


Physikalische Grundlagen der zahnärztlichen Materialkunde 7.

Mechanische Eigenschaften 1.

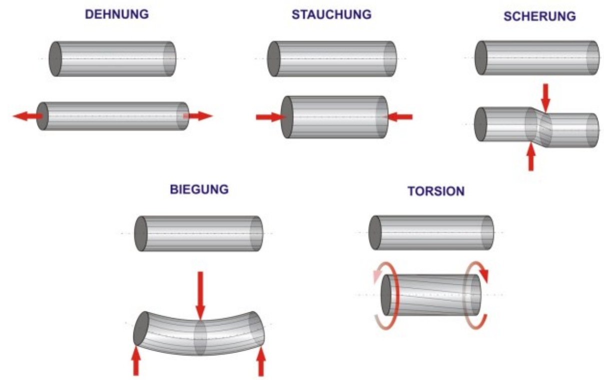
Schwerpunkte:
- ❖ Elastische Formänderungen
- ❖ Steifigkeit und ihr Zusammenhang mit der Bindungsenergie
- ❖ Geometrische Faktoren bei der Steifigkeit einer Körpers
- ❖ Elastizität

Kapitel des Lehrbuches: 14-15

Hausaufgaben: 4. Kapitel: 1, 2, 4-6, 9, 11, 14, 16, 17, 24

Deformationen (Verformungen)

Kraftwirkung ⟹ Verformung (Deformation)



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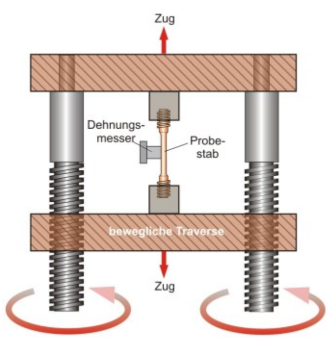
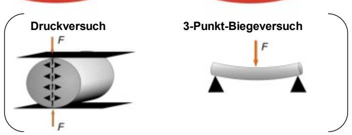
Test

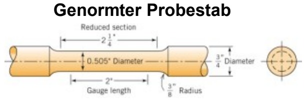




Die Ergebnisse sind beeinflusst durch:

- Deformationstyp (Zug, ...)
- Geometrie des Probestabes

Genormter Probestab



- Zeitlicher Verlauf des Beanspruchung
  - statisch
  - dynamisch
- Temperatur

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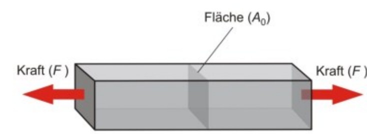
Zugversuch



Spannung (σ):

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

Technische (nominelle) Spannung!

Dehnung/Stauchung (ε):

Relative Formänderung → relative Längenänderung:

$$\varepsilon = \frac{\Delta l}{l_0} \qquad [\varepsilon] = 1$$

nominelle Dehnung!

Beim Druck/Stauchung: negatives Vorzeichen.

⟹ Innere Spannungen!

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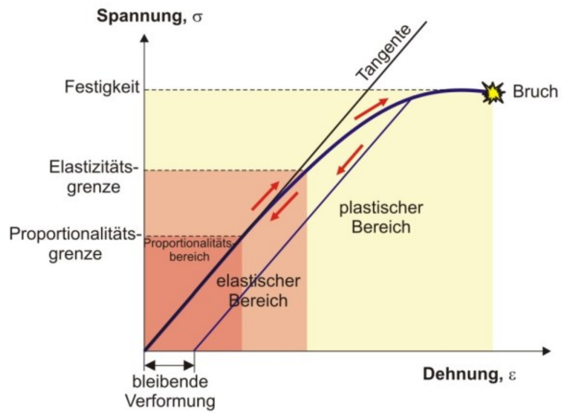
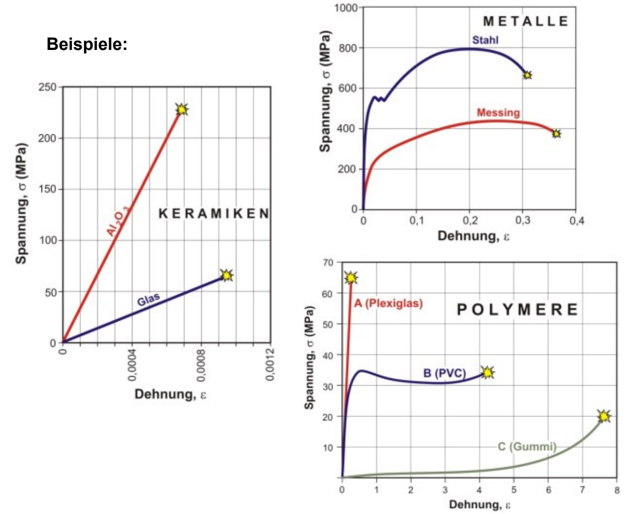
Belastungsdiagramm

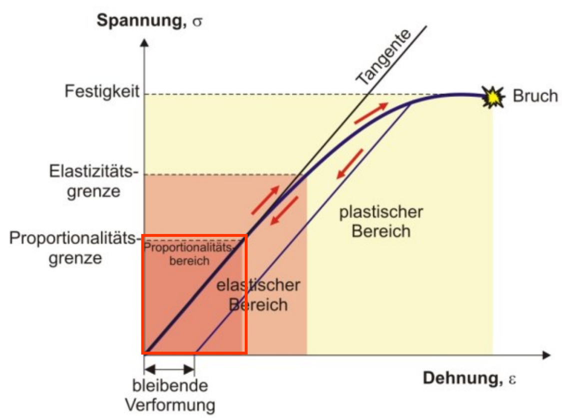
Spannungs-Dehnungs-Diagramm



Beispiele:



Belastungsdiagramm



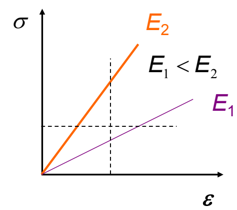
Elastische Verformung
(Proportionalitätsbereich)

1. Zug/Druck (Dehnung/Stauchung)

Hookesches Gesetz: $\sigma = E \cdot \varepsilon$

E — **Elastizitätsmodul** (Young-Modul)

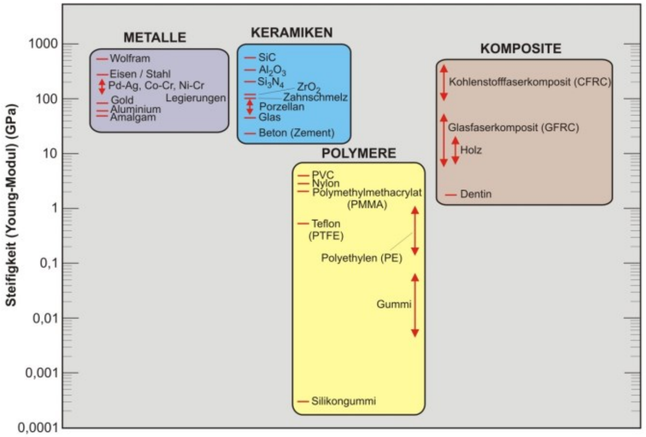
$[E]$ = Pa



E — Widerstand gegen Verlängerung, **„Steifigkeit eines Stoffes"**

$1/E$ — Fähigkeit für Verlängerung, **„Nachgiebigkeit eines Stoffes"**

Steifigkeit (Young-Modul)



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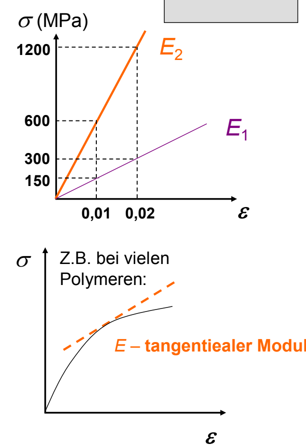
Beispiel:



Einige Steifigkeitswerte:

Material	*E* (GPa)
Zahnschmelz	≈ 100
Dentin	≈ 15
Stahl	200-230
Amalgam	50-60
Gold	79
Goldlegierungen	75-110
Pd-Ag-Legierungen	100-120
Co-Cr-Legierungen	120-220
Ni-Cr-Legirungen	140-190
Glas	60-90
Keramiken	60-130
Porzellan	60-110
PMMA (Polymethylmethacrilat)	2,4-3,8
Silikon	≈ 0,0003

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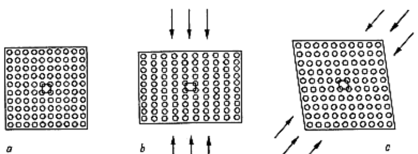
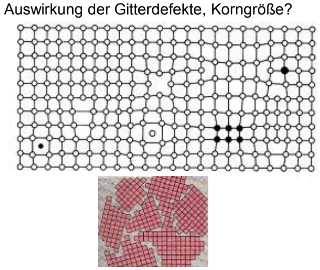
Elastische Verformung auf dem atomaren Niveau



Auswirkung der Gitterdefekte, Korngröße?



Der Young-Modul (*E*) und die Poisson-Zahl (μ) (s. später)

sind nicht empfindlich gegen Gitterdefekte.

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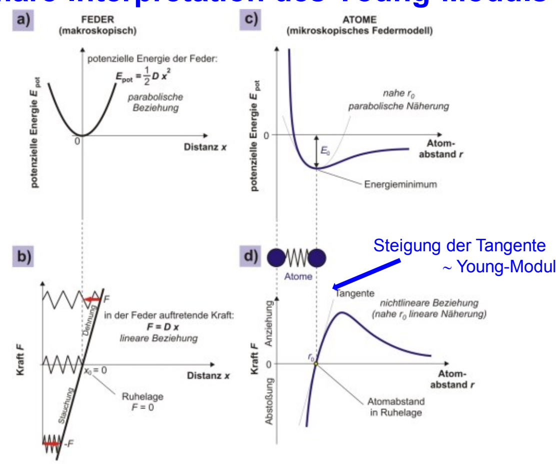
Atomare Interpretation des Young-Moduls



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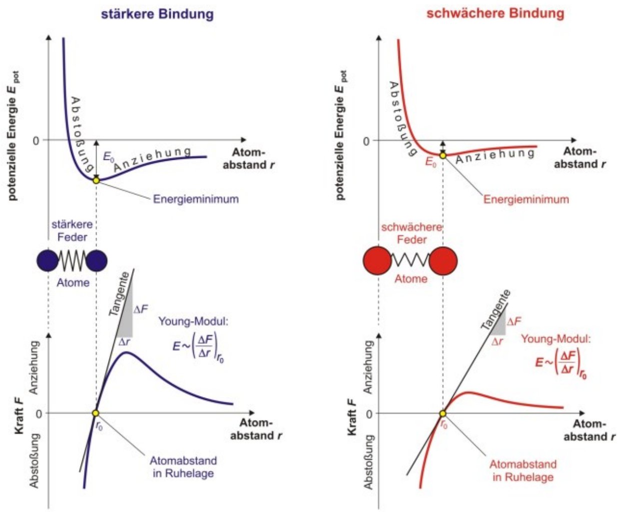

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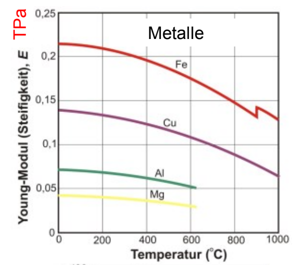
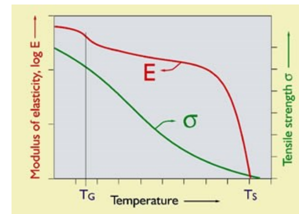
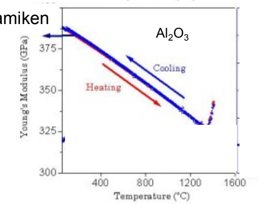
Bei Erwärmung:

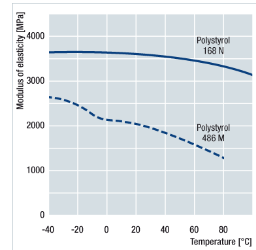


Teilkristalline Polymere



Keramiken





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Steifigkeit eines Körpers

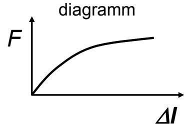
$$\sigma = E \cdot \varepsilon$$

Materialkoeffizient!
„Steifigkeit des Materials"

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

Körpereigenschaft
(Material + Geometrie)!
Steifigkeit
(Dehnsteifigkeit)

Belastungs-
diagramm



„Steifigkeit des Materials" : die zur einheitlichen relativen Längenänderung notwendige Spannung

Steifigkeit: die zur einheitlichen absoluten Längenänderung notwendige Kraft

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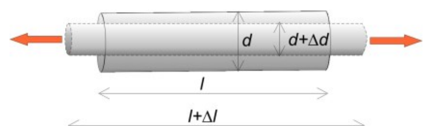
Querkontraktion/dehnung:



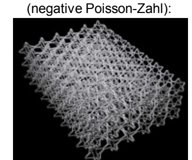
$$\frac{\Delta d}{d} = -\mu \frac{\Delta l}{l}$$ μ — **Poisson-Zahl** $[\mu] = 1$

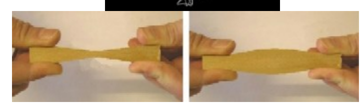
(Querkontraktionszahl, Querdehnungszahl)

Z.B.

Material	μ
Zahnschmelz	0,33
Dentin	0,31
Amalgam	0,31
PDL	0,45
Polymere	0,40–0,50

Auxetische Materialien
(negative Poisson-Zahl):





Elastische Formänderungen von homogenen isotropen Materialien sind durch E und μ völlig bestimmt.

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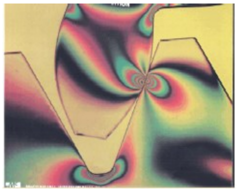
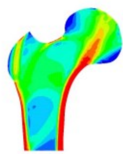
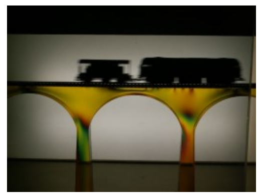
Untersuchung der Spannungsverteilung

- **experimentell**: Spannungsoptik



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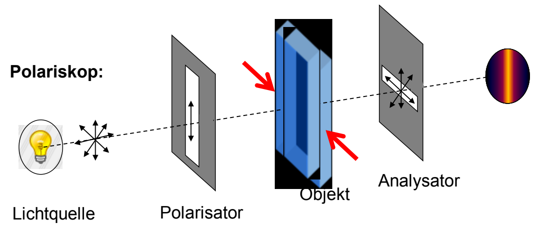
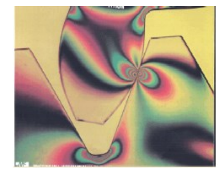


→ Spannungsverteilung



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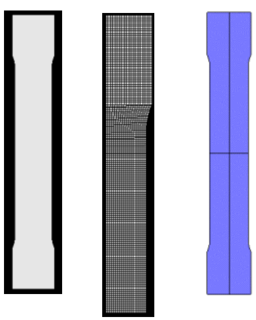
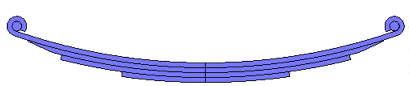
- **rechnerisch**: Finite-Elemente-Methode (finite element method)





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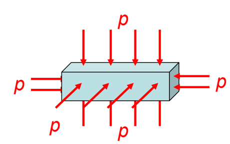
2. Kompression




$$p=\frac{E}{3(1-2\mu)}\frac{\Delta V}{V}$$

K : Kompressionsmodul
Volumenelastizitätskoeffizient (Pa)

$$\frac{\Delta V}{V}=\frac{3(1-2\mu)}{E}p$$

κ : Kompressibilität (1/Pa)

Material	κ (1/GPa)
Luft	7650
Wasser	0,45
Aluminium	0,009

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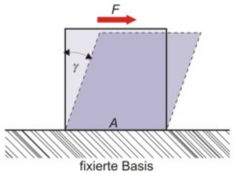
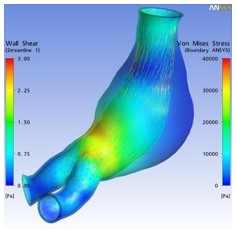
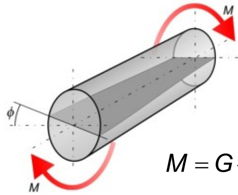
3. Scherung



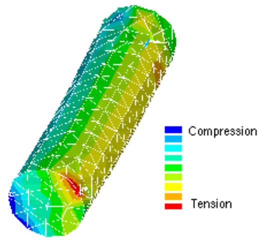
$$\sigma = G\gamma$$



4. Torsion

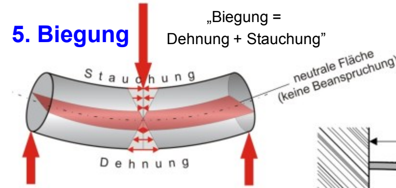


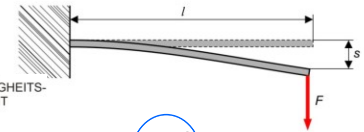
$$M = G\frac{r^4\pi}{2l}\phi$$

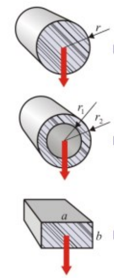


5. Biegung

„Biegung = Dehnung + Stauchung"







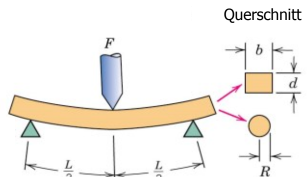
QUERSCHNITT	FLÄCHENTRÄGHEITS-MOMENT
Kreis	$\Theta = \frac{\pi}{4} \cdot r^4$
Kreisring	$\Theta = \frac{\pi}{4} \cdot (r_2^4 - r_1^4)$
Rechteck	$\Theta = \frac{1}{12} ab^3$

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

Biegesteifigkeit

Θ — Flächenträgheitsmoment

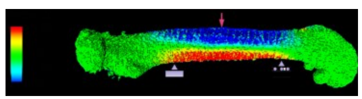
3-Punkt-Biegeversuch

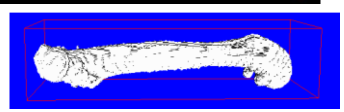


$$\sigma = \frac{Mc}{I}$$

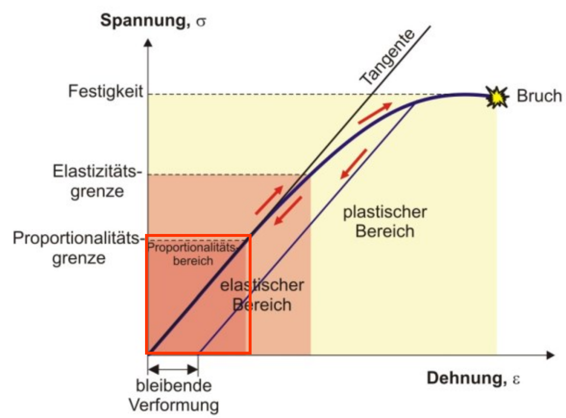
M = Biegemoment
c = Abstand neutrale Fläche-Rand
I = Flächenträgheitsmoment
F = Kraft

	M	c	I	σ
Rechteck	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Kreis	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$



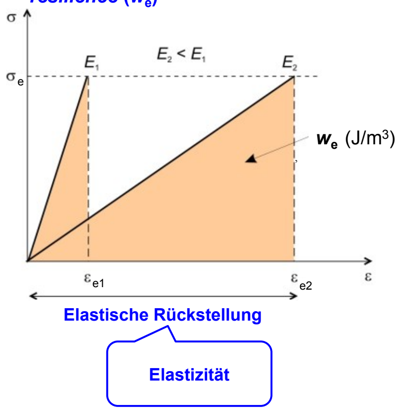


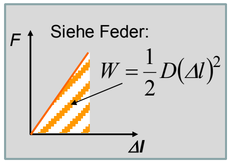
Belastungsdiagramm



Weitere elastische Kenngrößen

Spezifische elastische Verformungsarbeit; *resilience* (w_e)





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

$$w_e \approx \frac{1}{2}\sigma_e \varepsilon_e =$$

$$= \frac{1}{2} E \varepsilon_e^2 = \frac{1}{2E}\sigma_e^2$$

Nächste Vorlesung: Kapitel 16