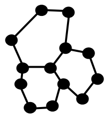
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

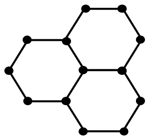
STRUCTURE AND PROPERTIES OF SOLIDS

1. Types of solids

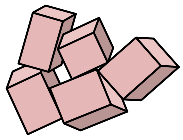
AMORPHOUS – irregular arrangement of molecules



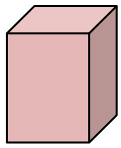
CRYSTALLINE – regular arrangement of molecules – crystal lattice



<u>polycrystals</u> – more „cores“, isotropic (same properties in all directions)
see attachment



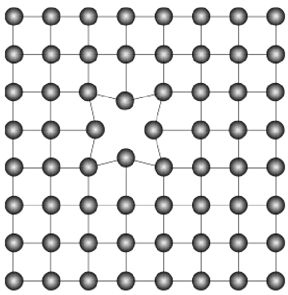
<u>monocrystals</u> – one lattice only, can be anisotropic

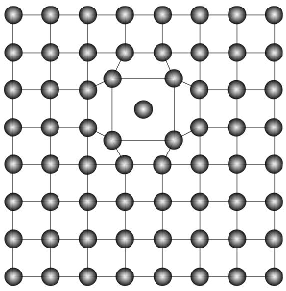


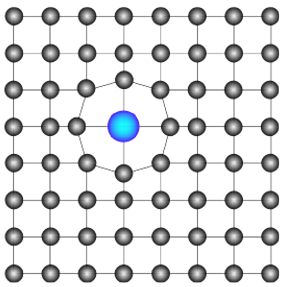
Find an example for all of the previous types of solids.

2. Dislocations

= irregularities in a crystal lattice – atom(s) missing, extra atoms, atoms of different elements



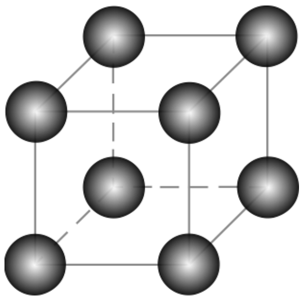




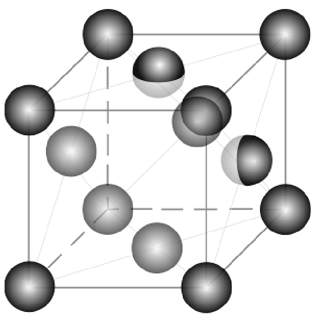
3. Ideal crystal lattice

unit cell – repeated over and over again

CUBIC
Po alpha

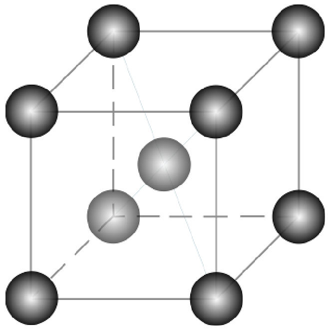


FACE-CENTRED CUBIC (FCC)
Al, Ni, Cu, Ag, Au, Fe γ

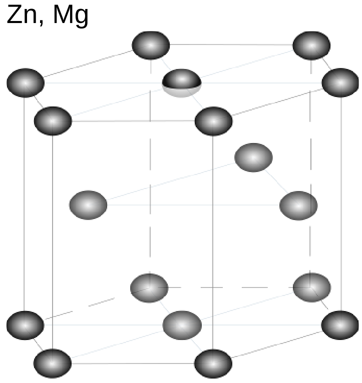


TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

BODY-CENTRED CUBIC (BCC)
Li, Na, Cr, K, W, Fe α



HEXAGONAL CLOSE-PACKING (HCP)
Zn, Mg



Questions:

1. How many Al atoms belong to one unit FCC on average?

2. Calculate the density of Al. Assume FCC, a = 0.405 nm, RAM = 26.98

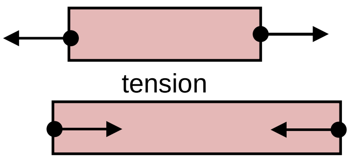
3. How many atoms belong to (on average)
   a simple cubic cell

   BCC cell

4. Calculate the side of a BCC cell of iron alpha. Assume RAM=55.85, density 7870 kg·m^{-3}.

4. Deformation of a solid

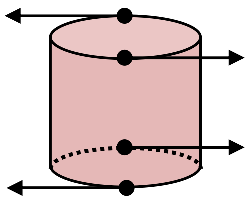
- ELASTIC – is temporary, when the force is removed the object returns to its original size and shape
- PLASTIC – is permanent



tension

compression

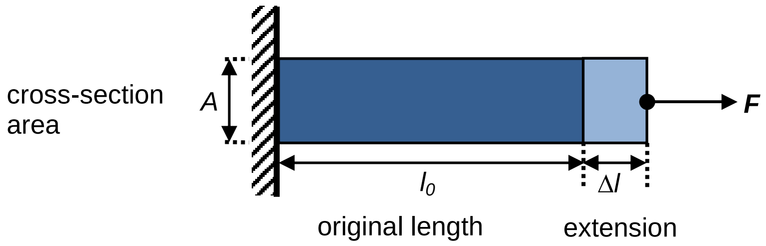
shear



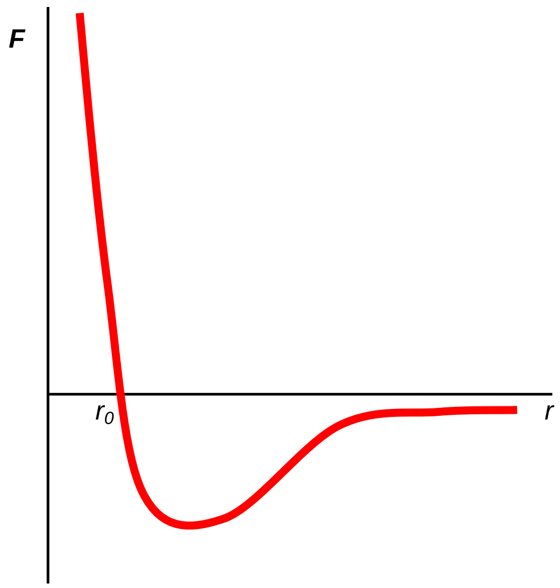
torsion

5. Stress (σ) and strain (ε), force and extension (Δl)

A wire is under tension – particles move further and they attract each other (*F-r* graph), at the beginning $F \propto \Delta l$

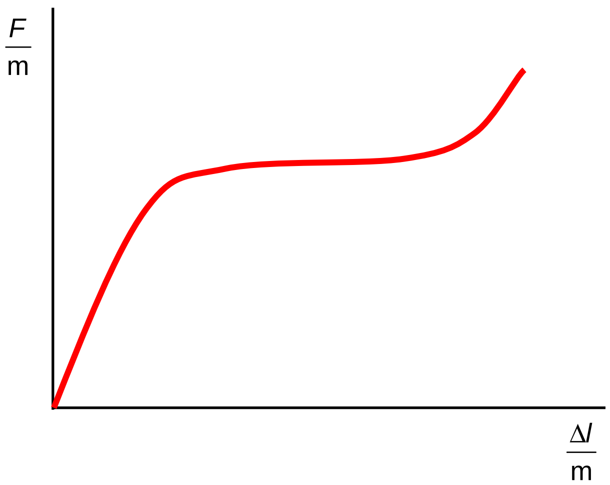


force separation graph (*F-r* graph)



..

the curve of deformation

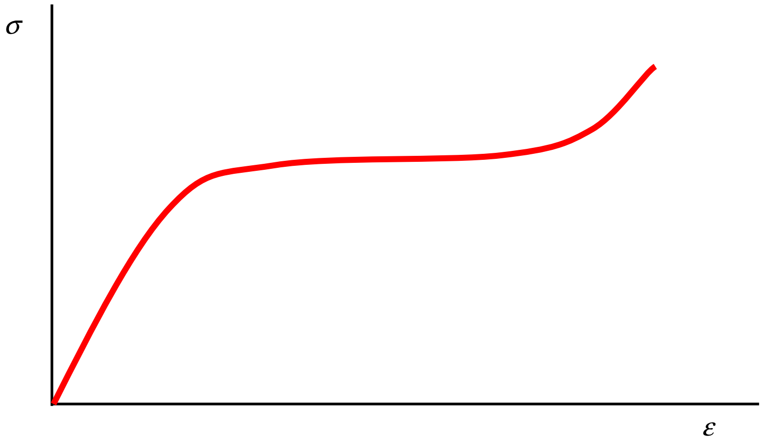


The curve has different shape for each material, but for different samples (A, l_0) of the same material it is similar. This is important for designers – they can choose suitable material. To compare the materials, a stress - strain curve is better.

stress : $\sigma = \dfrac{F}{A}$ $\qquad [\sigma] = \mathrm{N \cdot m^{-2}} = \mathrm{Pa}$

strain : $\varepsilon = \dfrac{\Delta l}{l_0}$ $\qquad [\varepsilon]$ ... no unit

stress-strain curve



label the points :
P ... limit of proportionality
E ... limit of elasticity – limit for temporary deformation
Y ... yield point – yielding/creeping of the material – min $\Delta\sigma$ causes big strain (extension)
B ... breaking stress/ultimate tensile strength - important quantity

in the book of data : σ_B

steel	350 – 2000 MPa
aluminium	70 – 190 MPa

6. Hooke's Law (1676)

is valid until the limit of proportionality!

$$\sigma = E\varepsilon$$

or $\dfrac{F}{A} = E\dfrac{\Delta l}{l_0}$

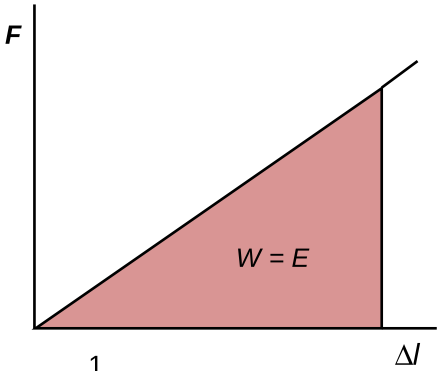
E ... Young modulus – material constant in the book of data

$$E = \frac{\sigma}{\varepsilon} = \frac{F l_0}{A\Delta l} \quad \Rightarrow \quad \{E\} = \{F\} \quad \Leftrightarrow \quad A = 1\,\mathrm{m}^2 \wedge \Delta l = 1\,\mathrm{m} \wedge l_0 = 1\,\mathrm{m}$$

material	steel	aluminium	copper
$\dfrac{E}{\mathrm{MPa}}$	220×10^3	67×10^3	125×10^3

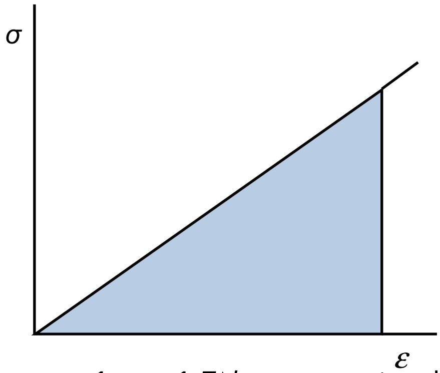
7. Elastic energy

revision – area under the force-displacement/distance graph = work done



$W = \frac{1}{2} F \Delta l = E$ energy stored in a given stretched sample

What does the area under stress-strain curve represent?



area under $= \frac{1}{2}\sigma\varepsilon = \frac{1}{2}\frac{F\Delta l}{A l_0} = \frac{\text{energy stored in a sample}}{\text{volume of the sample}} =$ energy stored in 1m^3 = energy density of the material under this stress

Questions:

5. What is the change of stress of an iron wire, when the stretching force rises 9 times and diameter of the wire 3 times?

6. What is the length of a copper wire suspended vertically when it breaks just because of its weight? Take density of copper 8 930kg·m^{-3}, breaking stress 180 - 450 MPa, acceleration due to gravity 9,81 m·s^{-2}.

L3/116-122

PRACTICALS

Compare the Young modulus of the materials, draw force-extension graphs and discuss.

Equipment: steel string, fishing wire, micrometer screw gauge or callipers, meter, loads

steel string

l_0 = d = A =

fishing wire

l_0 = d = A =

	steel string				fishing wire			
	$\frac{F}{N}$	$\frac{l}{m}$	$\frac{\Delta l}{m}$	$\frac{E}{MPa}$	$\frac{F}{N}$	$\frac{l}{m}$	$\frac{\Delta l}{m}$	$\frac{E}{MPa}$
1								
2								
3								
4								
5								

E = E =

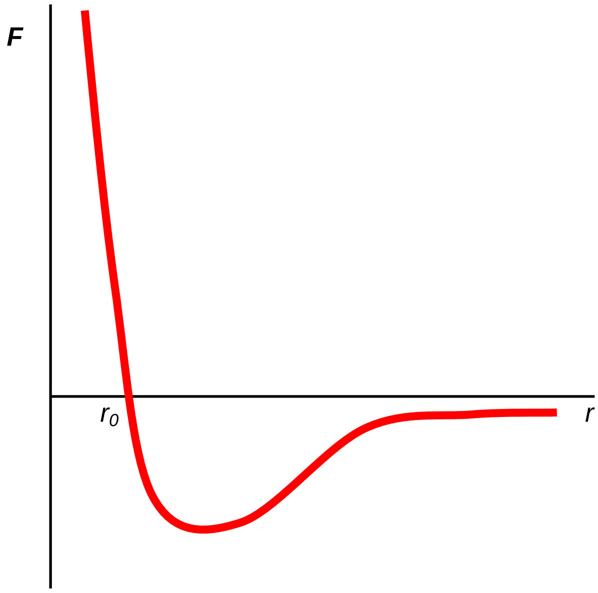
Graphs:

Discussion:

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

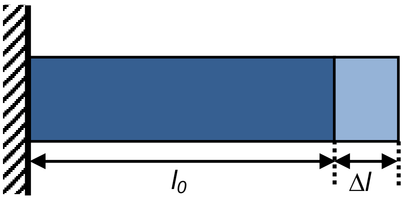
8. Thermal expansion of solids

To explain why particles move further apart when the temperature rises we can use a F-r graph again



at very low temperatures – symmetrical vibrations round equilibrium
higher temperatures – asymmetrical vibrations with displacement bigger on extension side

a) **linear expansion**



heat taken in – extension depends on the original length, temperature change and MATERIAL

α ... linear expansivity, material constant

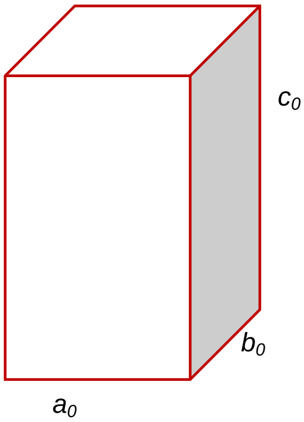
$$\alpha = \frac{\Delta l}{l_0 \Delta t} \qquad \{\alpha\} = \{\Delta l\} \Leftrightarrow l_0 = 1\,\text{m} \wedge \Delta t = 1\,\text{K}$$

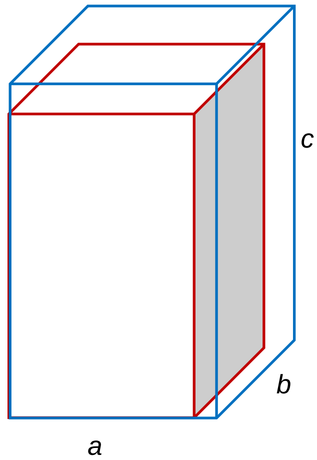
$[\alpha] = \text{K}^{-1}$

new length $l = l_0 + \Delta l = l_0 + l_0 \alpha \Delta t = l_0(1 + \alpha \Delta t)$

	copper	aluminium	iron
$\frac{\alpha}{10^{-5}\text{K}^{-1}}$	1.7	2.4	1.2

b) volume expansion





$$V = abc = a_0(1+\alpha\Delta t)b_0(1+\alpha\Delta t)c_0(1+\alpha\Delta t) = V_0(1+\alpha\Delta t)^3 \approx V_0(1+3\alpha\Delta t)$$

Questions:
7. Calculate the force needed to apply on a steel rod of cross-section 5 cm^2 so that it extends by the same value as if it were heated by 1 ^{o}C. Assume linear expansivity of steel $1{,}2 \cdot 10^{-5}$ K^{-1} and its Young modulus 200 GPa.

8. A steel measuring tape is calibrated at 20 ^{o}C. We measure the length of 35 m when the temperature is 30 ^{o}C. State the precise length. Assume the linear expansivity of steel $\alpha = 1{,}2 \cdot 10^{-5}$ K^{-1}.

L3/123-132

Answers:
1. 1+3=4
2. 2700 $kg \cdot m^{-3}$
3. 1; 2
4. 0.287 nm
5. it stays the same
6. 2 055 m – 5 137 m
7. 1 200 N
8. 35.0042 m

ATTACHMENT - CRYSTALS

kazivec
fluorite

galenit
galena

kalcit
calcite

kuprit
cuprite

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

bauxit
bauxite

granát
garnet

síra
sulphur

chlorid sodný
halite

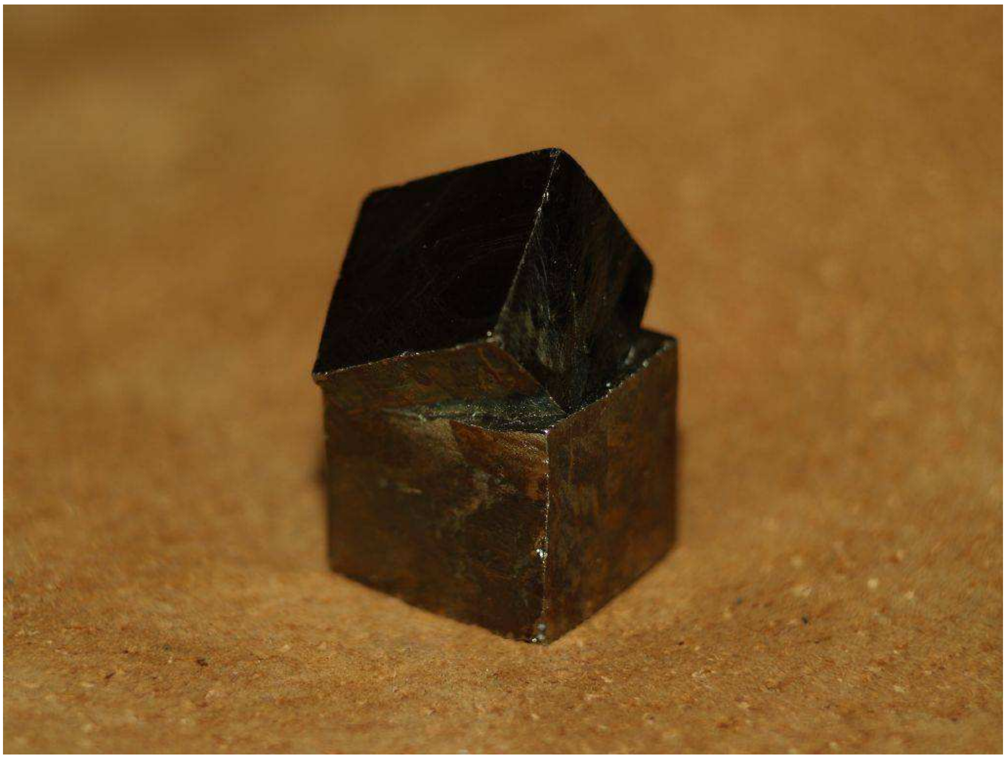
TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

hematit
haematite

křišťál
crystal

ametyst
amethyst

křemen
quartz



pyrit
pyrite

pyrit
pyrite

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

růženín
rose quartz

záhněda
smoke-stone

hyalit
hyalite

chalkopyrit
chalcopyrite

živec
feldspar

sádrovec
gypsum

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

turmalín
tourmaline

molybdenit
molybdenite

chalkantit
chalcantite