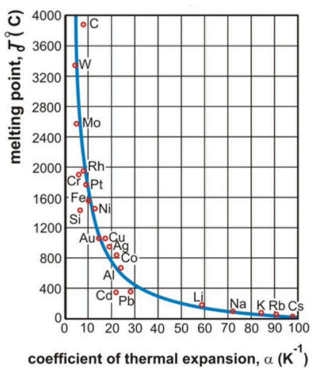
thermal expansion



6

6



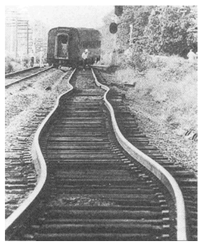


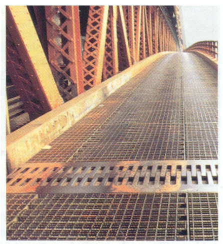
7

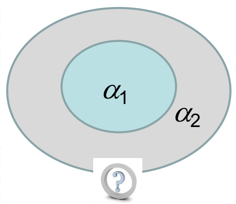
7

Consequences of heat expansion:

various heat expansions ⇨ stress (σ) !



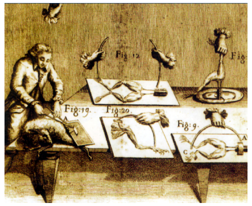




8

8

Electricity



9

9

Electric charge

Charge: intrinsic property (like mass).
Macroscopic bodies are usually neutral.

electron (ηλεκτρον) = amber

Electron negative, proton positive charge.

Electric charge is quantizes, its smallest unit is the ***elementary charge (e)***, that is the charge of a proton.
Unit: 1 C (Coulomb) = 1 A·s

$$e = |e^-| = 1{,}6 \cdot 10^{-19}\,\mathrm{C}$$

Faraday-constant (total charge of 1 mol protons):

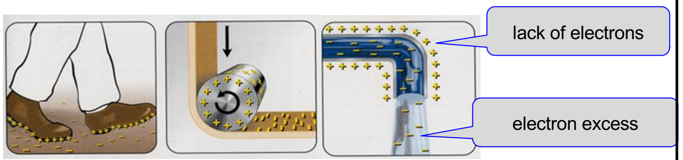
$F = 1{,}6 \cdot 10^{-19}$ C · $6 \cdot 10^{23}$ 1/mol= 96 500 C/mol

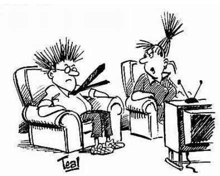
10

10

Charge separation

Charges can be separated by rubbing (static electricity)





"I told you nylon carpets were a mistake."

charge separation followed by discharge!

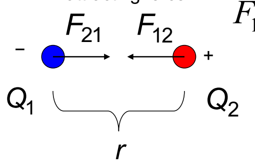
11

11

Electric interaction

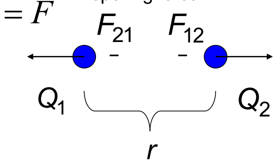
Bodies with electric charge interact with each other:
- unlike charges attract
- like charges repel

attracting force



$$F_{12} = F_{21} = F$$

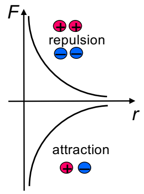
repelling force



Coulomb-force:

$$F = k\frac{Q_1 Q_2}{r^2}$$

k = $9 \cdot 10^9$ Nm²/C²



12

12

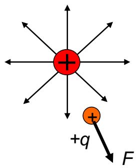
Electric field, filed lines

If the interaction is present without close contact, a field is present that transmits the force between the bodies.

The field is described by the field strength and represented by the field lines.

electric field strength, *E*:

$$E = \frac{F}{q} \qquad \left[\frac{N}{C}\right]$$



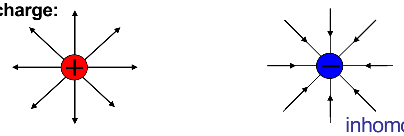
field lines:

- Direction shows the direction of field
- density shows the field strength

13

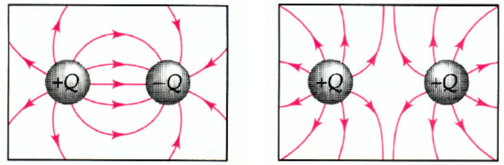
13

Field of a point charge:



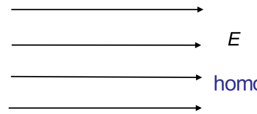
inhomogeneous field

field of a dipole and two like charges



inhomogeneous field

field between the plates of a planar capacitor



homogeneous field

14

14

Voltage (= potential difference)

The work of $W_{1\to2}$ is required to move a q point charge between point 1 and point 2 of the field. The $W_{1\to2}$ / q ratio id independent on the magnitude of charge and the path of movement. Thus:

Electric voltage between point 1 and point 2 is:

$$U_{21} = \frac{W_{1\to2}}{q}$$ Unit: Volt [V] $$1\,\mathrm{V} = \frac{1\,\mathrm{J}}{1\,\mathrm{C}}$$

15

15

Electric potential

$W_{0\to i}$ represents the work that is required to move a charge of q from a standard 0 point to point *i.*

$\frac{W_{0\to i}}{q}$ independent of charge and path of movement!

Electric potential: $$\varphi_i = \frac{W_{0\to i}}{q}$$ Unit: Volt (V)

Electric potential gives the potential energy of the 1 C charge at point *i,* after it has been moved there from the standard 0 point.

Often the standard point is at infinity, thus:

$$\varphi_i = \frac{W_{\infty\to i}}{q}$$

16

16

Electric current

Directed transport of charge carriers

charge carriers = freely moving , electrically charged particles

example in metals: **electrons**

example in electrolytes or gases: **ions**

Electric current (I):

$$I = \frac{\Delta Q}{\Delta t}$$

ΔQ: charge passing through the cross section of a conductor in Δt time

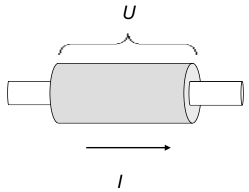
unit: ampere (A), 1A = 1C/1s

Technical current direction: direction of movement of positive charge carriers.

17

17

Ohm‘s law



Potential difference (U) and current (I) are directly proportional

$U \sim I$

$$U = RI$$

R: resistance

$GU = I$

G: conductance

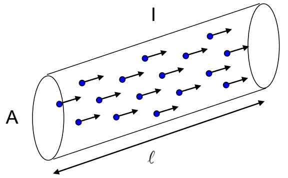
$R = \frac{U}{I}$ unit: ohm (Ω) $1\Omega = \frac{1\text{V}}{1\text{A}}$

$G = \frac{1}{R}$ unit: siemens (S), $1\text{S} = \frac{1}{1\Omega}$

18

18

Resistance of a conductor



$$\left.\begin{aligned} I &\sim \frac{A}{\ell}U \\ I &= \frac{U}{R} \end{aligned}\right\} R \sim \frac{\ell}{A} \Rightarrow R = \rho\frac{\ell}{A}$$

resistivity
SI-unit: Ωm

conductivity (σ): $\sigma = \frac{1}{\rho}$
SI-unit: S/m

19

19

- **resistivity**
  or specific resistance (ρ):

$$\rho = \frac{R \cdot A}{l} \quad (\Omega\text{m})$$

- **conductivity (σ):**

$$\sigma = \frac{1}{\rho} \quad ((\Omega\text{m})^{-1} = \text{S/m})$$

material	σ (S/m)	
silver	$6{,}8 \cdot 10^{7}$	conductors
gold	$4{,}3 \cdot 10^{7}$	
platinum	$0{,}94 \cdot 10^{7}$	
germanium	2,2	semi conductors
silicon	$4 \cdot 10^{-4}$	
cirkonia	$\approx 10^{-10}$	insulators
porcelain	$\approx 10^{-11}$	
glass	$\approx 10^{-13}$	
PMMA	$\approx 10^{-12}$	
PE	$\approx 10^{-16}$	

Depends on:

-- quantity of free charge carriers (electorns, ions)

-- mobility of charge carriers

20

20

Electric structure of solid bodies

Bands fill according to:

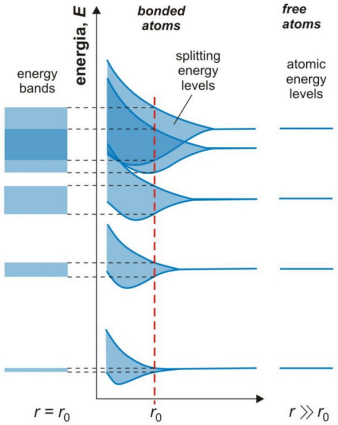
- energy minimum
- Pauli-principle
- number of electrons

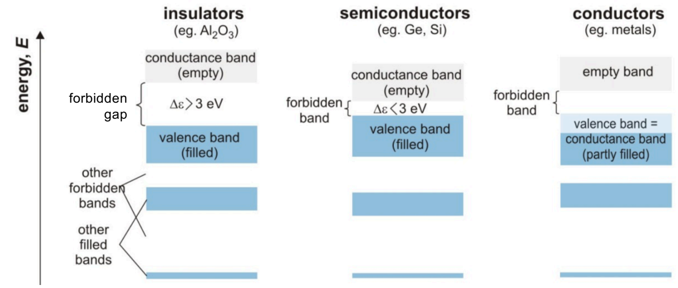
- **conduction band**

  Lowest empty or partially filled band

- **valence band:**

  outermost band that his filled with electrons.





width of forbidden band:

f.e. NaI (Δε = 5 eV)

Si (Δε = 1,1 eV)

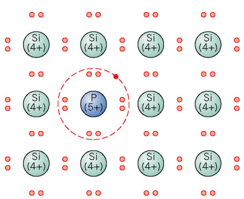
Ge (Δε = 0,7 eV)

Intrinsic semiconductors

Doped semiconductors

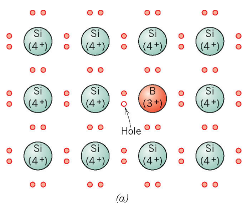
$_{14}$Si: $1s^2 2s^2 2p^6$ $\mathbf{3s^2 3p^2}$

$_{15}$P: $1s^2 2s^2 2p^6$ $\mathbf{3s^2 3p^3}$



$_{14}$Si: $1s^2 2s^2 2p^6$ $\mathbf{3s^2 3p^2}$

$_{5}$B: $1s^2$ $\mathbf{2s^2 2p^1}$



Szennyezett félvezető

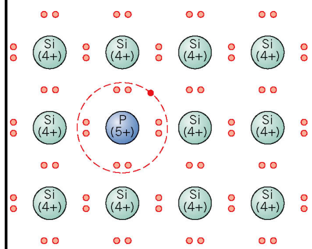
alapkristály pl. Si

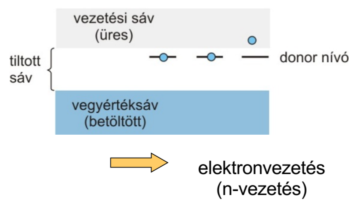
$_{14}$Si: $1s^2 2s^2 2p^6$ $\mathbf{3s^2 3p^2}$

n-félvezető

adalék pl. P

$_{15}$P: $1s^2 2s^2 2p^6$ $\mathbf{3s^2 3p^3}$





elektronvezetés
(n-vezetés)

Szennyezett félvezető

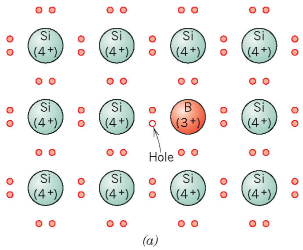
alapkristály pl. Si

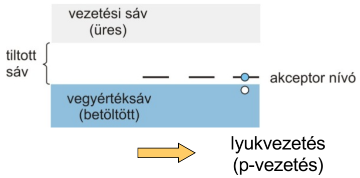
$_{14}Si$: $1s^2 2s^2 2p^6$ **$3s^2 3p^2$**

p-félvezető

adalék pl. B

$_{5}B$: $1s^2$ **$2s^2 2p^1$**





lyukvezetés
(p-vezetés)