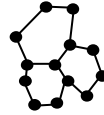


# STRUCTURE AND PROPERTIES OF SOLIDS

## 1. Types of solids

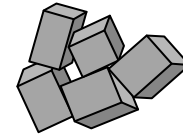
AMORPHOUS – irregular arrangement of molecules



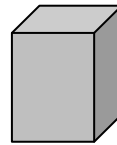
CRYSTALLINE – regular arrangement of molecules – crystal lattice



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



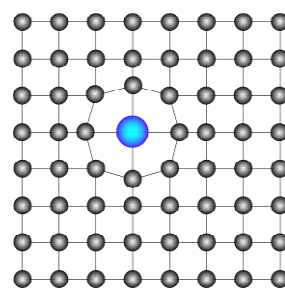
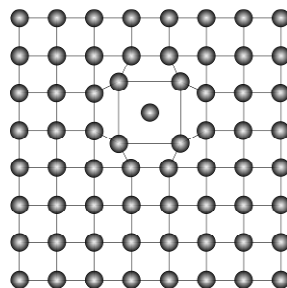
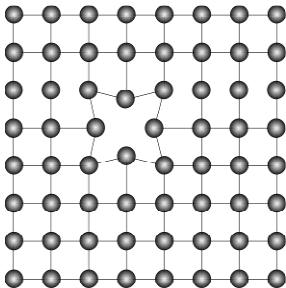
monocrystals – one lattice only, can be anisotropic



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

## 2. Dislocations

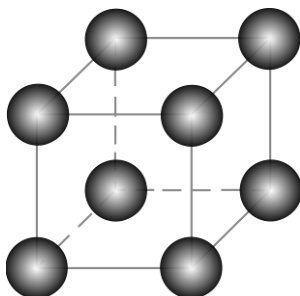
= irregularities in a crystal lattice – atom(s) missing, extra atoms, atoms of different elements



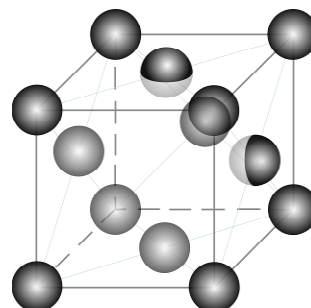
## 3. Ideal crystal lattice

unit cell – repeated over and over again

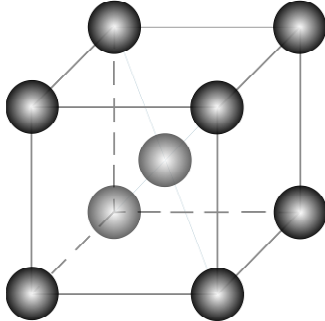
CUBIC  
Po alpha



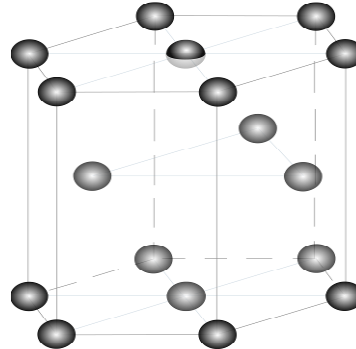
FACE-CENTRED CUBIC (FCC)  
Al, Ni, Cu, Ag, Au, Fe  $\gamma$



BODY-CENTRED CUBIC (BCC)  
Li, Na, Cr, K, W, Fe  $\alpha$



HEXAGONAL CLOSE-PACKING (HCP)  
Zn, Mg

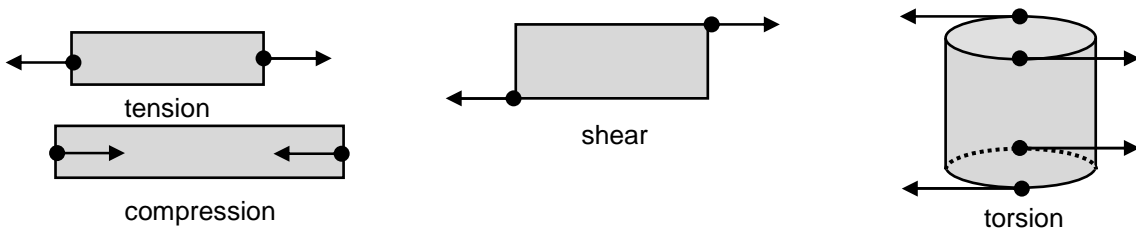


**Questions:**

1. How many Al atoms belong to one unit FCC on average?
2. Calculate the density of Al. Assume FCC,  $a = 0.405 \text{ nm}$ ,  $RAM = 26.98$
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  $7870 \text{ kg}\cdot\text{m}^{-3}$ .

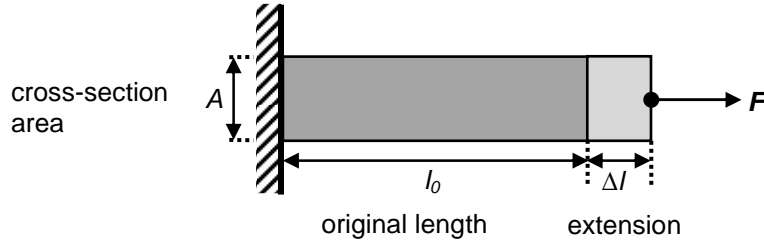
**4. Deformation of a solid**

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

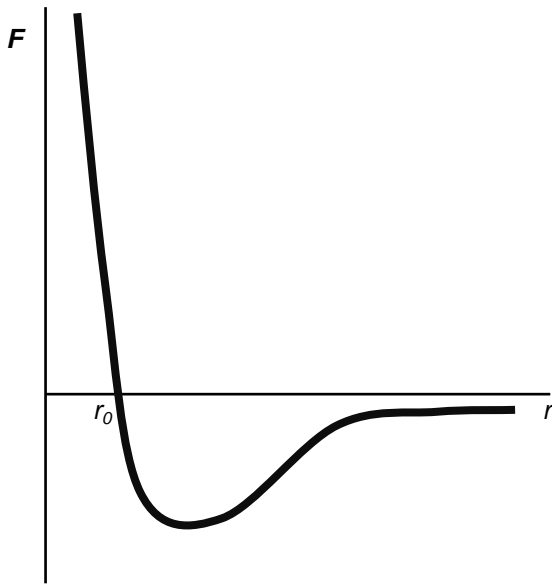


## 5. Stress ( $\sigma$ ) and strain ( $\varepsilon$ ), force and extension ( $\Delta l$ )

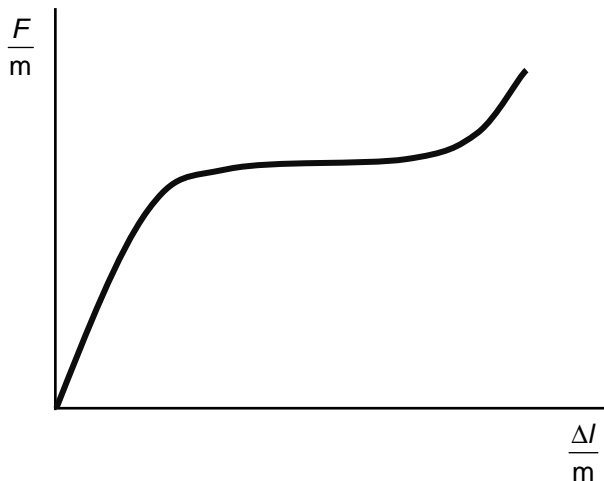
A wire is under tension – particles move further and they attract each other ( $F$ - $r$  graph),  
at the beginning  $F \propto \Delta l$



force separation graph ( $F$ - $r$  graph)



the curve of deformation

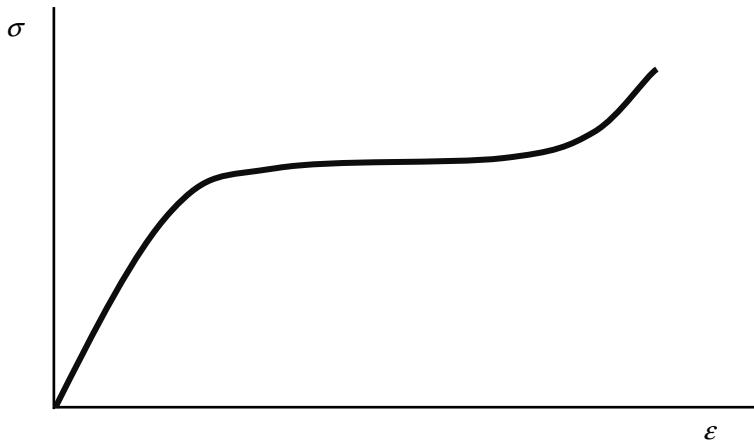


The curve has different shape for each material, but for different samples ( $A, l_0$ ) of the same material it is similar. This is important for designers – they can choose suitable material. To compare the materials, a stress - strain curve is better.

$$\text{stress : } \sigma = \frac{F}{A} \quad [\sigma] = \text{N} \cdot \text{m}^{-2} = \text{Pa}$$

$$\text{strain : } \varepsilon = \frac{\Delta l}{l_0} \quad [\varepsilon] \dots \text{ no unit}$$

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 :  $\sigma_B$

steel	350 – 2000 MPa
aluminium	70 – 190 MPa

## 6. Hooke's Law (1676)

is valid until the limit of proportionality!

$$\sigma = E\varepsilon$$

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

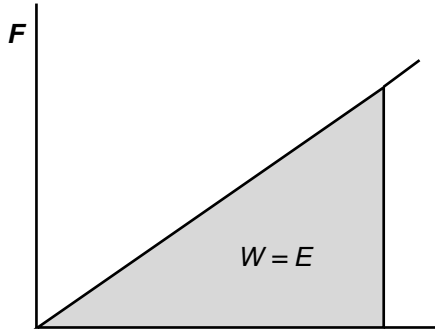
$E$  ... Young modulus – material constant in the book of data

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

material	steel	aluminium	copper
$\frac{E}{\text{MPa}}$	$220 \times 10^3$	$67 \times 10^3$	$125 \times 10^3$

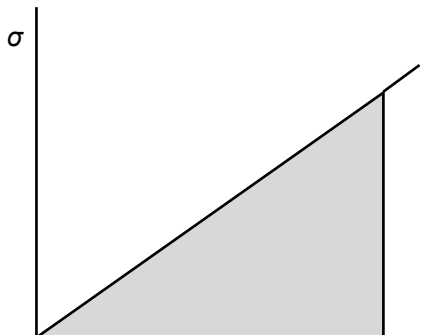
## 7. Elastic energy

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



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

What does the area under stress-strain curve represent?



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

### 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  $8930\text{kg}\cdot\text{m}^{-3}$ , breaking stress 180 - 450 MPa, acceleration due to gravity  $9,81\text{ m}\cdot\text{s}^{-2}$ .



INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

## 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								

$E =$

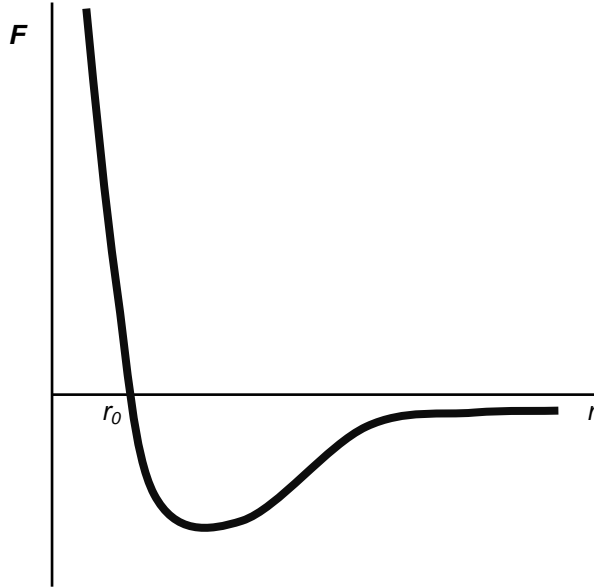
$E =$

**Graphs:**

**Discussion:**

## 8. Thermal expansion of solids

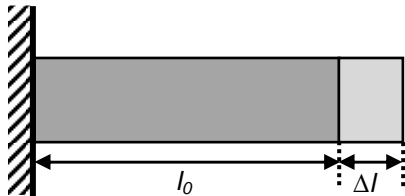
To explain why particles move further apart when the temperature rises we can use a F-r graph again



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

$\alpha$  ... linear expansivity, material constant

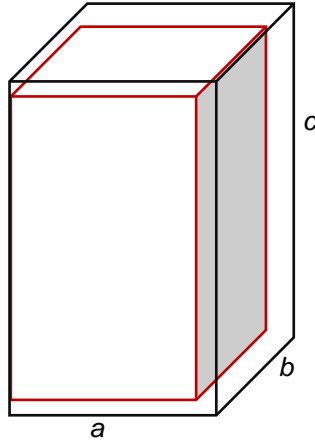
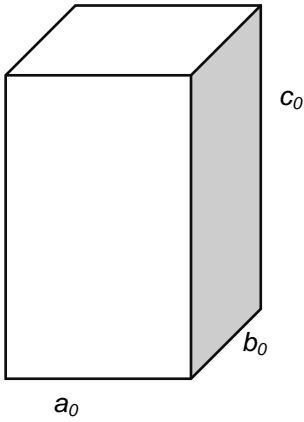
$$\alpha = \frac{\Delta l}{l_0 \Delta t} \quad \{\alpha\} = \{\Delta l\} \Leftrightarrow l_0 = 1 \text{ m} \wedge \Delta t = 1 \text{ K}$$

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

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

	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  $5 \text{ cm}^2$  so that it extends by the same value as if it were heated by  $1^\circ\text{C}$ . Assume linear expansivity of steel  $1,2 \cdot 10^{-5} \text{ K}^{-1}$  and its Young modulus  $200 \text{ GPa}$ .

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

L3/123-132

**Answers:**

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



## ATTACHMENT - CRYSTALS



kazivec  
fluorite



galenit  
galena



kalcit  
calcite



kuprit  
cuprite



bauxit  
bauxite



granát  
garnet



síra  
sulphur



chlorid sodný  
halite



hematit  
haematite



křišťál  
crystal



ametyst  
amethyst



křemen  
quartz



pyrit  
pyrite



pyrit  
pyrite



růženín  
rose quartz



záhněda  
smoke-stone





hyalit  
hyalite



chalkopyrit  
chalcopyrite



živec  
feldspar



sádrovec  
gypsum



turmalín  
tourmaline



molybdenit  
molybdenite



chalkantit  
chalcantite