Mechanical properties of solids   Lecture 10   1

(slides) states of matter

1) 4 states solid, liquid, gas, plasma

2) a) change of state (phase transition) by providing energy, e.g. heat

b) microscopic view: atomic arrangement defines state of matter

State of matter depends on external parameters,

pressure, temperature, electrical and/or magnetic fields

and on the interaction between atoms and molecules forming the solid

(slide) fire ants mechanics: it's all about the interaction between ... ants.

(exp) Gittermodelle NaCl, $CaCO_3$

+ Kristalle sodium calcium carbonate

(exp) "Wunderkit" (# 700): balls different materials

- elastic ball (rubber, polymer): bouncing ball
- cork / wood; steel: no ~~rebound~~ bouncing
- play doh / playdough
- silly-putty paste: time scale of interaction!

Bonding : interaction between atoms in a solid
will define the mechanical properties of the solid

types of crystals : · covalent : sharing of e^- pairs between atoms
· metallic : collective interaction of mobile e^- fluid with ions
· ionic : electrostatic forces
· molecular ; weak, van der Waals interaction (London dispersion force)

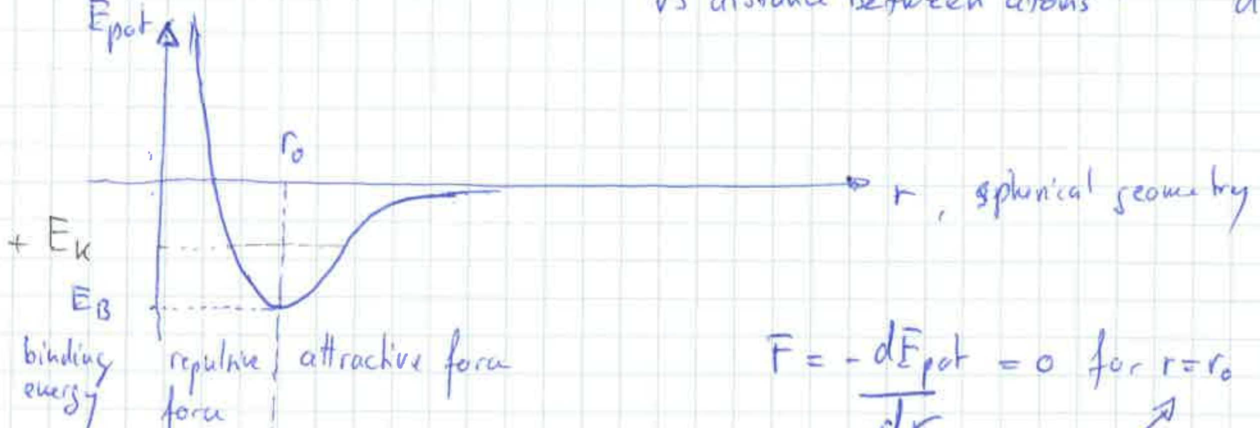
(slide) interatomic forces

example forces: $F \propto \frac{1}{r^2}$ Coulomb (electrostatic) between (+) and (−) charge

$F \propto \frac{1}{r^7}$ Van der Waals

↖ rapid decay, short distance ordering

· binding energy between atoms : potential energy E_{pot} vs distance between atoms $\left(F = -\frac{dE_p}{dr}\right)$



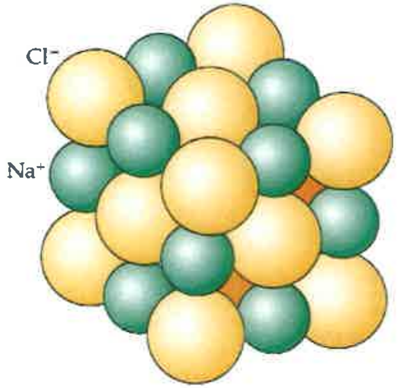
$F = -\frac{dE_{pot}}{dr} = 0$ for $r = r_0$ ← equilibrium position

· increase temperature T ⇒ E_{kin} to atoms, vibrations rotations

⇒ higher energy state

· if $E_K \sim E_B$ → melting of solid

(slide) NaCl E_{pot}



ionic crystal: NaCl

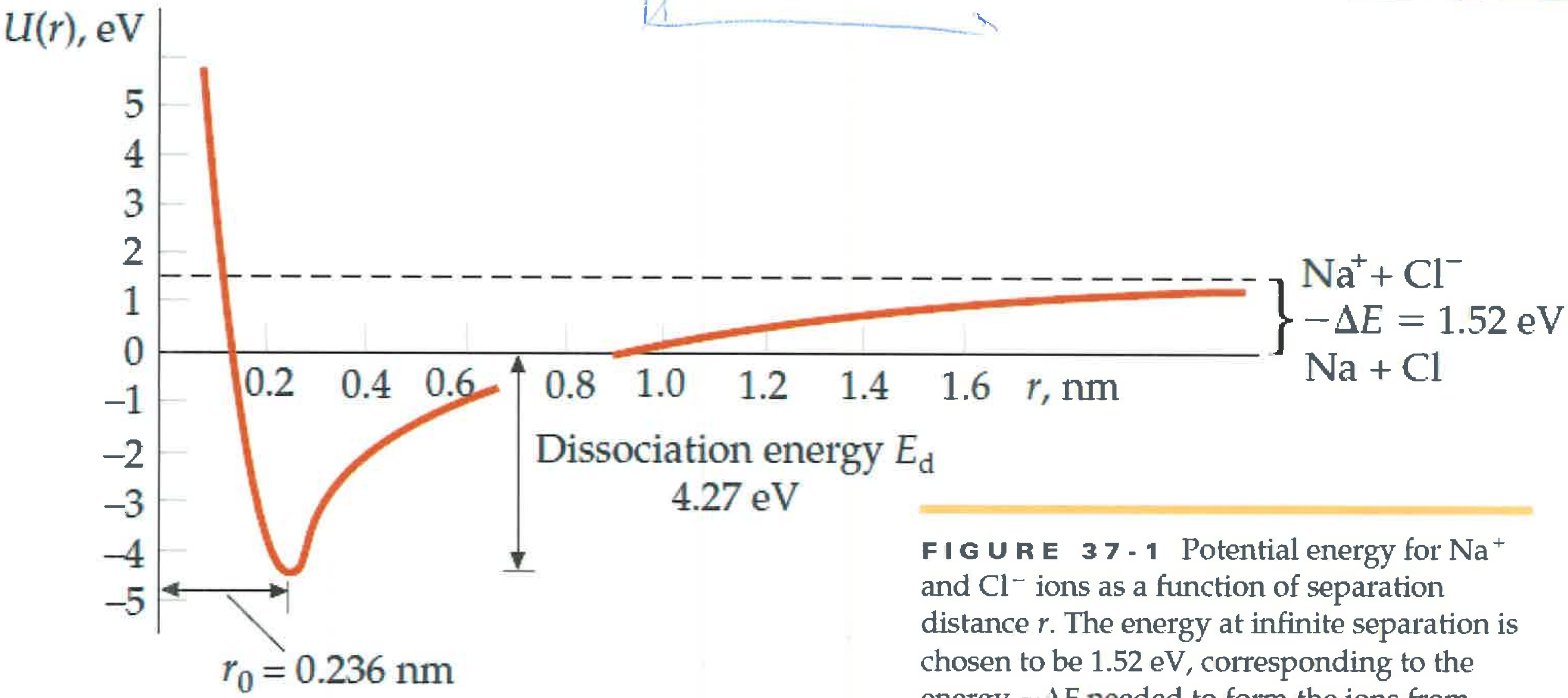
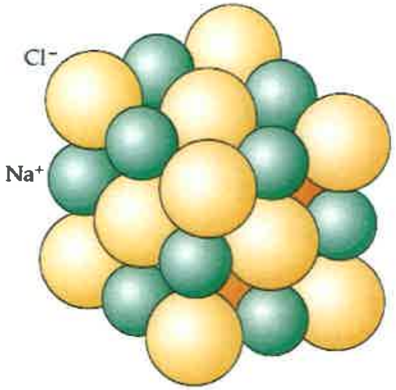
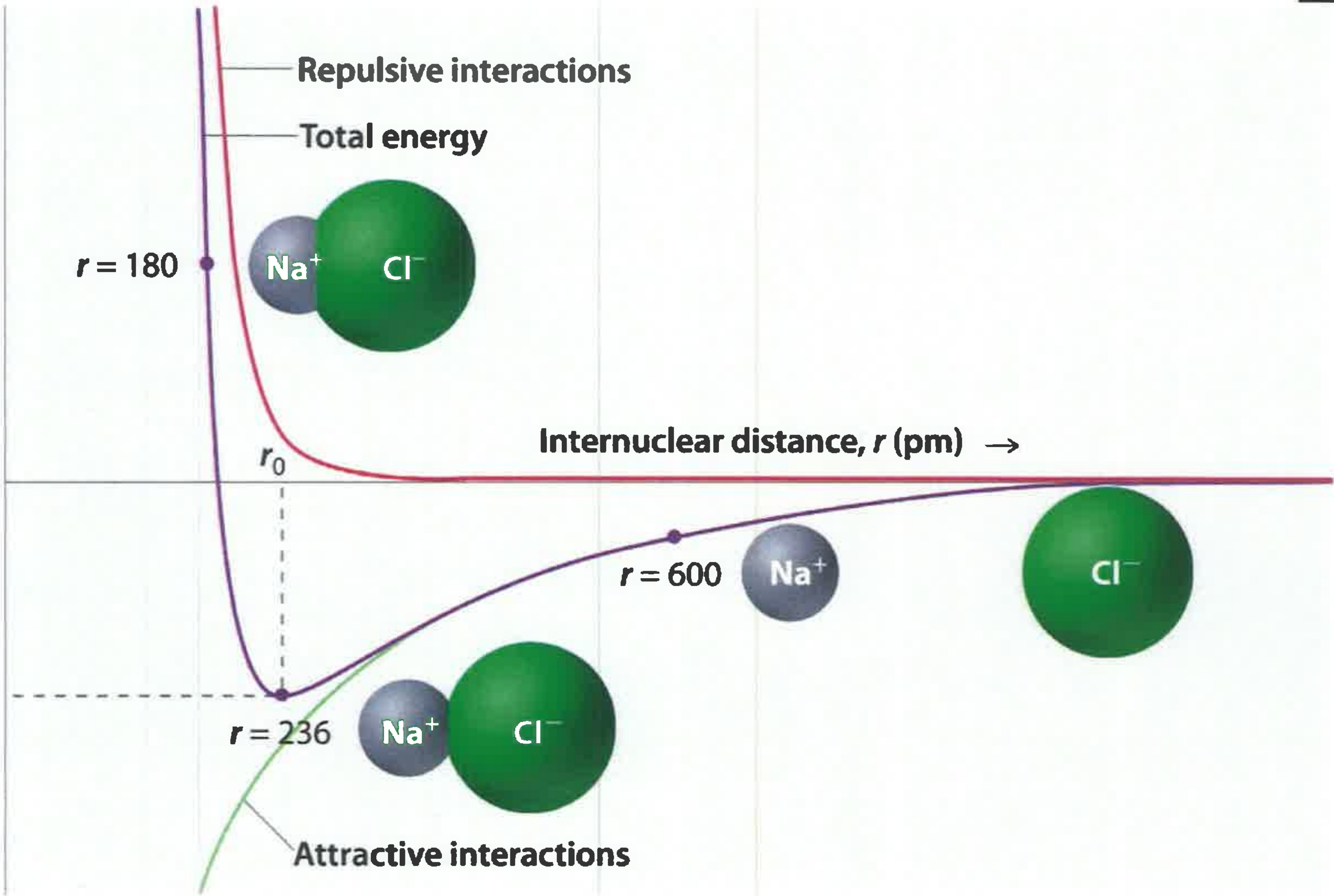


FIGURE 37-1 Potential energy for Na^+ and Cl^- ions as a function of separation distance r. The energy at infinite separation is chosen to be 1.52 eV, corresponding to the energy $-\Delta E$ needed to form the ions from atoms. The minimum energy is at the equilibrium separation $r_0 = 0.236$ nm for the ions.

Tipler, Mosca, Physics, 6th ed. (2008)

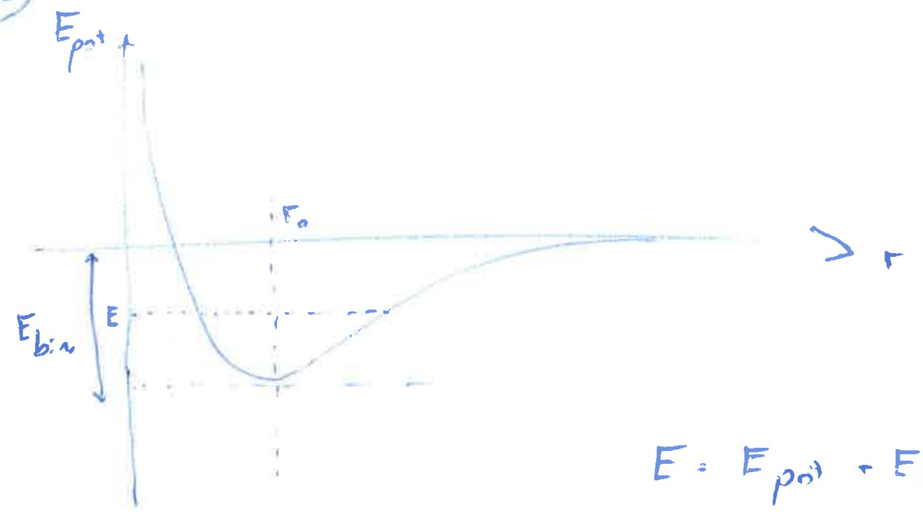


ionic crystal: NaCl



Thermal Expansion

Microscopic



$$E = E_{pot} + E_{kin}$$

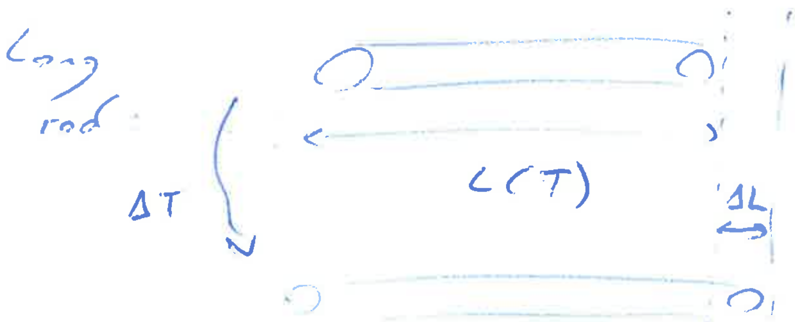
Since $E_{kin} \propto T$,

when $E_{kin} = E_{bin}$, a solid melts;

when $E_{kin} > 0$ and $E_{kin} < E_{bin}$,

$r > r_0$.

Macroscopic

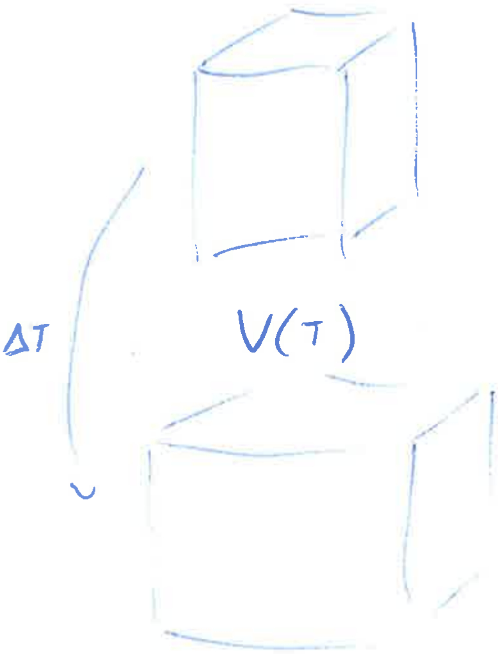


$$\frac{\Delta L}{L} = \alpha \cdot \Delta T$$

$$L(T+\Delta T) = L(T) + \Delta L$$

$\alpha \; \left[\frac{1}{K}\right]$ coefficient of linear expansion

2



$$\frac{\Delta V}{V} = \alpha_V \cdot T$$

↳ volumetric thermal expansion coefficient

$$V(T + \Delta T) = V(T) + \Delta V$$

Exp 1 Steel sphere in aluminium ring ...

$$\alpha_{steel} = 11 \times 10^{-6} \frac{1}{k}$$
$$\alpha_{Aluminium} = 2.4 \times 10^{-6} \frac{1}{k}$$

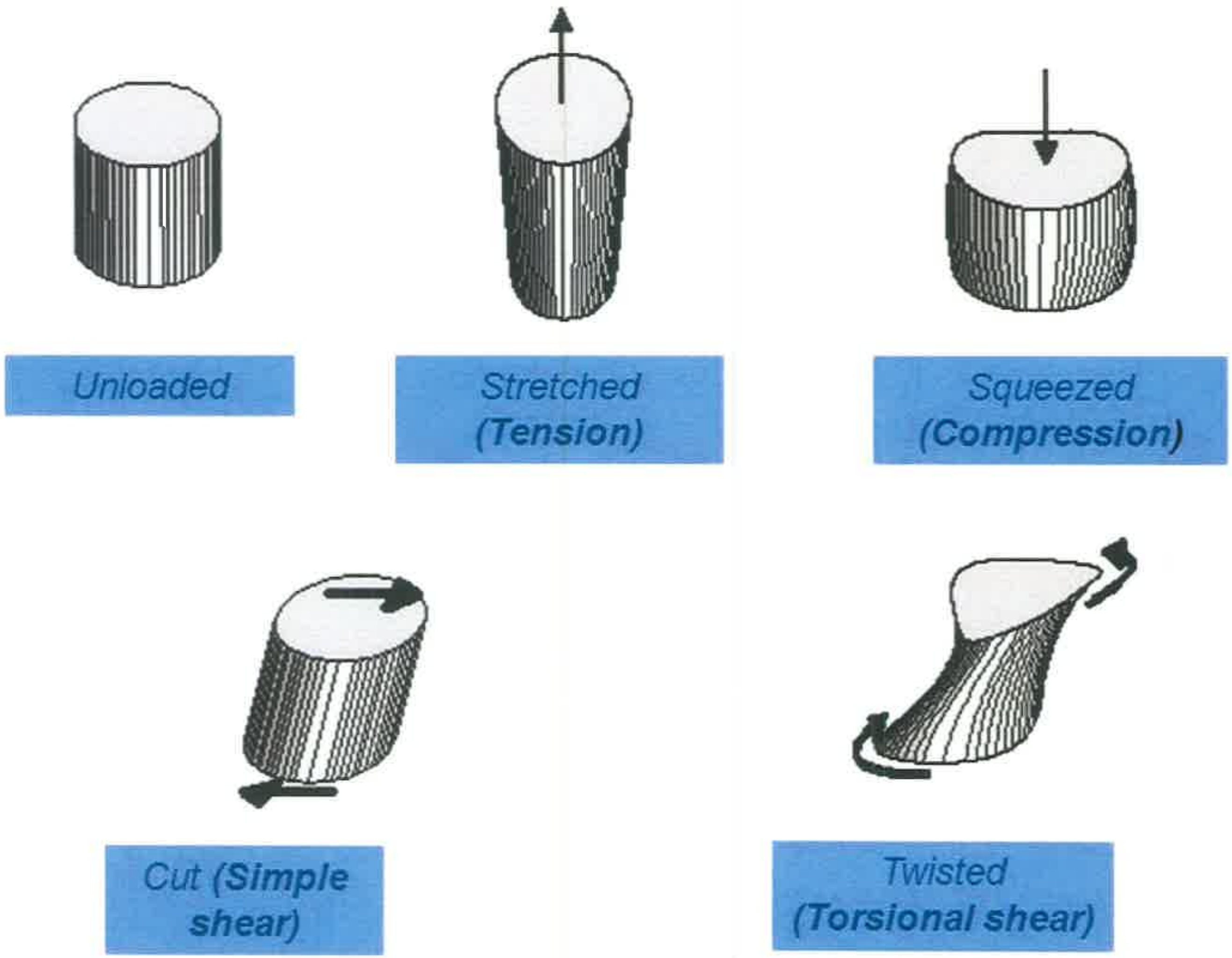
$\} \quad \alpha_{steel} < \alpha_{aluminium}$

3 Exp

Iron
Steel
Fashion

4 Exp Putty

forces on solid



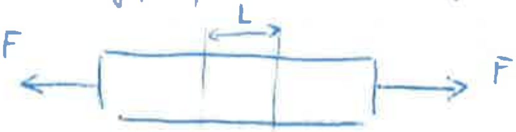
macroscopic properties of solids

mechanical properties of homogeneous solids

(slide)

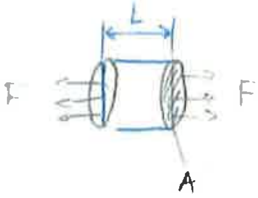
- force on solids : shape change
  if reversible deformation : elastic behavior (def.)

- tensile (stretching) force F acting on solid bar



elongation

section of bar :



elements of bar left and right of section L exert forces on section. Forces distributed equally over cross-sectional area

fractional change of length of segment L : ΔL

def : strain (Dehnung) $\varepsilon = \frac{\Delta L}{L}$

def stress $\sigma = \frac{F}{A}$ ratio of force to cross-sectional area

$[\sigma] = \frac{N}{m^2} = $ Pascal pressure

Hooke's law : $\frac{\Delta L}{L} \propto \frac{F}{A}$

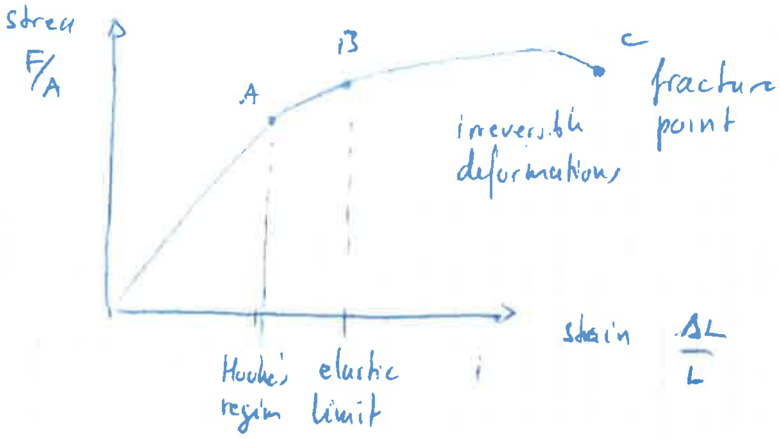
$$\Vert \quad \frac{\Delta L}{L} = \frac{1}{E} \cdot \frac{F}{A}$$

E : Young's modulus

$[E] = \frac{N}{m^2}$ Pascal

$$\varepsilon = \frac{1}{E} \cdot \sigma$$

$$\sigma = E \cdot \varepsilon$$



Hooke: $\frac{\Delta L}{L} = \frac{1}{E} \cdot \frac{F}{A}$

exp — Reiß Versuch (#724)

Cu wire

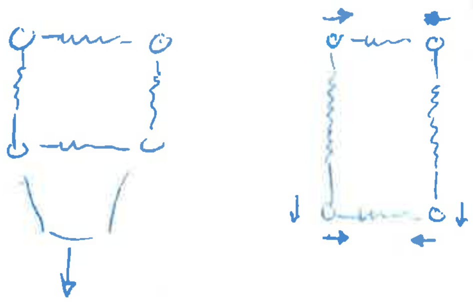
steel wire
(Fe, C, ...)

exp — steel and tin springs (#701)
(Stahl) (Zinn)

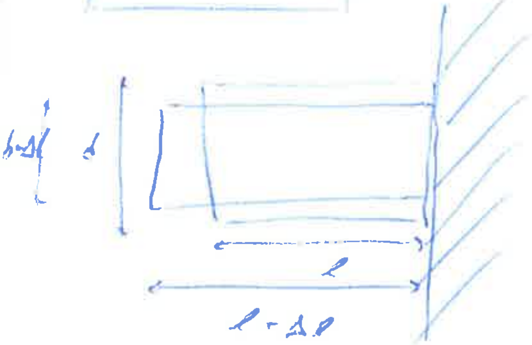
elastic deformation

soft metal, plastic
↑
"mobile" atoms

exp — Federmodell (#710)



Poisson Ratio



(Quer Kontraktion)

lateral contraction

elongation (Dehnung)

$$\frac{\Delta d}{d} = -\mu \frac{\Delta l}{l}$$

→ Poisson's ratio (Poissonzahl)

Fernzugversuch [Exp]

$V = l d^2$

$\Delta d, \Delta l$ are small : $\Delta d, \Delta l \ll l, d$

$$V + \Delta V = (l + \Delta l)(d + \Delta d)^2 = (l + \Delta l)(d^2 + 2d\Delta d + \Delta d^2)$$

$$V + \Delta V = l d^2 + 2 l d \Delta d + d^2 \Delta l + 2 d \Delta d \Delta l$$

For constant volume :

$$l d^2 = l d^2 + 2 l d \Delta d + d^2 \Delta l$$

$$2 l d \Delta d = - d^2 \Delta l$$

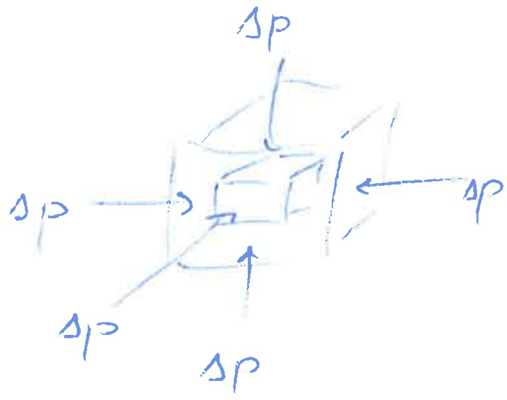
$$\frac{\Delta d}{d} = -\frac{1}{2} \frac{\Delta l}{l}$$

→ $\mu = \frac{1}{2}$ ← maximum value

[Exp]

Typical μ : $0.2 < \mu < 0.5$

Bulk Modulus (Kompressionsmodul)



$$\Delta p = -K \frac{\Delta V}{V}$$

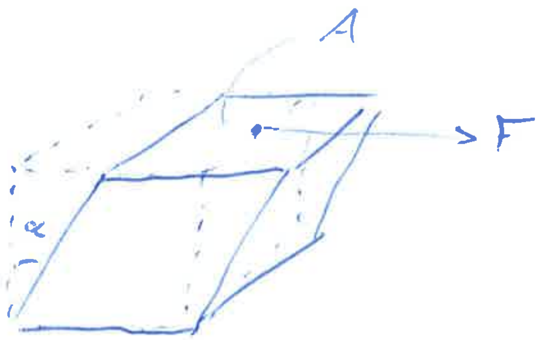
$K \quad \left[\frac{N}{m^2} = Pa \right]$

Glass	35 - 55	GPa
Steel	160	GPa
Diamond	443	GPa

$\frac{1}{K} = \kappa$ ← compressibility (Kompressibilität)

$\left[\frac{m^2}{N} = \frac{1}{Pa} \right]$

Shear Modulus (Schubmodul)



$\tau = \frac{F}{A}$ ← shear stress (Schubspannung)

$$\alpha = \frac{1}{G} \frac{F}{A} = \frac{1}{G} \tau$$

G ← shear modulus (Schubspannung)

$[Pa]$

Glass	26.2	GPa
Steel	79.3	GPa
Diamond	478.0	GPa

Ex2