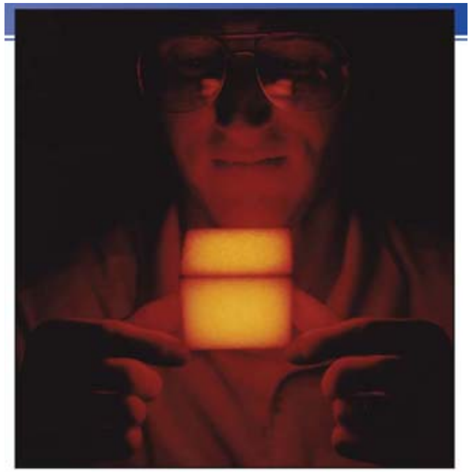
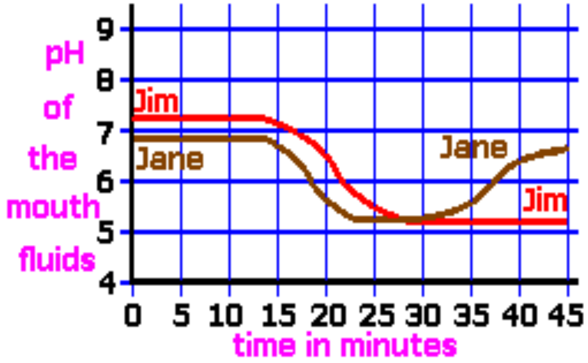


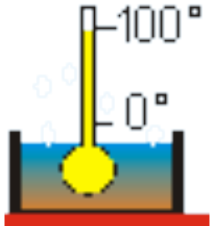
Physical foundations of dental materials 10.

Thermal and electric properties

e-book chapter.: 19

Thermal properties

- temperature



- heat uptake/release

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

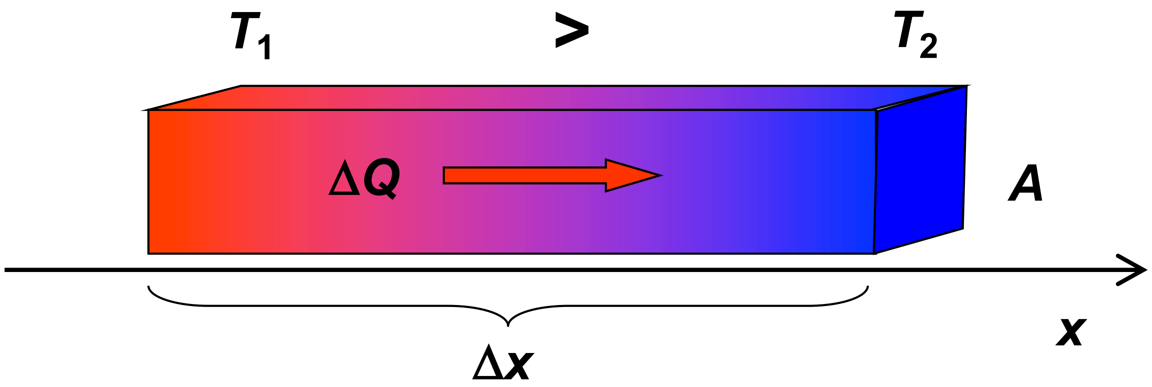
molar heat capacity (c_ν): $$c_\nu = \frac{C}{\nu}$$

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

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



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

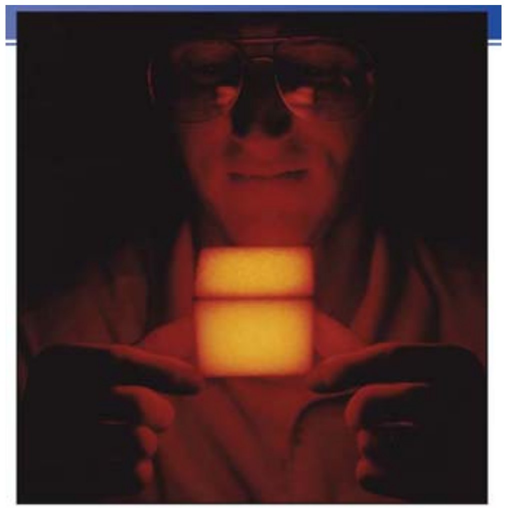
Fourier's law

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

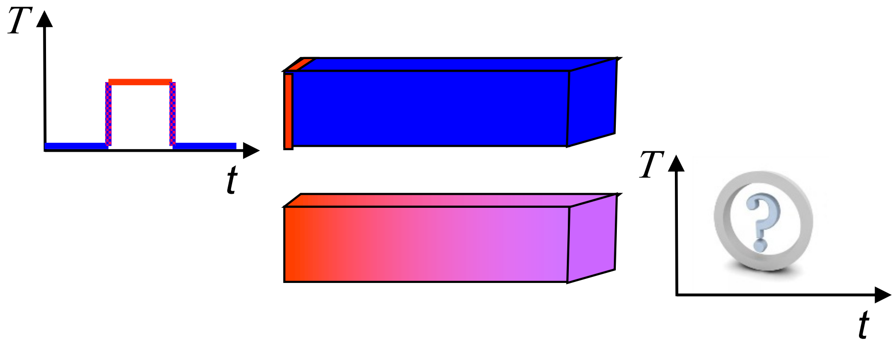
used in case of stationary conditions

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



non-stationary conditions:



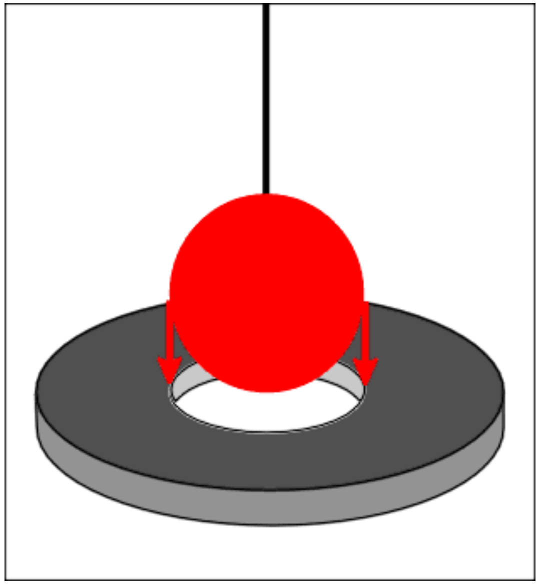
$$D = \frac{\lambda}{c \cdot \rho}$$

D — **thermal diffusivity**
(m²/s)

thermal diffusivity of dental materials

material	λ (W/(mK))	D (10^{-6} m^2/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

• thermal expansion



Linear thermal expansion:

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

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

Volumetric thermal expansion

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

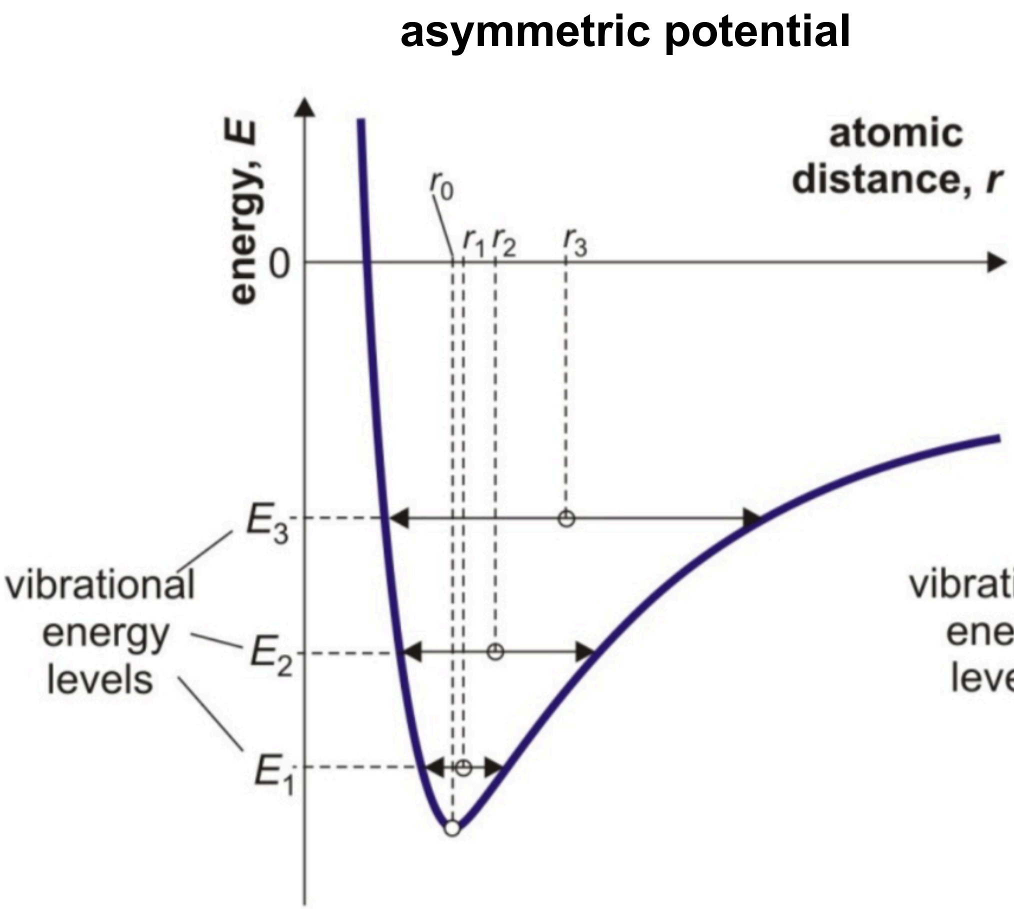
β — **volumetric thermal expansion coefficient** (1/K)

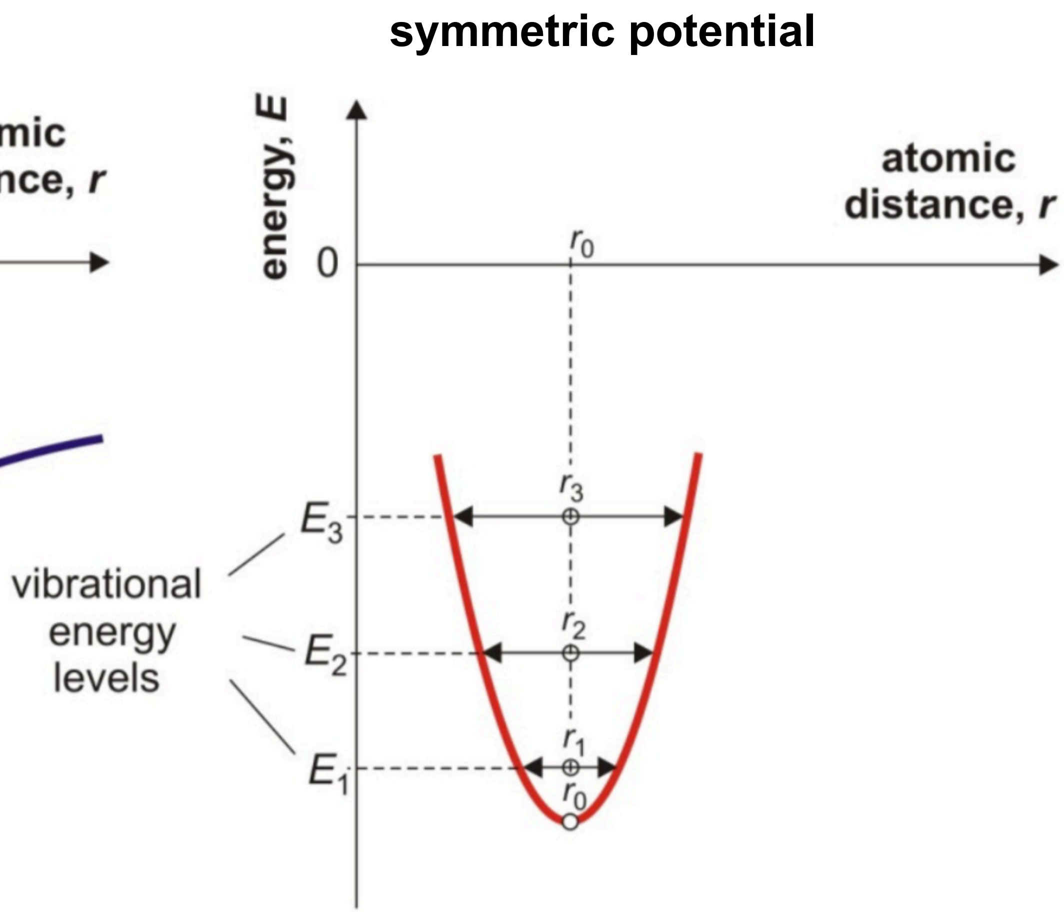
$$\beta = 3\alpha$$

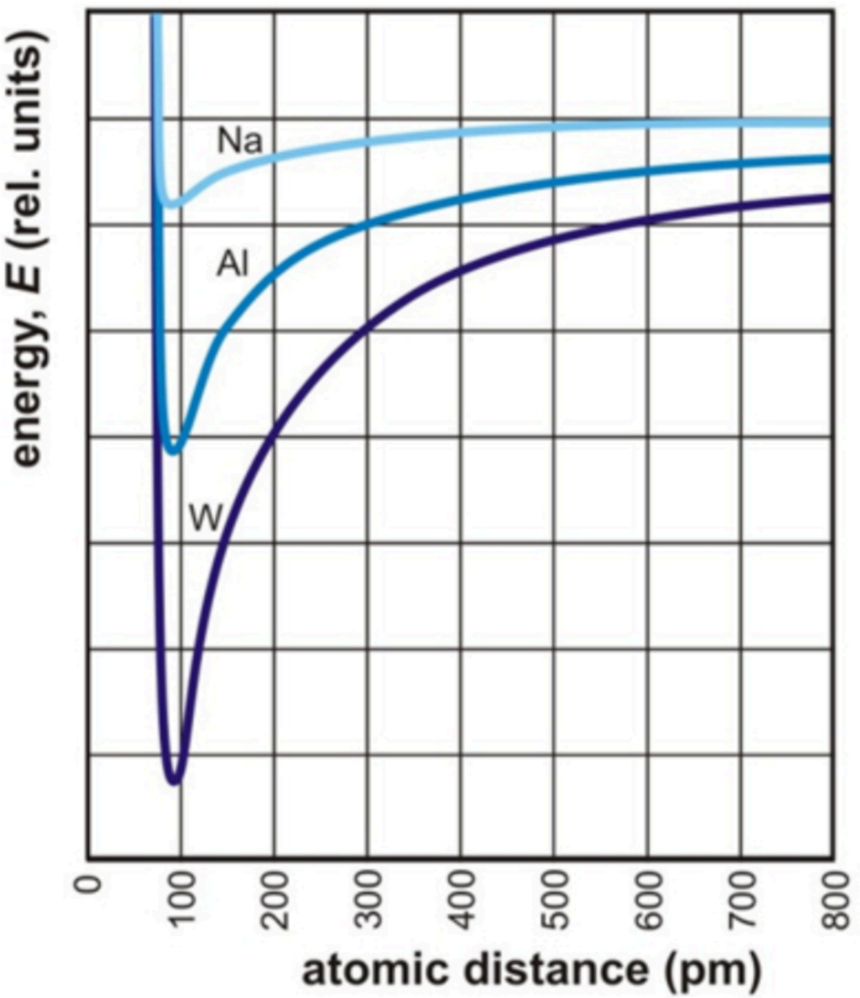
thermal expansion coefficient of dental materials:

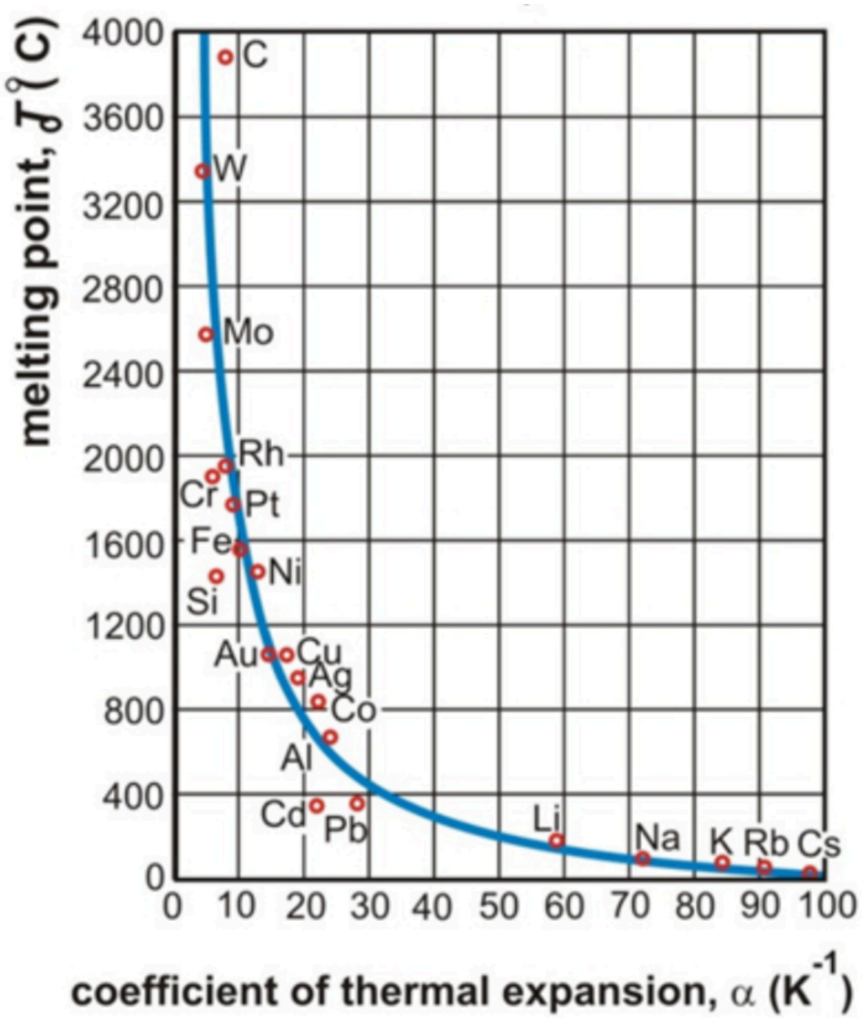
anyag	α (10^{-6} 1/K)
enamel	11,4
dentine	8,3
gold	14,2
gold alloys	11-16
amalgam	≈ 25
porcelain	4-16
acrylate	90
glass	8
PMMA	90-160
silicone	100-200
gypsum	15-20
wax	300-500

thermal expansion



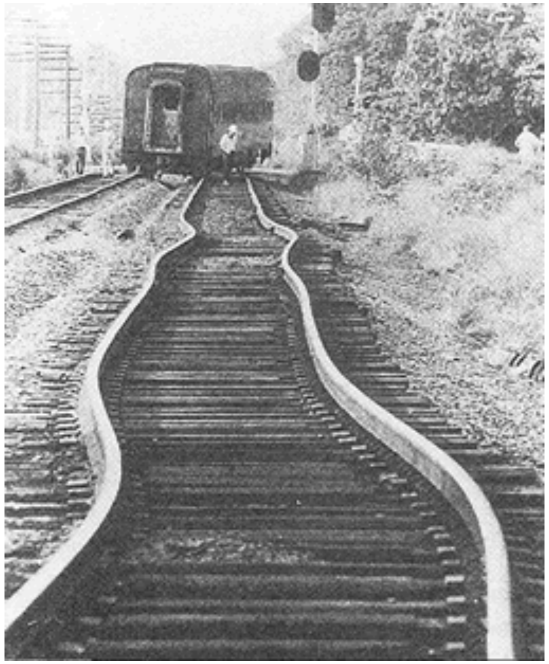


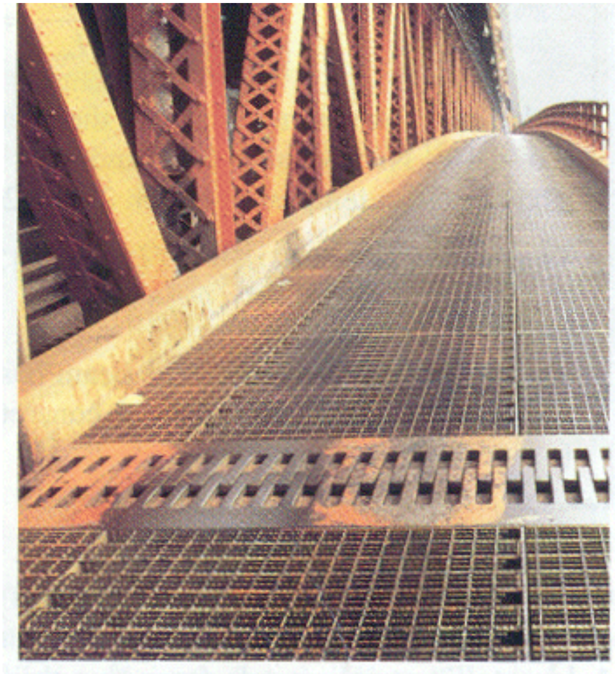

energy, E (rel. units)
Na
Al
W
0 100 200 300 400 500 600 700 800
atomic distance (pm)

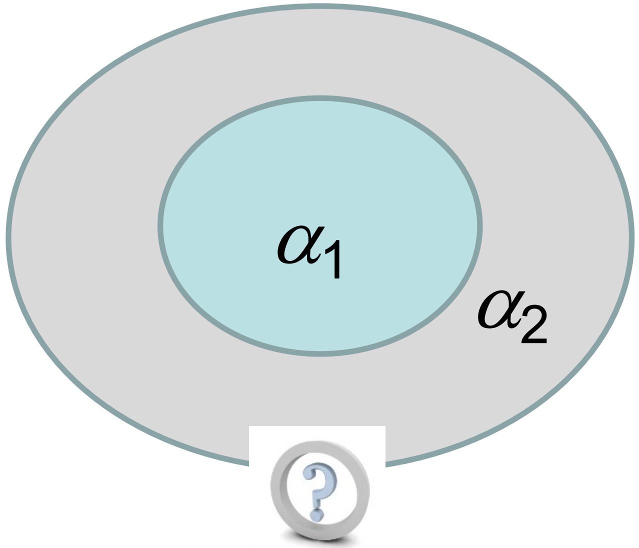

melting point, T (°C)
4000 3600 3200 2800 2400 2000 1600 1200 800 400 0
C
W
Mo
Rh
Cr
Pt
Fe
Ni
Si
Au
Cu
Ag
Co
Al
Cd
Pb
Li
Na
K
Rb
Cs
0 10 20 30 40 50 60 70 80 90 100
coefficient of thermal expansion, α (K⁻¹)

Consequences of heat expansion:

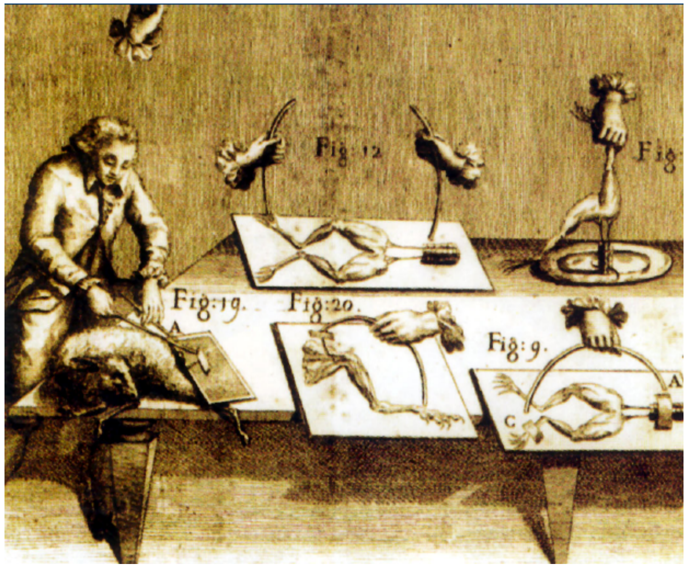
various heat expansions ⇨ stress (σ) !







Electricity



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

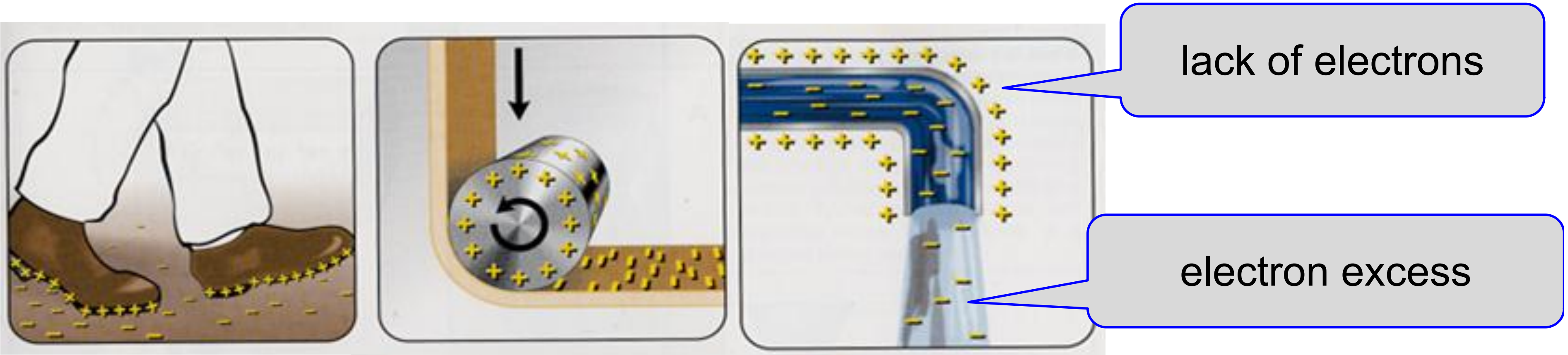
$$e = \left| e^{-} \right| = 1{,}6 \cdot 10^{-19}\,\mathrm{C}$$

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

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

Charge separation

Charges can be separated by rubbing (static electricity)



"I told you nylon carpets were a mistake."

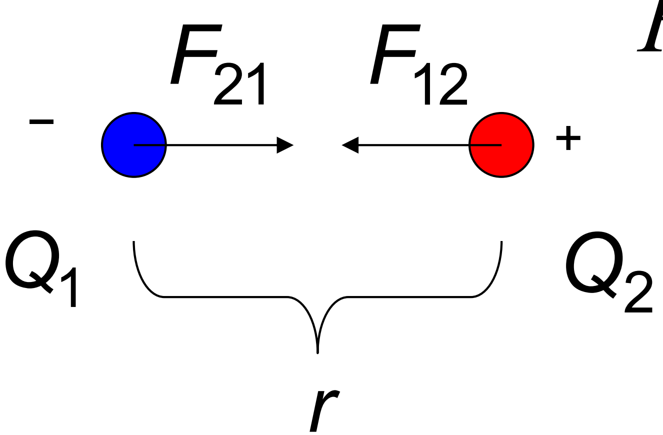
charge separation followed by discharge!

Electric interaction

Bodies with electric charge interact with each other:

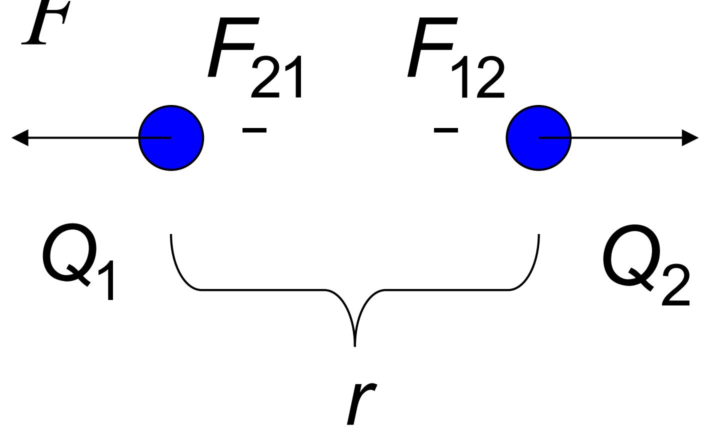
- unlike charges attract
- like charges repel

attracting force



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

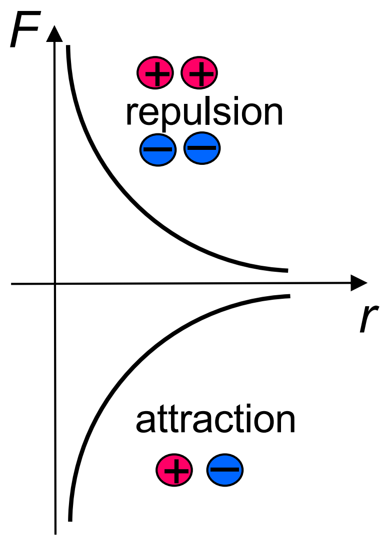
repelling force



Coulomb-force:

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

k = $9 \cdot 10^9$ Nm^2/C^2



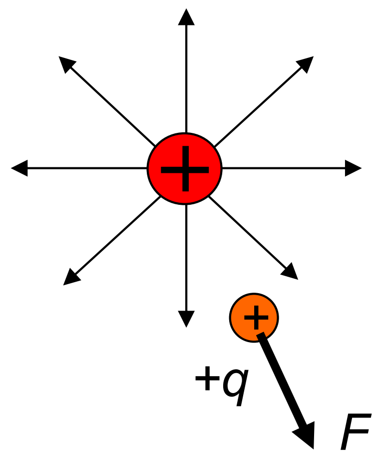
Electric field, filed lines

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*:

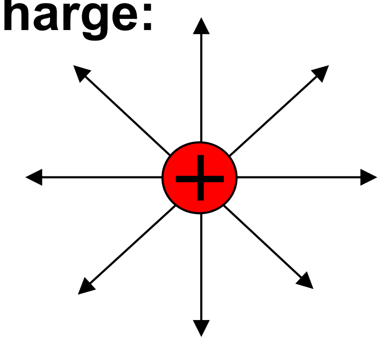
$$E = \frac{F}{q} \qquad \left[\frac{N}{C}\right]$$

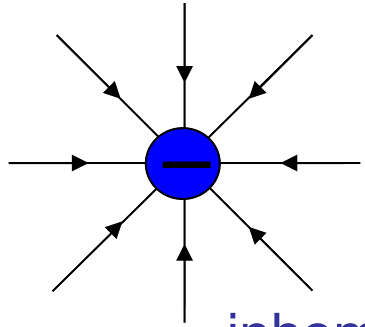


field lines:

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

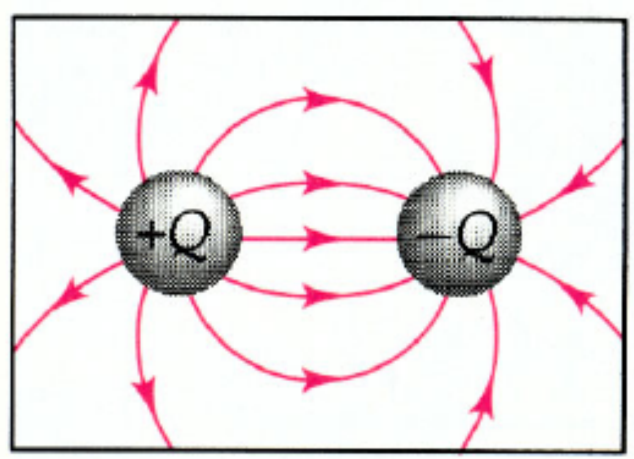
Field of a point charge:

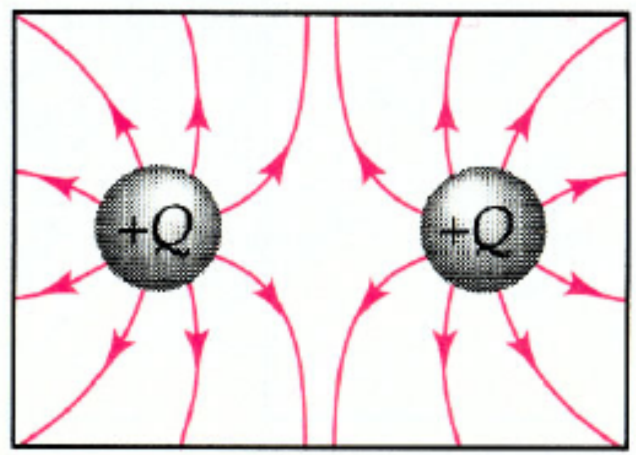




inhomogeneous field

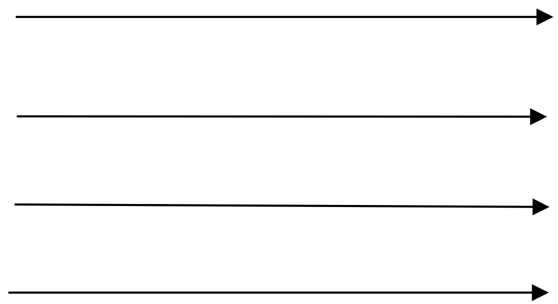
field of a dipole and two like charges





inhomogeneous field

field between the plates of a planar capacitor



E

homogeneous field

Voltage (= potential difference)

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

Electric voltage between point 1 and point 2 is:

$$U_{21} = \frac{W_{1\to 2}}{q}$$

Unit: Volt [V]

$$1\,\text{V} = \frac{1\,\text{J}}{1\,\text{C}}$$

Electric potential

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

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

Electric potential: $$\varphi_i = \frac{W_{0\rightarrow i}}{q}$$ 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:

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

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*):

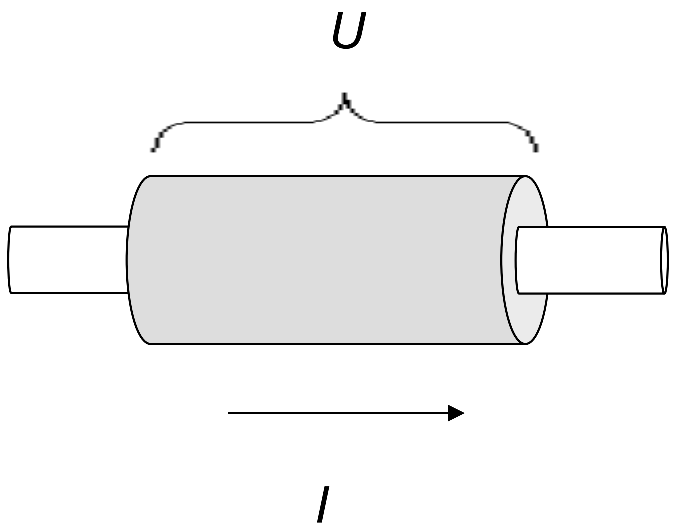
$$I = \frac{\Delta Q}{\Delta t}$$

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.

Ohm's law



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

$U \sim I$

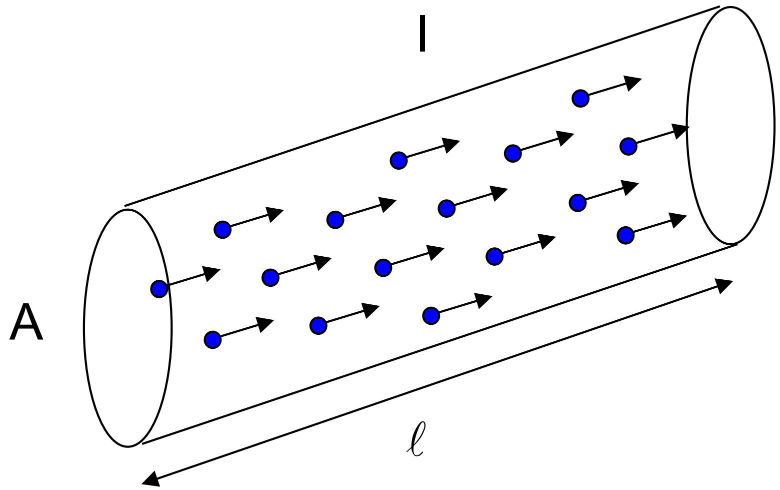
$U = RI$ — R: resistance

$GU = I$ — G: conductance

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

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

Resistance of a conductor



$$\left.\begin{array}{l} I \sim \dfrac{A}{\ell} U \\ I = \dfrac{U}{R} \end{array}\right\} R \sim \frac{\ell}{A} \Rightarrow \boxed{R = \rho \frac{\ell}{A}}$$

resistivity
SI-unit: Ωm

conductivity (σ):
SI-unit: S/m

$$\sigma = \frac{1}{\rho}$$

- **resistivity**

  or specific resistance (ρ):

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

- **conductivity (σ):**

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

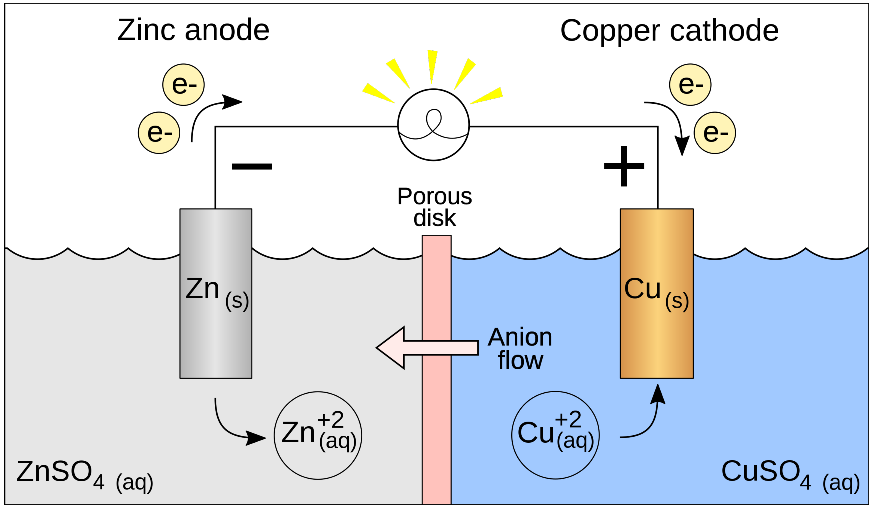
material	σ (S/m)	
silver	$6{,}8 \cdot 10^{7}$	conductors
gold	$4{,}3 \cdot 10^{7}$	conductors
platinum	$0{,}94 \cdot 10^{7}$	conductors
germanium	2,2	semi conductors
silicon	$4 \cdot 10^{-4}$	semi conductors
cirkonia	$\approx 10^{-10}$	insulators
porcelain	$\approx 10^{-11}$	insulators
glass	$\approx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

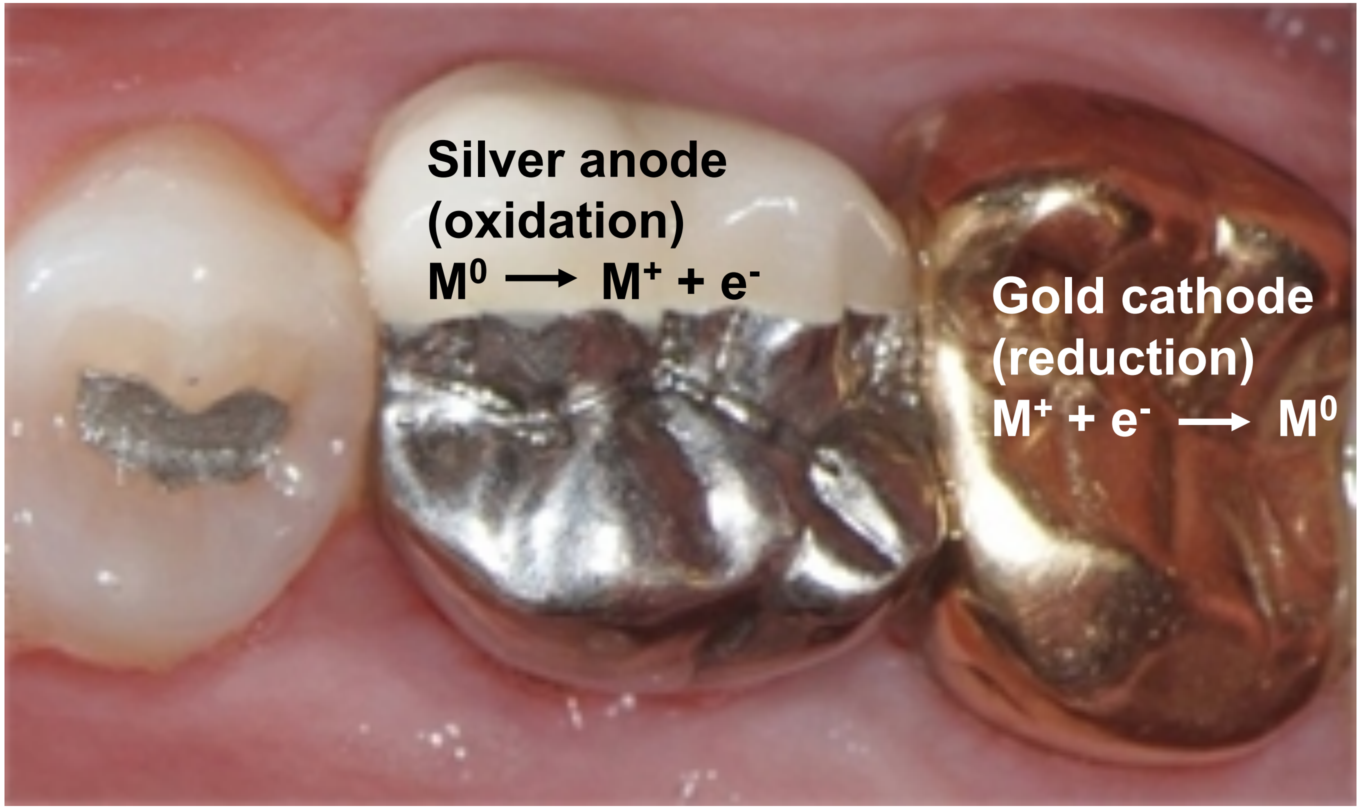
Depends on:

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

-- mobility of charge carriers

- **Galvanic cells**

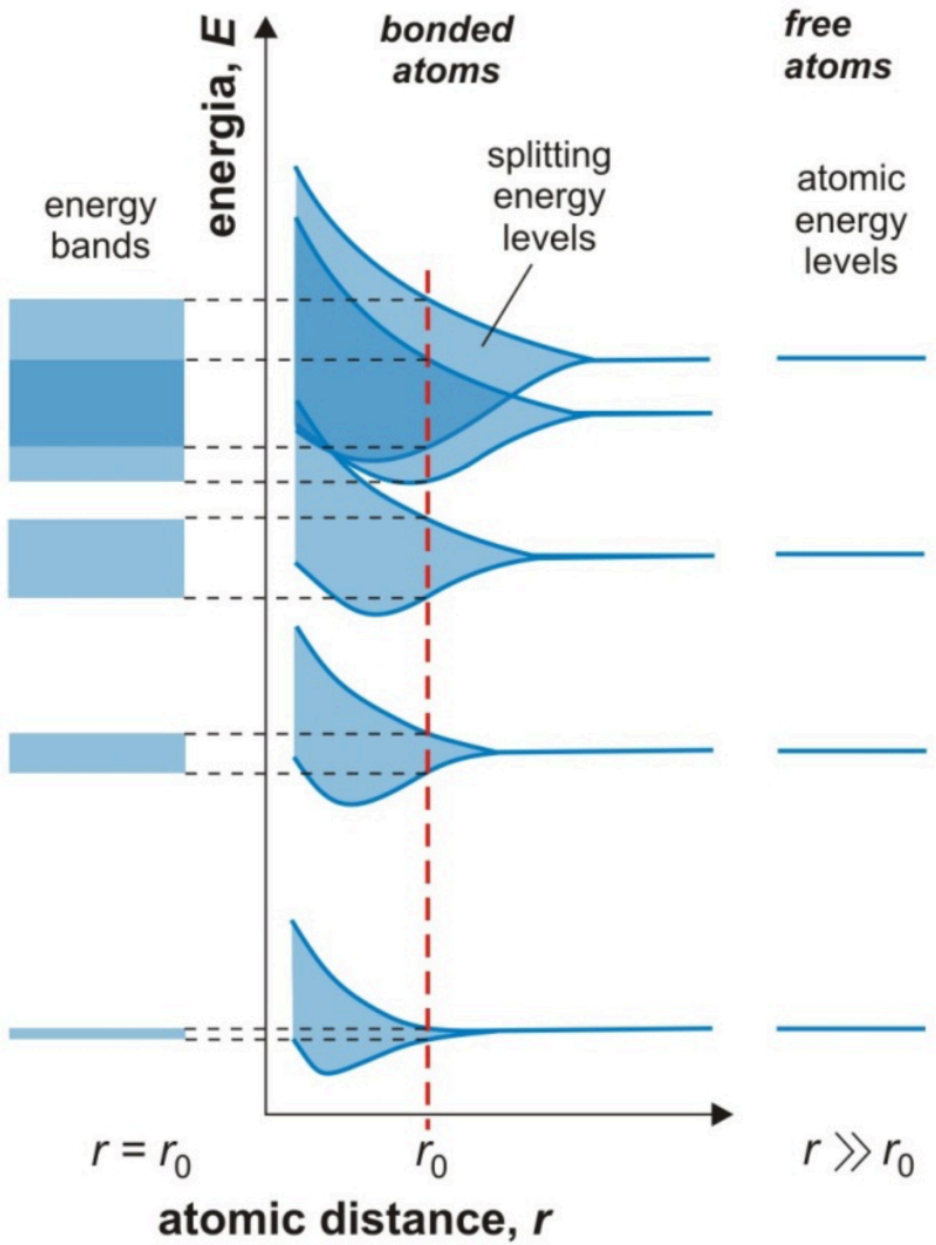




Electric structure of solid bodies

Bands fill according to:

- energy minimum
- Pauli-principle
- number of electrons

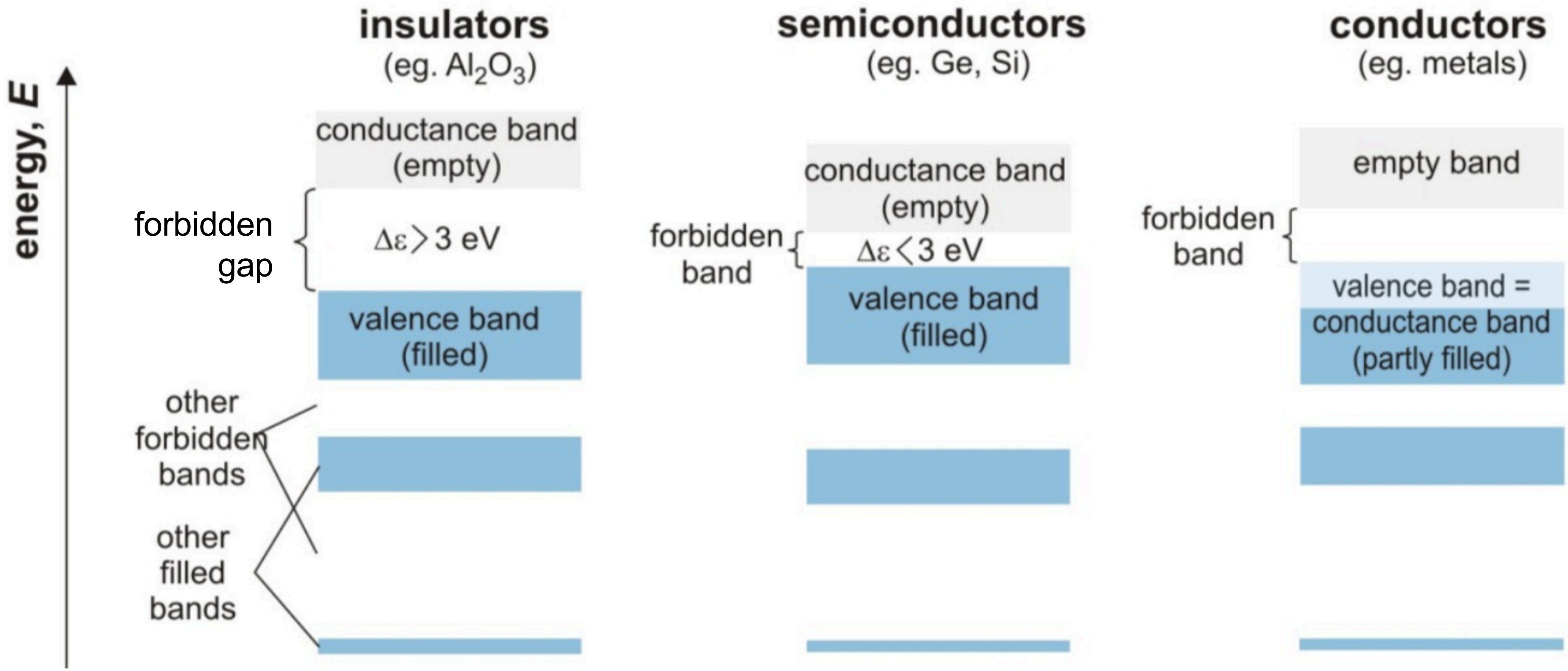


- **conduction band**

  Lowest empty or partially filled band

- **valence band:**

  outermost band that his filled with electrons.



width of forbidden band:

f.e. NaI ($\Delta\varepsilon$ = 5 eV)

Si ($\Delta\varepsilon$ = 1,1 eV)

Ge ($\Delta\varepsilon$ = 0,7 eV)

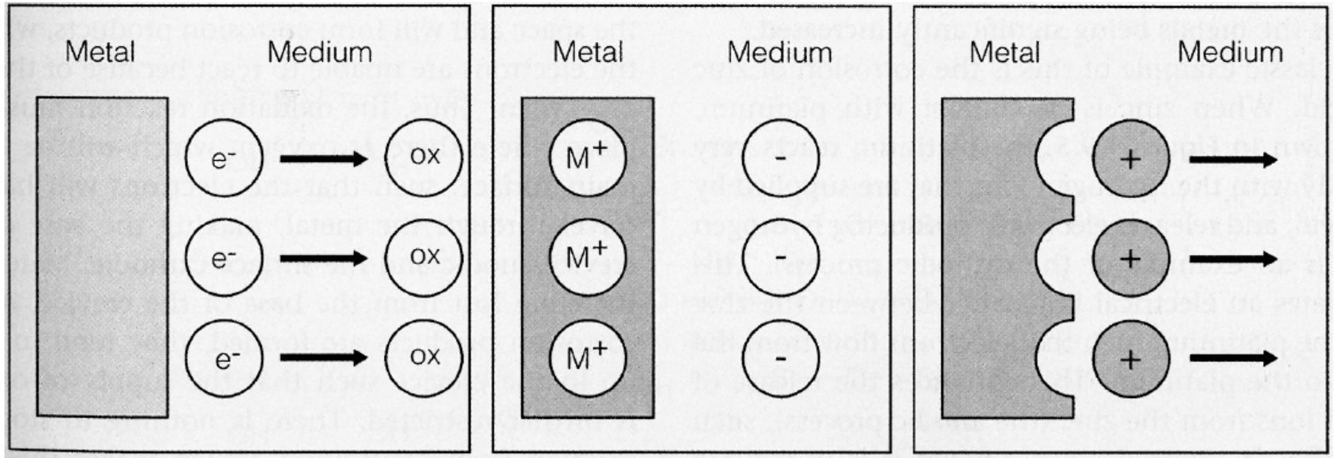
- **chorrosion**
- oxidation of metals $$M \rightarrow M^{n+} + n \cdot e^-$$

in acidic medium: $$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

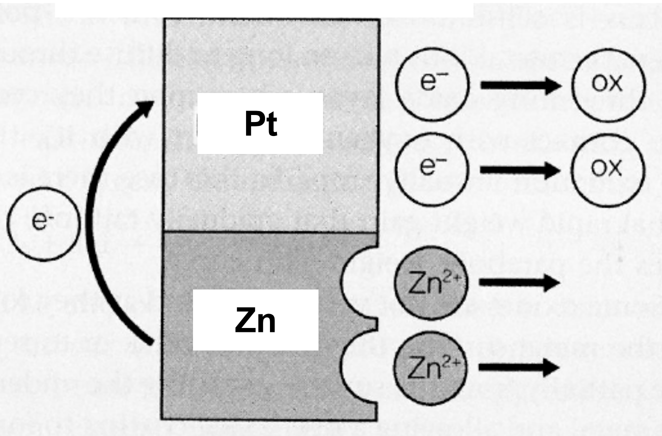
in neutral of basic medium: $$O_2 + 2H_2O + 4e^- \rightarrow 4(OH)^-$$

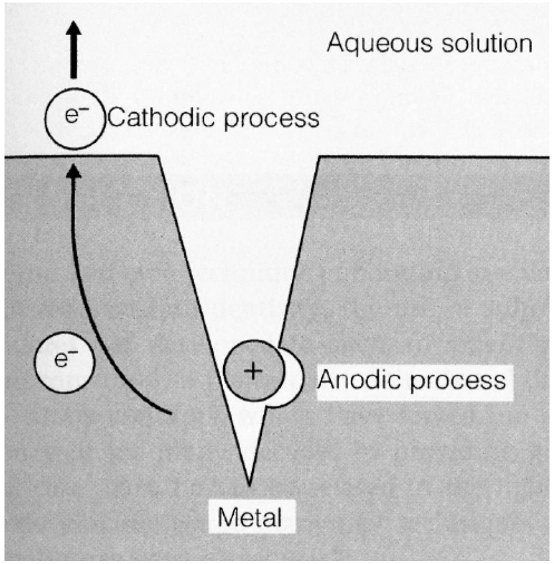
Galvanic series (in see water):

Pt ↑ inert
Au
Ti
Ag
Cu
Ni
Sn
Pb
Al
Zn ↓ aktív

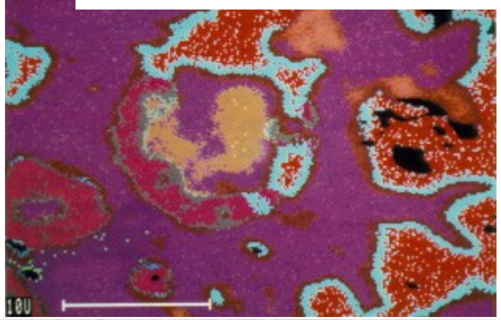


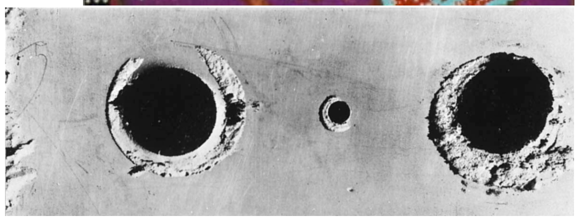
Galvanic corrosion:





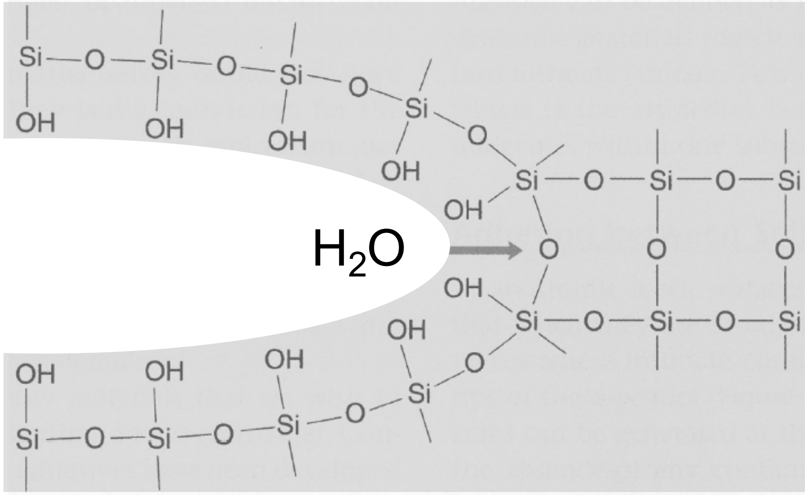
amalgám korrziója





- Chorrosion of ceramics

dissolution



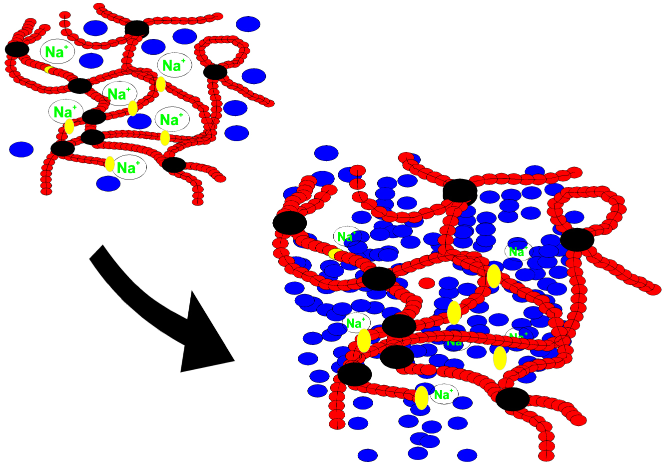
→ crack growth

(„static fatique”)

- Polimer degradation

water → swelling, dissolution → weakening of bonds →

Changes in mechanical, optical properties



UV irradiation → ionization → broken covalent bonds → chain rupture