orthodontics

conservative dentistry

prosthetic dentistry

Physical basis of dental material science 7.

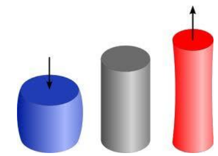
Mechanical properties 1.

Effect of the force

If motion is possible: **displacement**

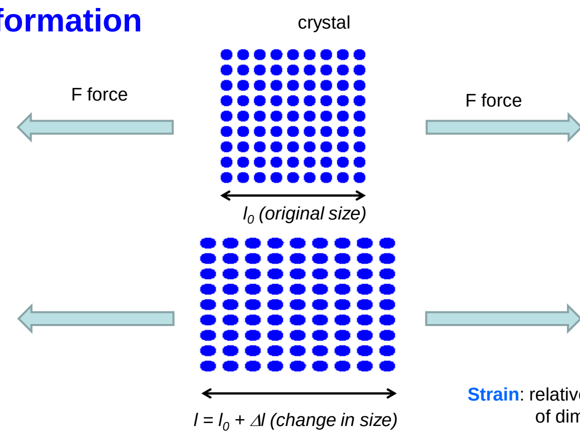
e.g.: orthodontics

If motion is impossible: **deformation**



e.g.: conservative dentistry

Deformation

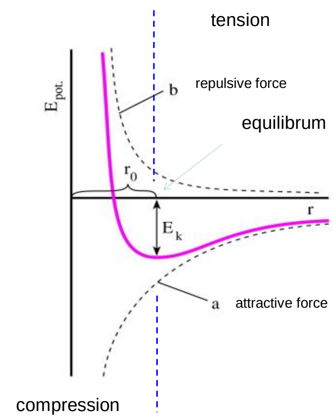


Strain: relative change of dimensions.

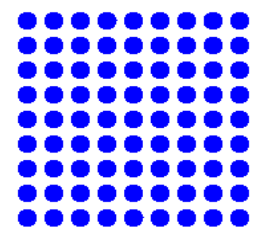
$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l - l_0}{l_0}$$

The integrity of the object doesn't change! Only the size changes!

Internal forces compensate external foces



lattice



Both elongation and compression result opposite atomic internal forces! (repulsive or attractive force.)

Characterization of the load:

stress(σ):

$$\sigma = \frac{F}{A_0} \qquad [\sigma] = \frac{\mathrm{N}}{\mathrm{m}^2} = \mathrm{Pa}$$

Engineering system!
(No drastic change in shape, e.g. A_0 is constant!)

⟹ Internal stresses

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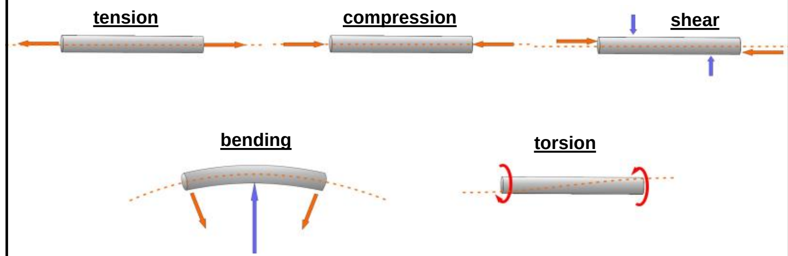
Deformations (an object gets changed due to force)

force ⟶ deformation



(arrows = forces – direction and magnitude)

Isotrope material: properties are independent from the direction.

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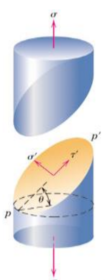
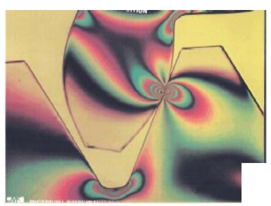
Examination of the stress distribution

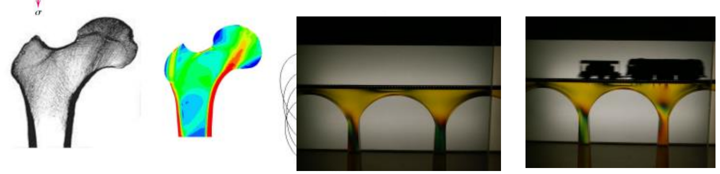


- **Experimental methods**: optical measurments



e.g. :
usage of polarized light

(observation of anistropy produced by the force)



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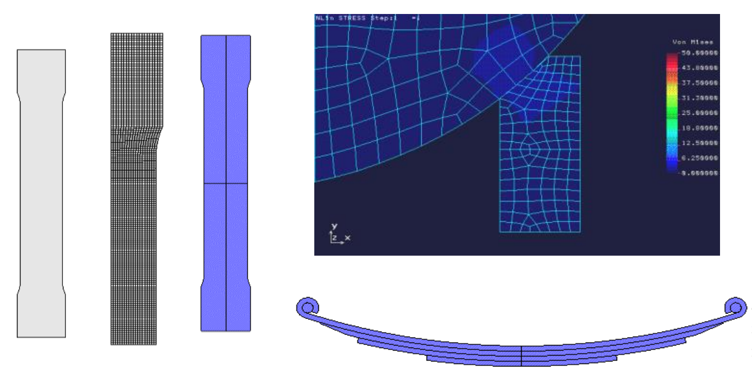
- **Theoretical method**:

Finite Element Method
(computer builds up the body from small elementary shapes and analysis forces.)



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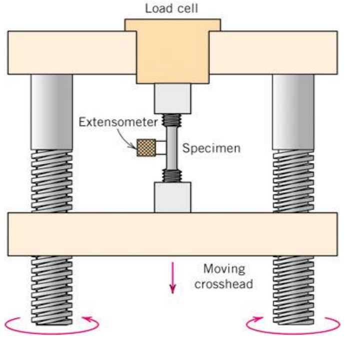
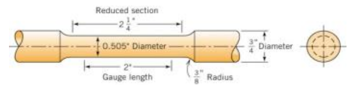
Physical test methods

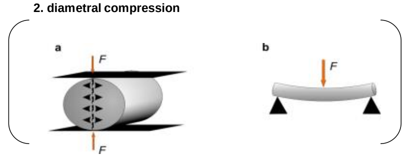
1. tension test



standard body



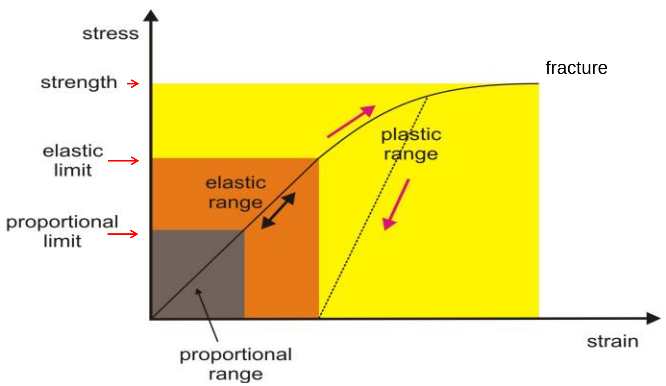
2. diametral compression



3. 3-point bending test

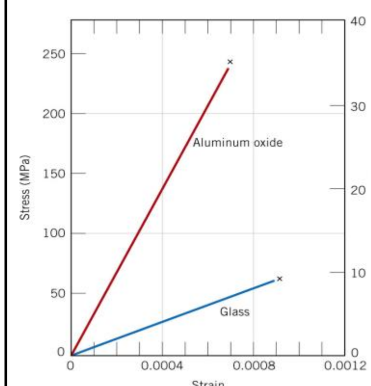
Stress-strain diagram

strength: maximum of the stress
elastic limit: maximum stress in elastic range
proportional limit: maximum stress in the proportional range



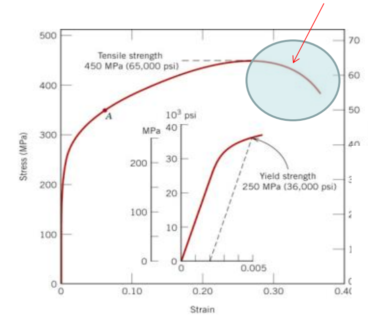
examples:

ceramics



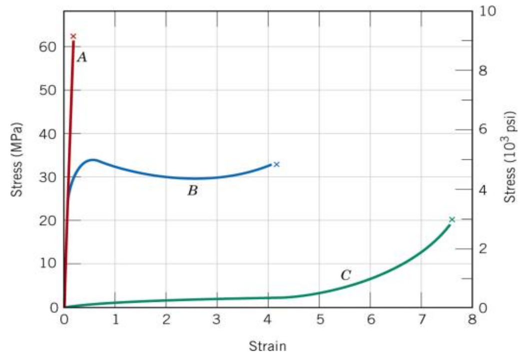
metals, e.g. brass

???



polymers

A: hard (glass -like)
B: semi-crystalline
C: rubber



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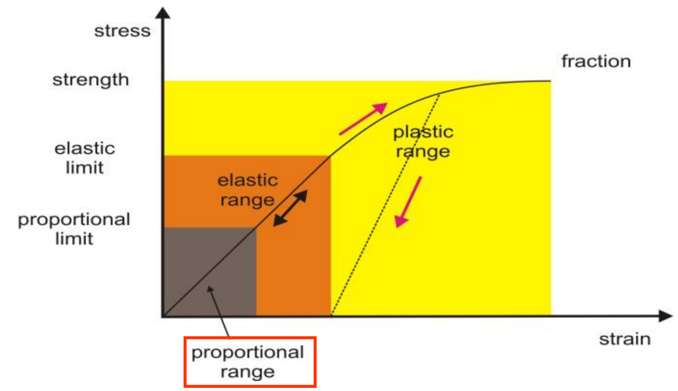
Stress-strain diagram



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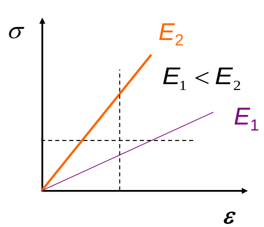
Elasticity (to the proportional limit)

- tension/compression

strain →
relative tension/compression (changing of the length):

$\varepsilon = \frac{\Delta l}{l_0}$ $[\varepsilon] =$ no unit

Hooke's law: $\sigma = E \cdot \varepsilon$ *E* — **elastic**(Young's) **modulus** [*E*] = Pa



E — resistance against the tension or compression, **stiffness**

1/*E* — propensity for tension or compression, **elasticity**

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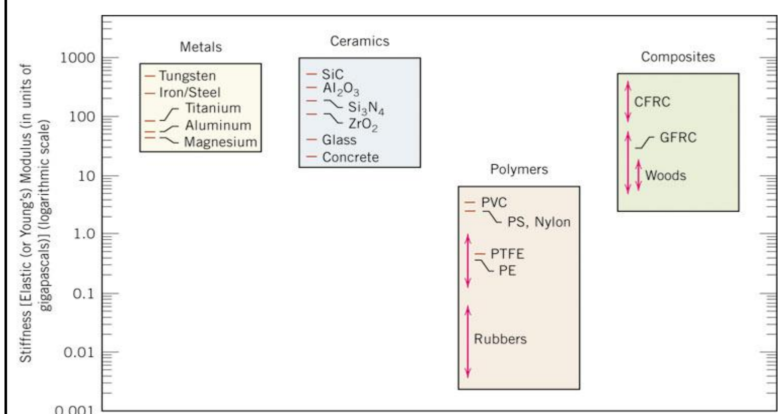
Stiffness of different materials



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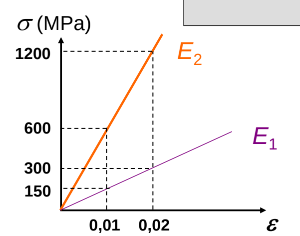
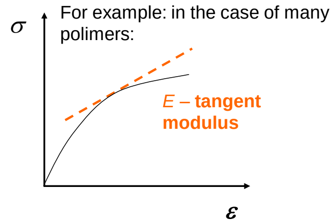
E.g.:





Stiffnes of a few dental materials:

material	E (GPa)
Enamel of the teeth	≈ 100
dentin	≈ 15
steel	200-230
Amalgam	50-60
gold	79
Gold alloys	75-110
Pd-Ag alloys	100-120
Co-Cr alloys	120-220
Ni-Cr alloys	140-190
glass	60-90
ceramics	60-130
Porcelain	60-110
PMMA (polimetilmetacrylate)	2,4-3,8
silicon	≈ 0,0003

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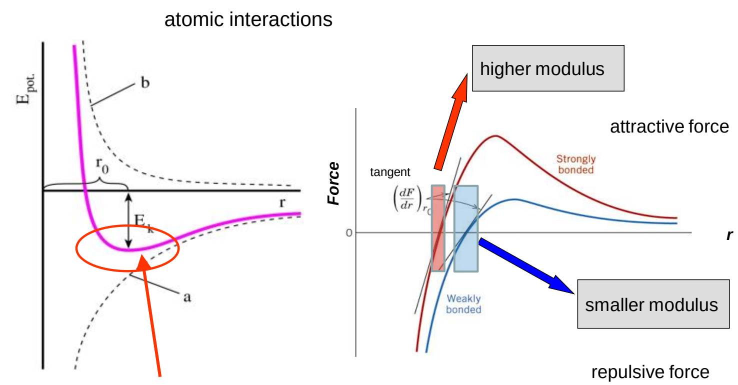
reminder:

atomic interactions



near parabolic profile → it is characteristic for a linear force law.

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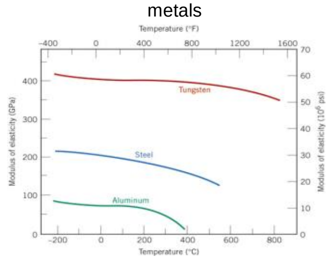
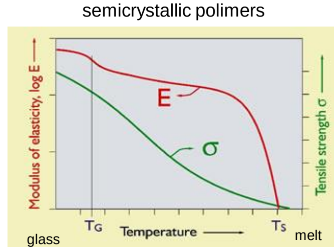
Influence of the temperature:

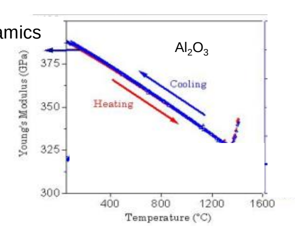
metals

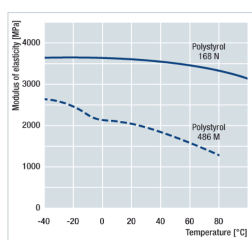


semicrystallic polimers



ceramics





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

$$F = E \cdot \frac{A_0}{l_0} \Delta l = D \Delta l$$

Material parameter! **Stiffness of the material**

$$\sigma = \frac{F}{A_0}, \quad \varepsilon = \frac{\Delta l}{l_0}$$

Body parameter (material + geometric factors)! **Stiffness of the body (at tension)**

Stiffness of the material: stress that is necessary for unit strain.

Stiffness of the body: force that is necessary for unit changing of the length.

(See spring: D — spring constant)

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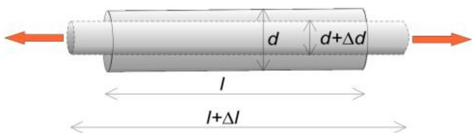
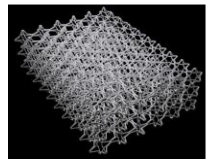
lateral changing of the size:



Auxetic materials
(negative Poisson's ratio):

(e.g.: special foams,
variants of
Polytetrafluoroethylene)



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

ν — **Poisson's ratio (no unit)**

e.g.

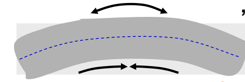
material	ν
Enamel	0.33
Dentin	0.31
amalgam	0.31
PDL	0.45
polimers	0.40–0.50

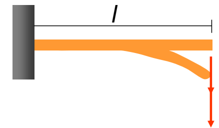
(„normal material")

The elastic property of a homogene, isotrope material is exactly determined by E and ν.

• bending

„bending = tension + compression"





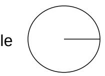
$$F = 3E \cdot \frac{\Theta}{l^3} \cdot s$$

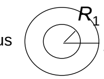
Θ — surface moment of inertia

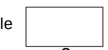
s: static deflection

Stiffness of the body (bending)

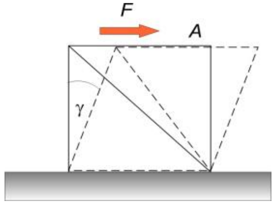
Cross-section e.g.:

circle  R $\Theta = \frac{\pi}{4} \cdot R^4$

annulus  R_1 R_2 $\Theta = \frac{\pi}{4} \cdot (R_2^4 - R_1^4)$

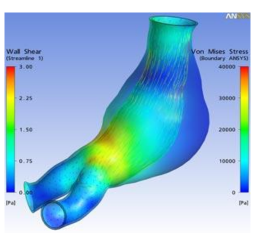
rectangle  b a $\Theta = \frac{1}{12} ab^3$

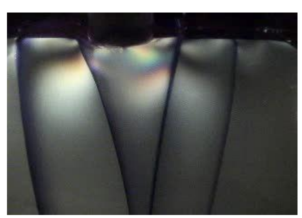
• shearing



$$\sigma = G\gamma$$

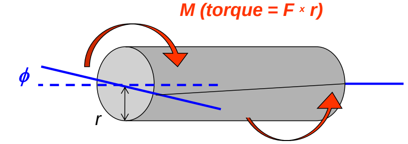
$$G = \frac{E}{2(1+\nu)}$$ shear modulus



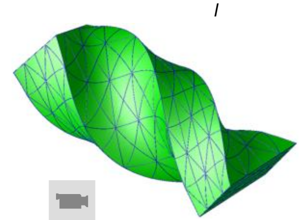


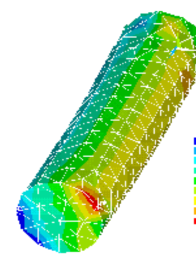
• twisting (torsion)

M (torque = F × r)



$$M = G\frac{r^4\pi}{2l}\phi$$





Summary:

Hooke's law:

	for material	for body
• tension/compression	$\sigma = E \cdot \varepsilon$	$F = E \cdot \frac{A}{l} \Delta l$
• shear	$\sigma = G\gamma$	$F = 2G \cdot \frac{A}{L^3} \cdot \Delta L$
• bending		$F = 3E \cdot \frac{\Theta}{l^3} \cdot s$
• twisting (torsion)		$M = G\frac{r^4 \pi}{2l}\phi$

E — elastic (Young's) modulus [E] = Pa

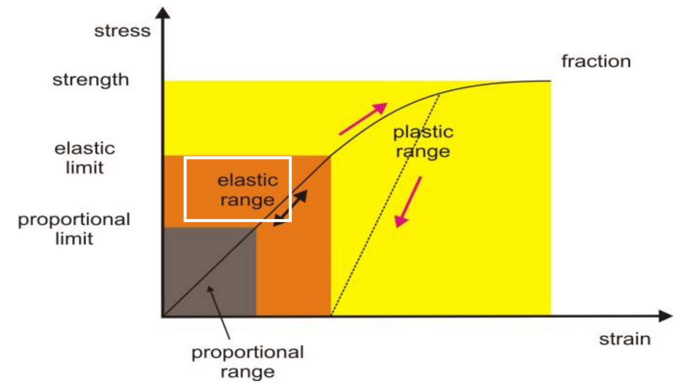
ν — Poisson's ratio [ν] = 1

G — shear modulus [G] = Pa

Θ — surface moment of inertia

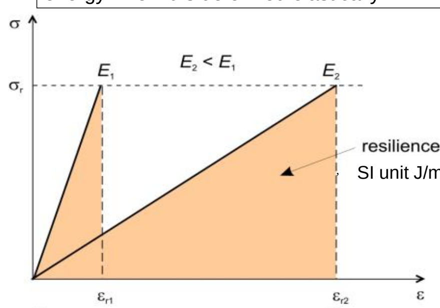
$$G = \frac{E}{2(1+\nu)}$$

Stress-strain diagram



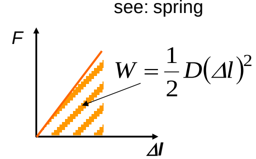
Elastic behavior (to elastic limit)

***resilience* (w_r):** property of a material to absorb energy when it is deformed elastically.



Elastic strain recovery (maximum elastic strain)

see: spring



$$W = \frac{1}{2} D (\Delta l)^2$$

$$w_r \approx \frac{1}{2}\sigma_r \varepsilon_r = \frac{1}{2} E \varepsilon_r^2 = \frac{1}{2E}\sigma_r^2$$

elastic energy:

	for material	for body
• tension/compression	$w_r = \frac{1}{2} E \cdot \varepsilon^2$	$W_r = \frac{1}{2} E \cdot \frac{A}{l} \Delta l^2$
• bending		$W_r = \frac{1}{2} 3E \cdot \frac{\Theta}{l^3} \cdot s^2$

remark: „elastic" =
- small E (large $1/E$)
- large elastic strain recovery
- large resilience