orthodontics

conservative dentistry

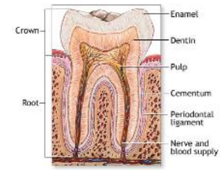
prosthetic dentistry

# Physical basis of dental material science 7.

Mechanical properties 1.



## Structure




enamel: strong, hard and resistant
dentin: less hard and porous
pulp: soft living tissue

embedding: cementum and periodontal ligandum
elastic, but stable

pottery

base material:
porous and less hard

glaze: strong, hard and resistant



## Other properties

thermal behavior
(large change in the mouth)

a few °C

60-80 °C

optical properties
(aesthetics)

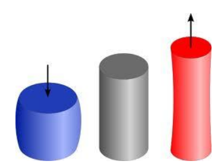


## Effect of the force

If motion is possible:
**displacement**

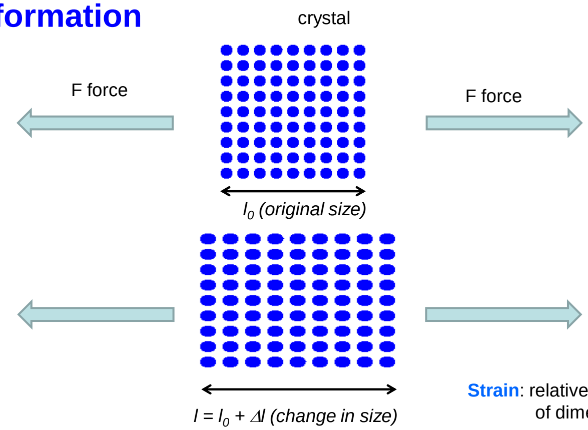
e.g.: orthodontics

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!

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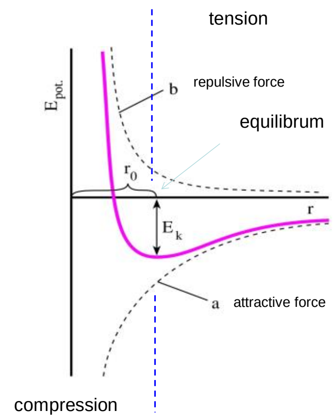
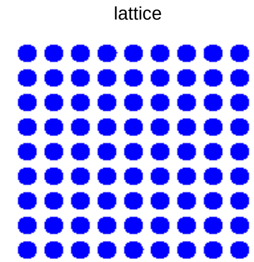
# Internal forces compensate external foces




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

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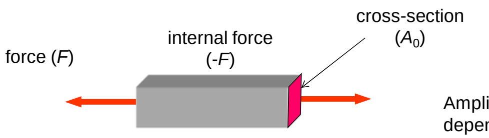
# Characterization of the load:




Amplitude of the internal force depends on the cross-section!

**stress($\sigma$):**

unit: Pa (like the pressure)

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

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

⇨ Internal stresses

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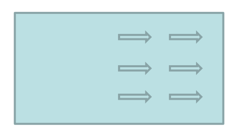
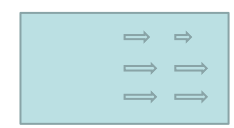
# Stress distribution





Homogenous distribution:

The stress is same in each point of the object.
(ideal case: no such matter)

Inhomogenous distribution:

Weaker segment of the object may result unexpected consequences.
Important information!

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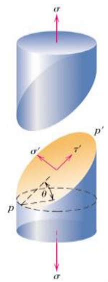
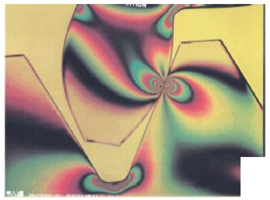
# Examination of the stress distribution

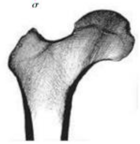


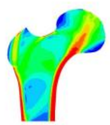

- **Experimental methods**: optical measurments

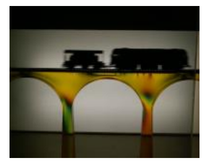


e.g. :
usage of polarized light

(observation of anistropy produced by the force)





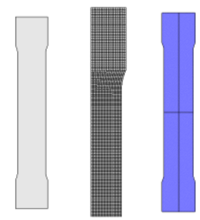


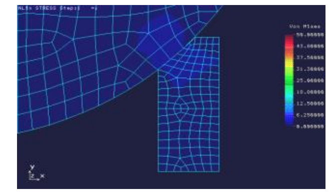


- **Theoretical method**:

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

advantage: if the test is impossibel we can modelize.
disadvantage: model is not the object!

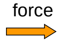






# Deformations (an object gets changed due to force)

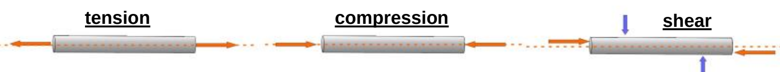
force ⟶ deformation



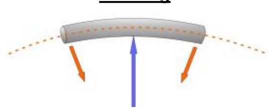
**tension** (object is streched)

**compression** (object is shortened)

**shear**



**bending**



**torsion** (object is twisted)

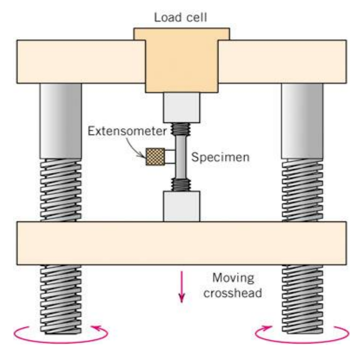
(arrows = forces – direction and magnitude)

**Isotrope material**: properties are independent from the direction.

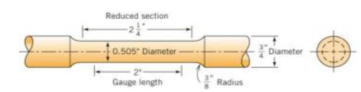


# Physical test methods

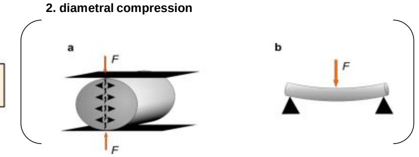
**1. tension test**




**standard body**



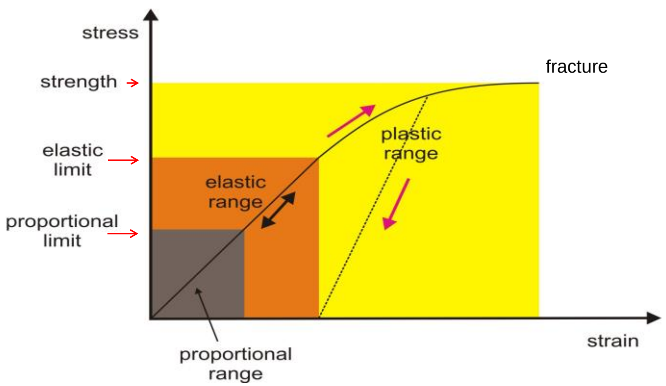

**2. diametral compression**




**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



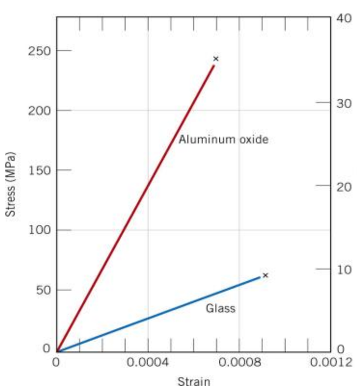



# Testing materials



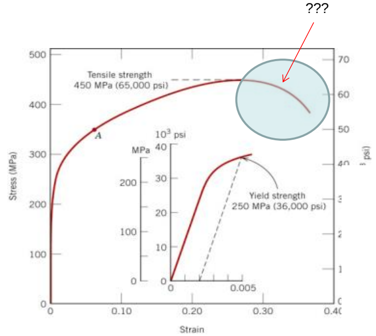
**examples:**

**ceramics**




**metals, e.g. brass**

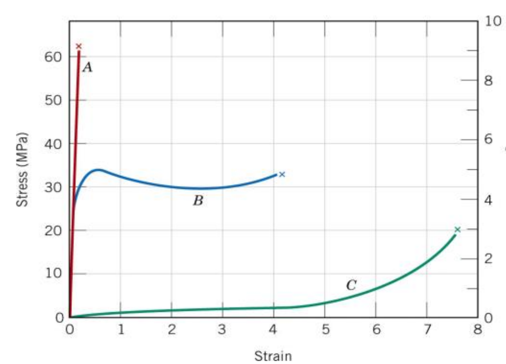
???



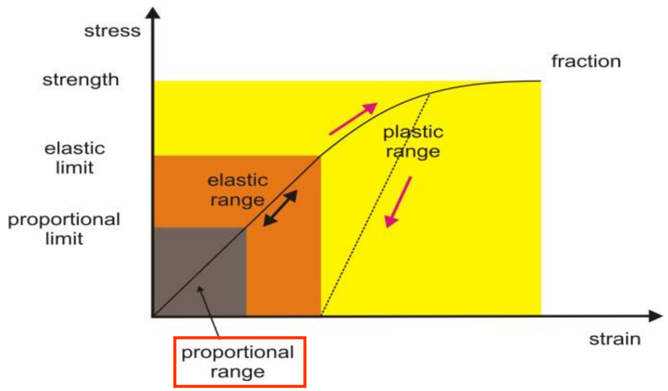



A: hard (glass -like)
B: semi-crystalline
C: rubber

# polymers



## Stress-strain diagram





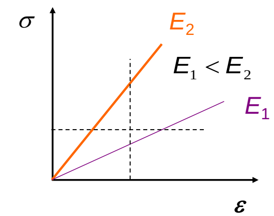

## Elasticity (to the proportional limit)

- tension/compression

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

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

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

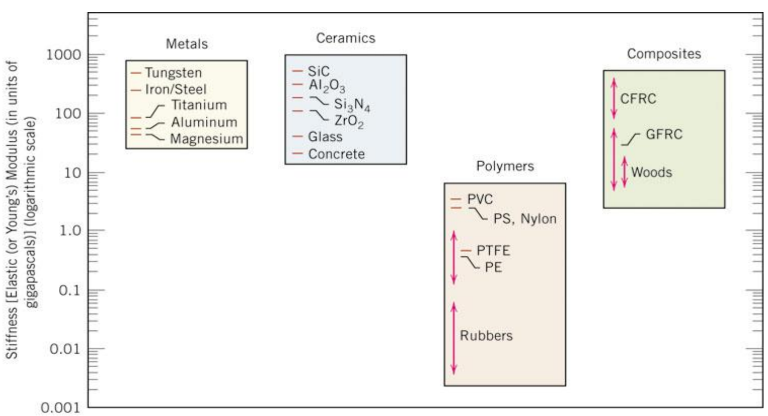



$E$ — resistance against the tension or compression, **stiffness**

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

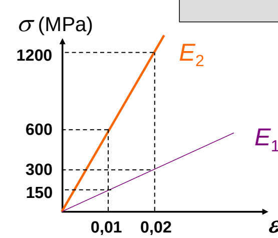


## Stiffness of different materials

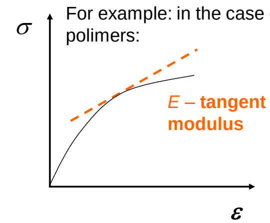





E.g.:




For example: in the case of many polimers:

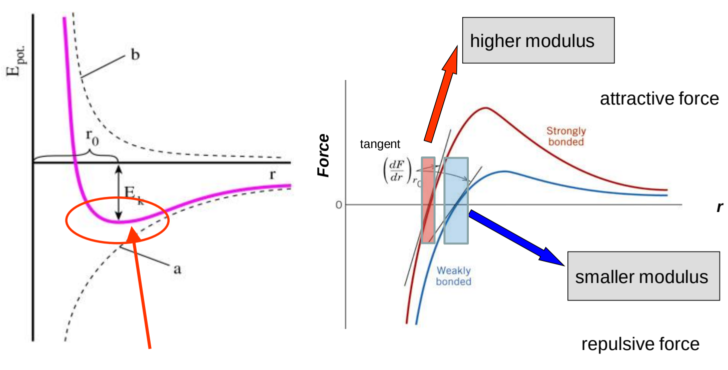



**Stiffnes of a few dental materials:**

| 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 |

**reminder:**

atomic interactions

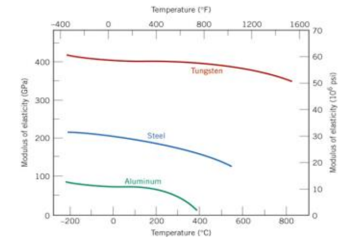



**near parabolic profile → it is characteristic for a linear force law.**

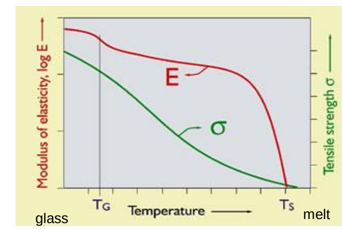


## Influence of the temperature:

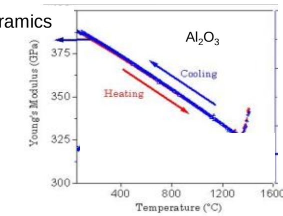
metals

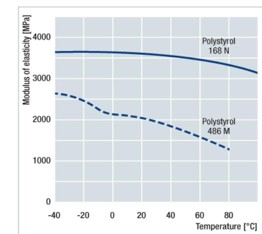



semicrystallic polimers




ceramics







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

Material parameter! **Stiffness of the material**

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

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

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.

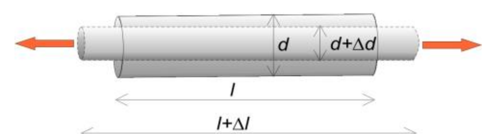
(See spring: $D$ — spring constant)



## lateral changing of the size:

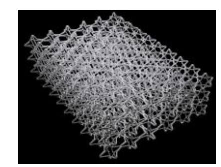
Auxetic materials (negative Poisson's ratio):

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



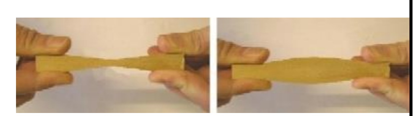

$$\frac{\Delta d}{d} = -\nu \frac{\Delta l}{l}$$

$\nu$ — **Poisson's ratio (no unit)**



e.g.

| material | $\nu$ |
|---|---|
| Enamel | 0.33 |
| Dentin | 0.31 |
| amalgam | 0.31 |
| PDL | 0.45 |
| polimers | 0.40–0.50 |



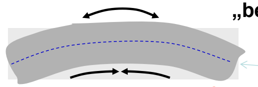
(„normal material")

**The elastic property of a homogene, isotrope material is exactly determined by $E$ and $\nu$.**

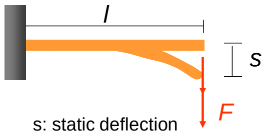
- **bending**

(orthodontics)

**„bending = tension + compression"**




„Neutral surface"



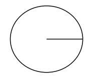

s: static deflection

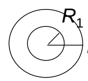
$$F = 3E \cdot \frac{\Theta}{l^3} \cdot s$$

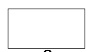
**$\Theta$ — surface moment of inertia**

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

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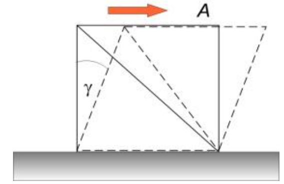
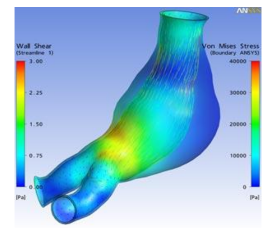
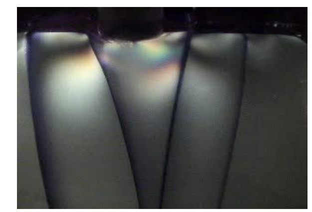
- **shearing**




$$\sigma = G\gamma$$

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





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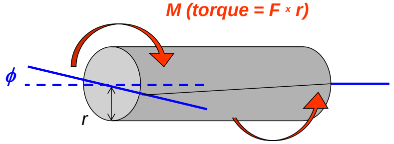
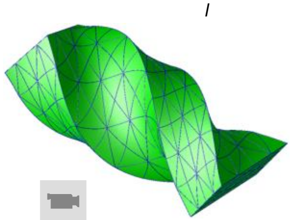
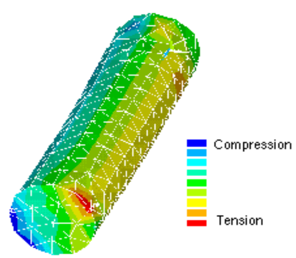
- **twisting (torsion)**

*M (torque = F × r)*




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



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**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

$\nu$ — Poisson's ratio $[\nu] = 1$

$G$ — shear modulus $[G]$ = Pa

$\Theta$ — surface moment of inertia

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

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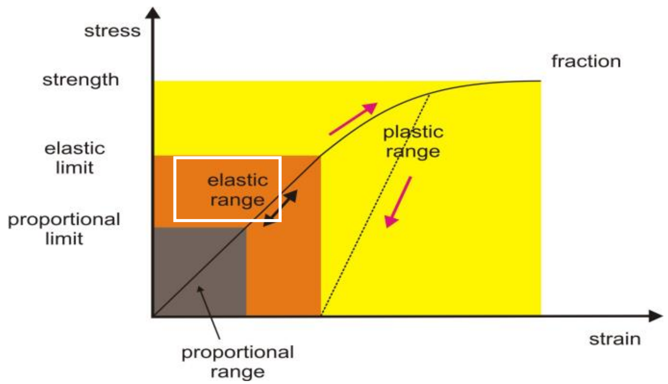
## Stress-strain diagram

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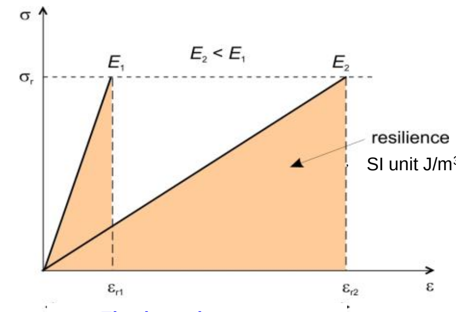
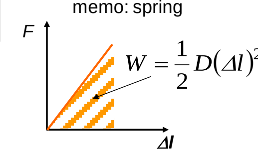
## Elastic behavior (to elastic limit)

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




**Elastic strain recovery (maximum elastic strain)**

memo: spring




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

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

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**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

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