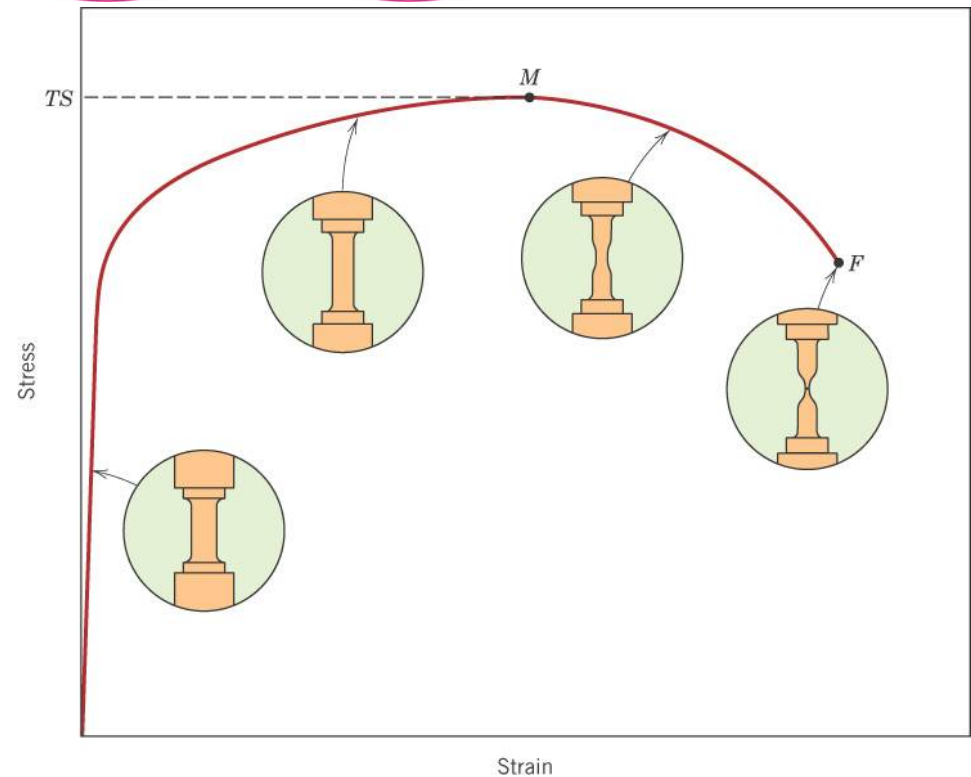
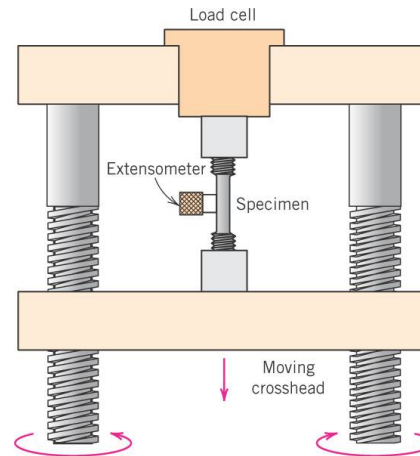
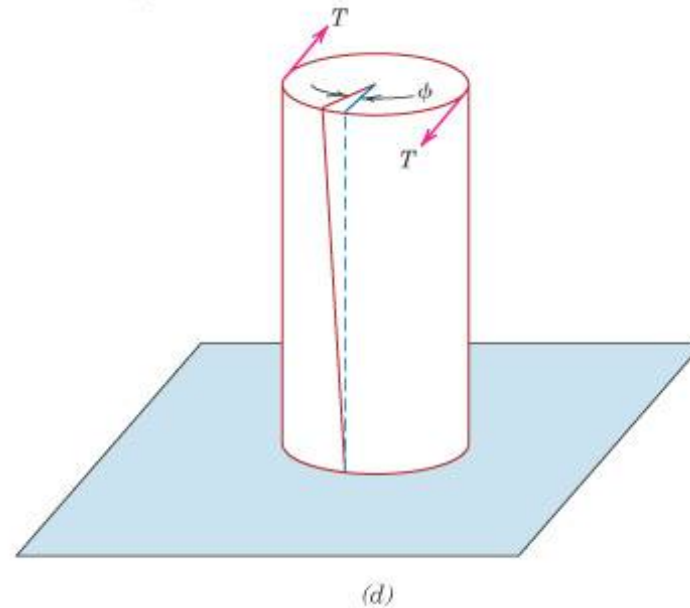
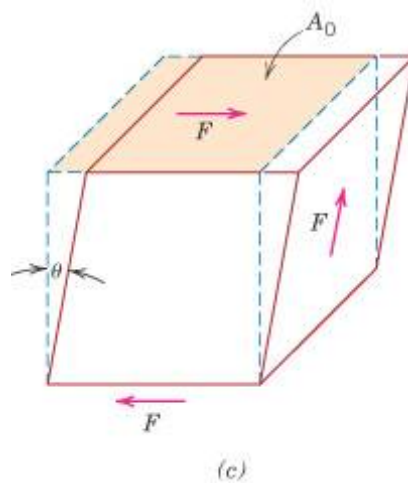
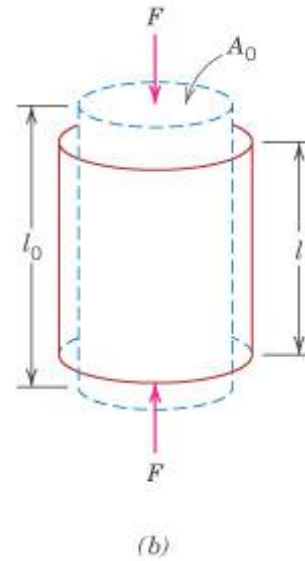
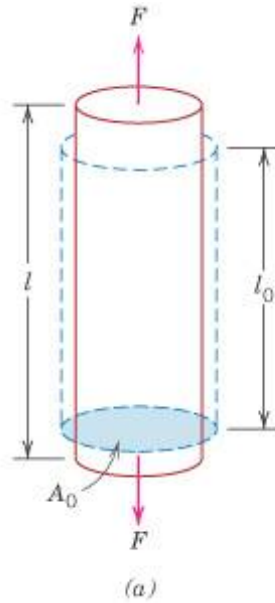


Chapter 7: (Mechanical Properties)

- Tensile & Hardness Testing;
- Macroscopic Behavior;
- Elastic Deformation;
- Elastic Modulus;
- Proportional Limit;
- Poisson's Ratio;
- Plastic deformation;
- Yielding and Yielding Strength;
- Tensile Strength;
- Fracture Strength;
- Ductility;
- Resilience;
- Toughness
- Property Variability;
- Design Safety Factors.



7.2 (Stress and Strain)



Common States of Stress

- **Simple tension:** cable

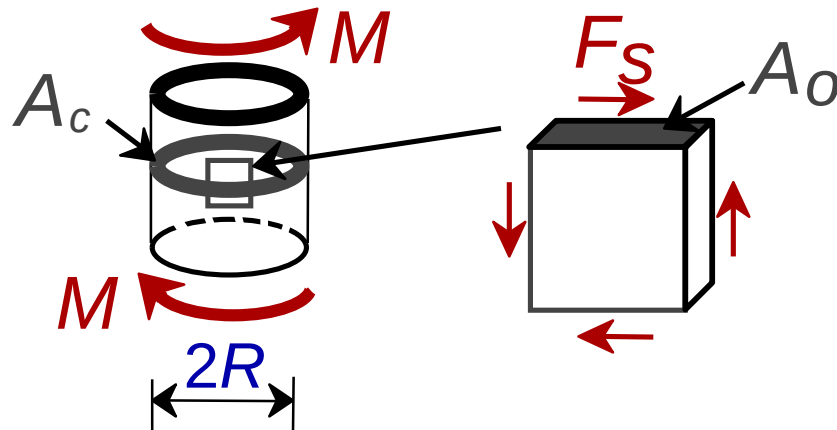


A_0 = cross sectional area (when unloaded)

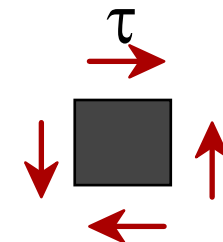
$$\sigma = \frac{F}{A_0}$$



- **Torsion** (a form of shear): drive shaft



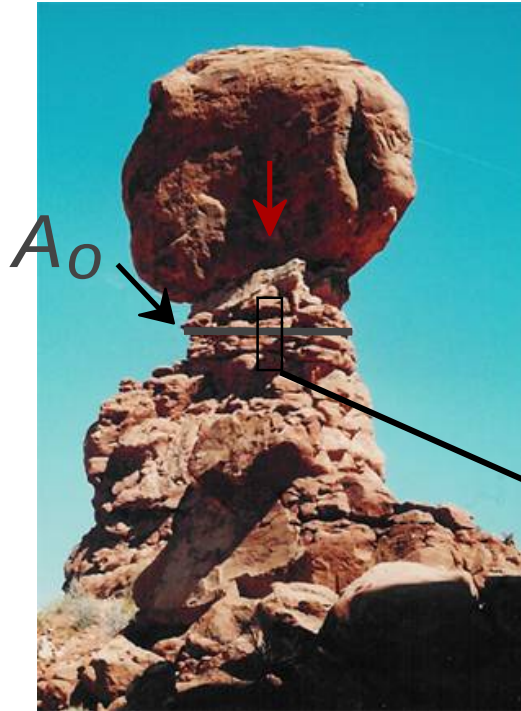
$$\tau = \frac{F_s}{A_0}$$



Note: $R \times \tau \times A_c = M$ here.

OTHER COMMON STRESS STATES (i)

- **Simple** compression:



Balanced Rock, Arches
National Park
(photo courtesy P.M. Anderson)



Canyon Bridge, Los Alamos, NM
(photo courtesy P.M. Anderson)

$$\sigma = \frac{F}{A_o}$$



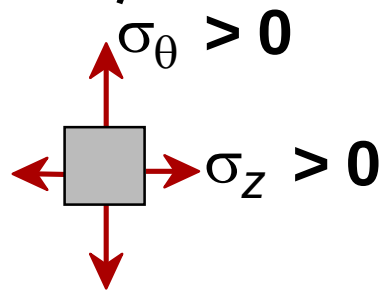
Note: compressive
structure member
($\sigma < 0$ here).

OTHER COMMON STRESS STATES (ii)

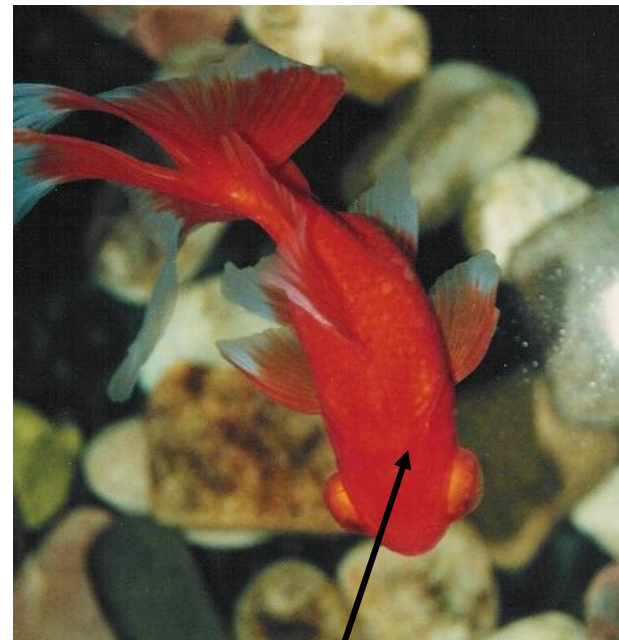
- **Bi-axial** tension:



Pressurized tank
(photo courtesy
P.M. Anderson)

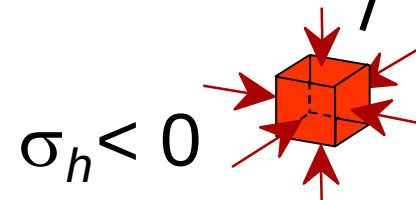


- **Hydrostatic** compression:



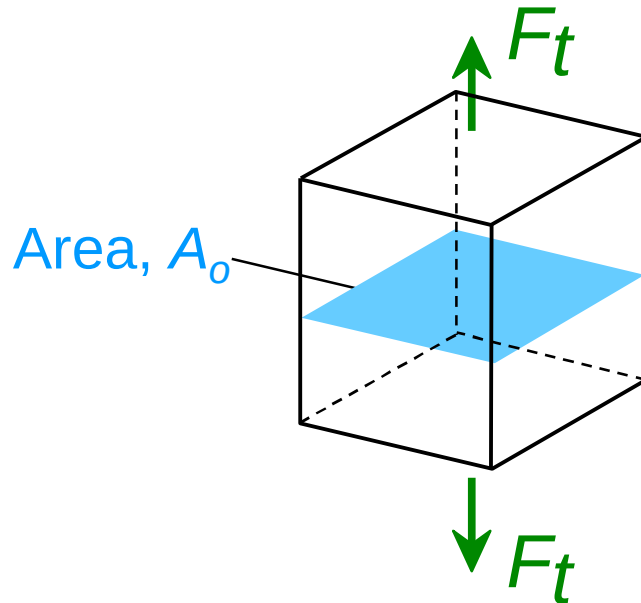
Fish under water

(photo courtesy
P.M. Anderson)



Engineering Stress

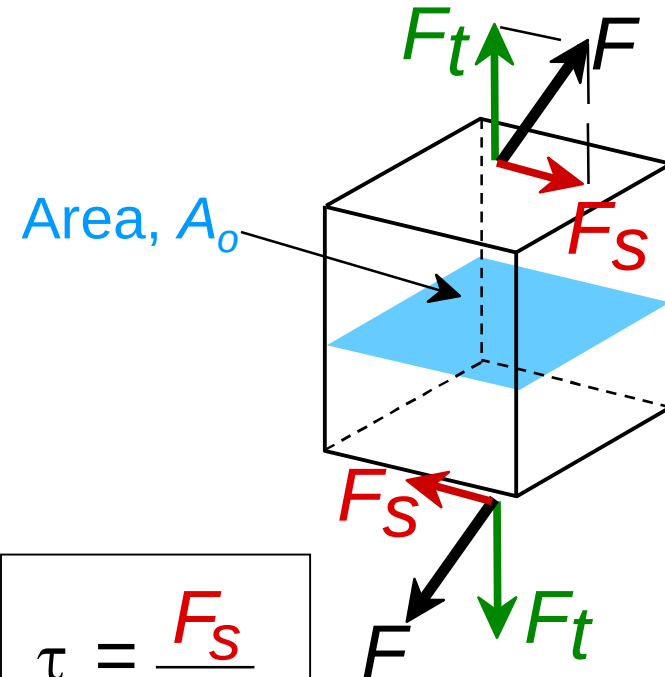
- Tensile stress, σ :



$$\sigma = \frac{F_t}{A_o} = \frac{\text{lb}_f}{\text{in}^2} \text{ or } \frac{\text{N}}{\text{m}^2}$$

original area
before loading

- Shear stress, τ :



$$\tau = \frac{F_s}{A_o}$$

$\therefore$ Stress has units:
 N/m^2 or lb_f/in^2

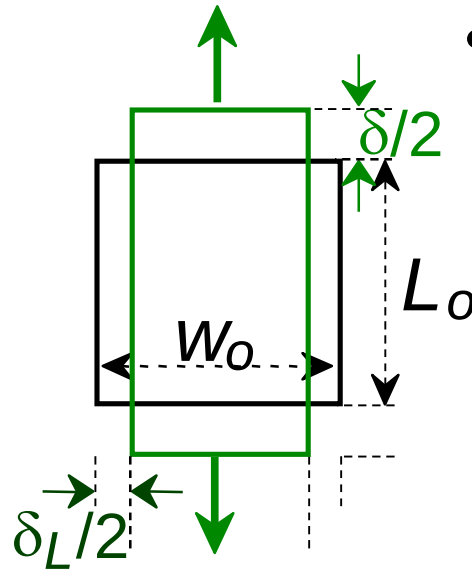
Engineering Strain

- **Tensile strain:**

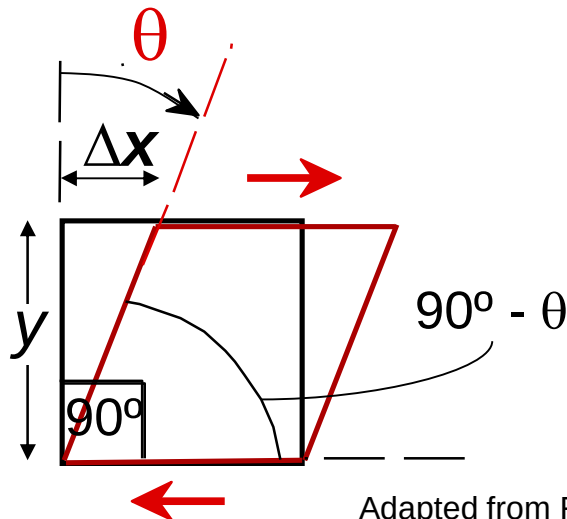
$$\varepsilon = \frac{\delta}{L_o}$$

- **Lateral strain:**

$$\varepsilon_L = \frac{-\delta_L}{W_o}$$



- **Shear strain:**



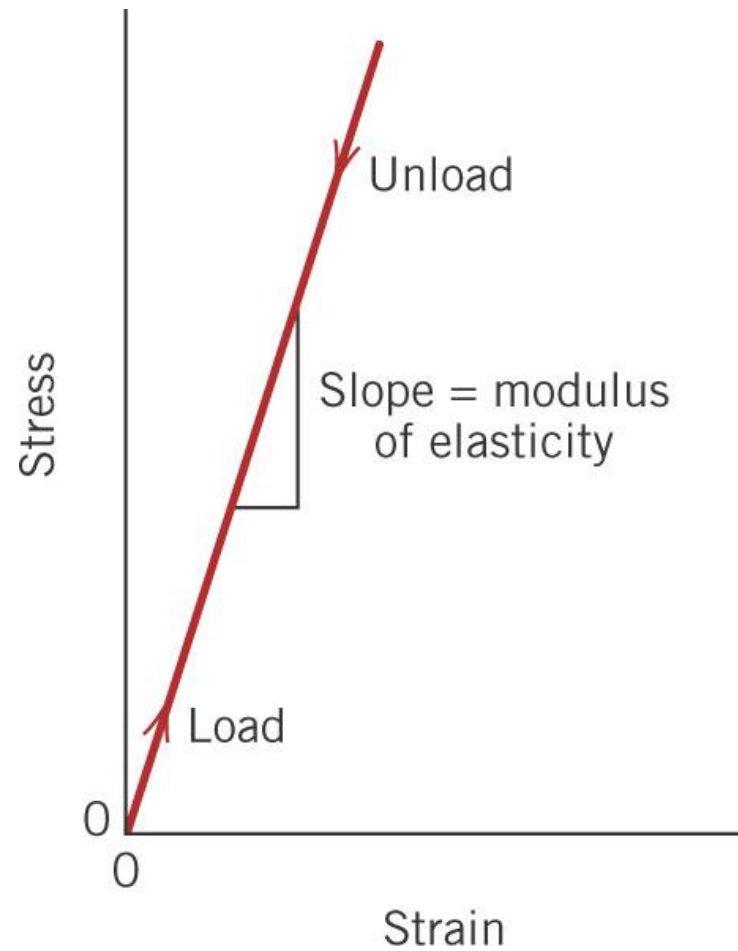
$$\gamma = \Delta x / y = \tan \theta$$

Strain is always dimensionless.

Adapted from Fig. 7.1 (a) and (c), Callister & Rethwisch 3e.

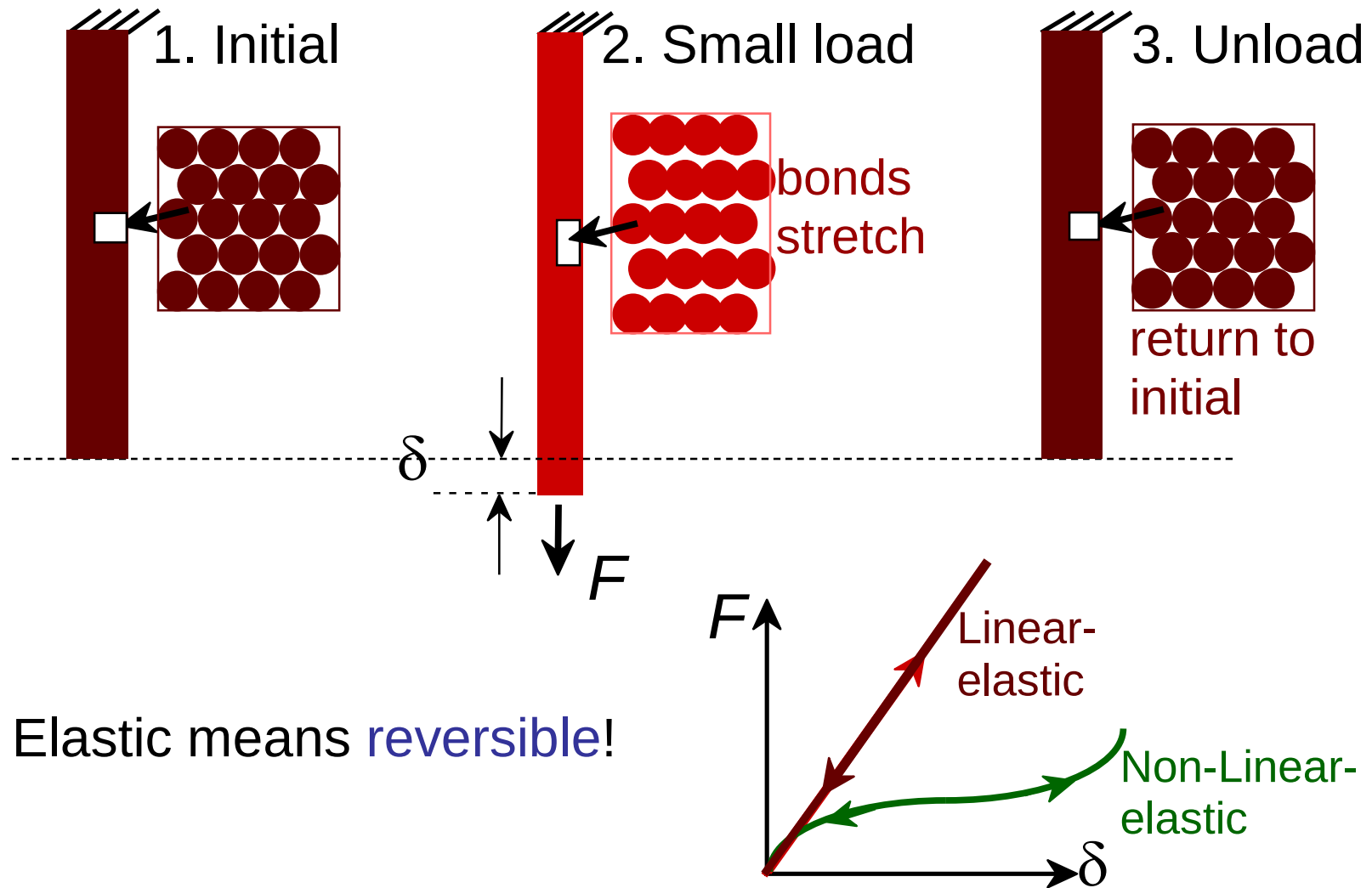
(Elastic Deformation)

7.3(Stress-Strain behavior)



c07f05

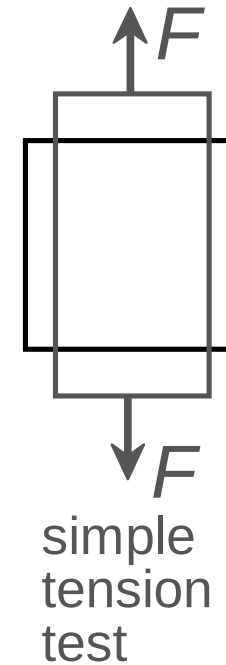
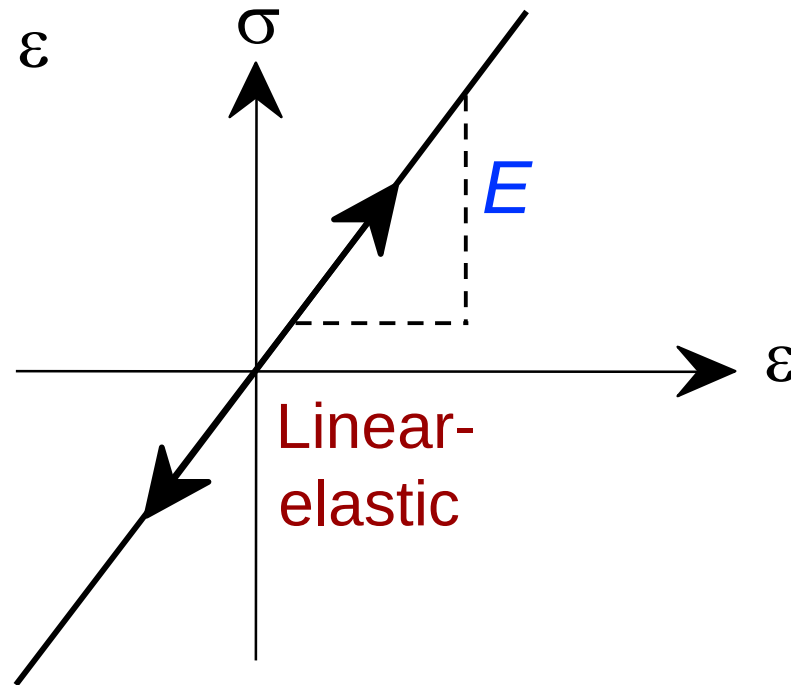
Elastic Deformation



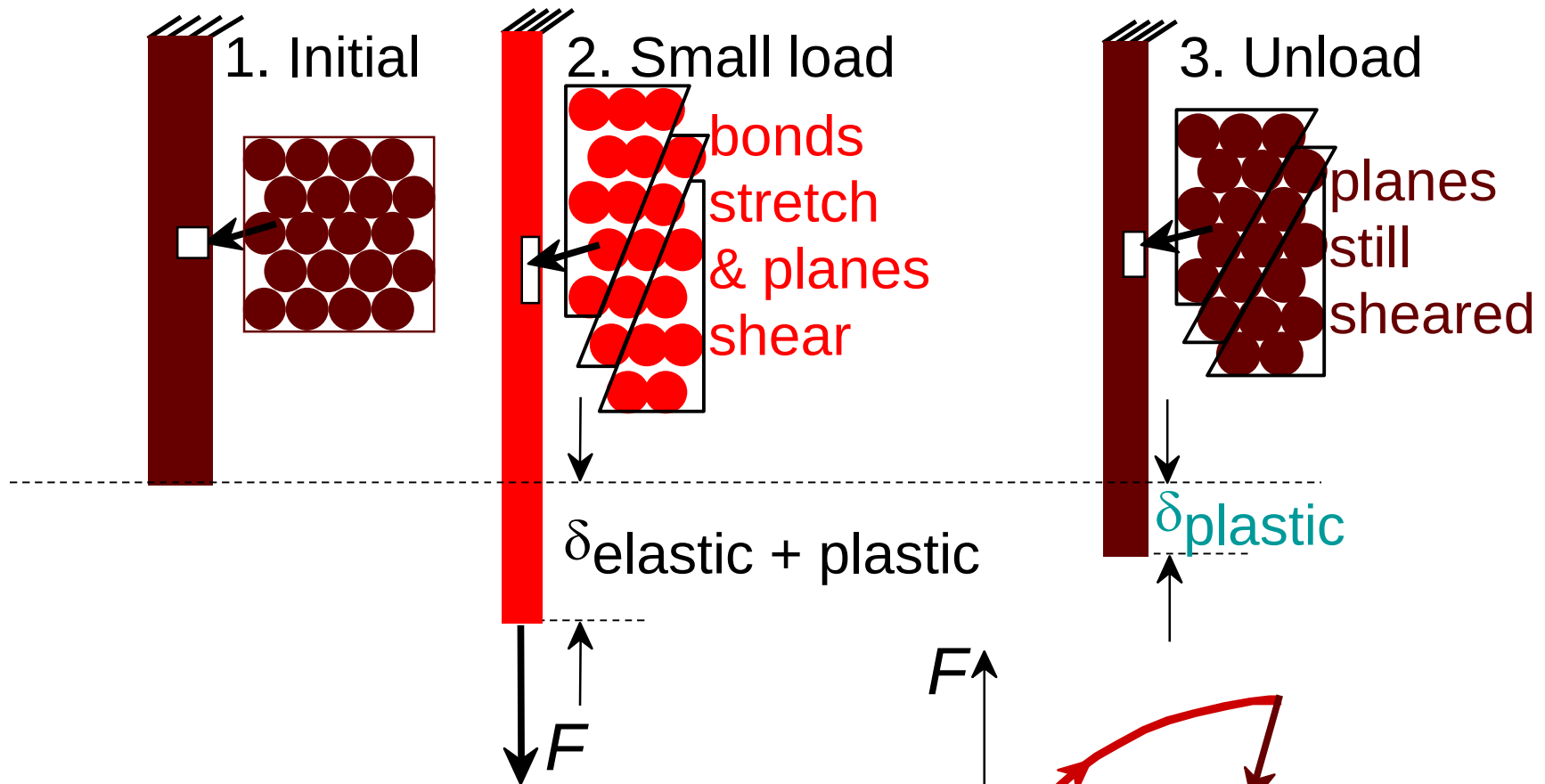
Linear Elastic Properties

- **Modulus of Elasticity, E :**
(also known as Young's modulus)
- **Hooke's Law:**

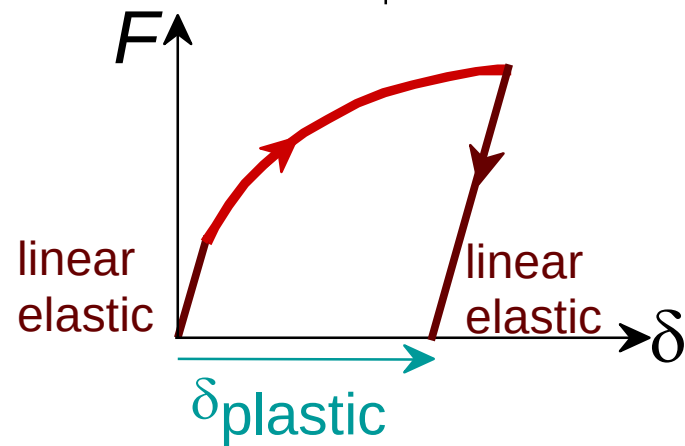
$$\sigma = E \varepsilon$$



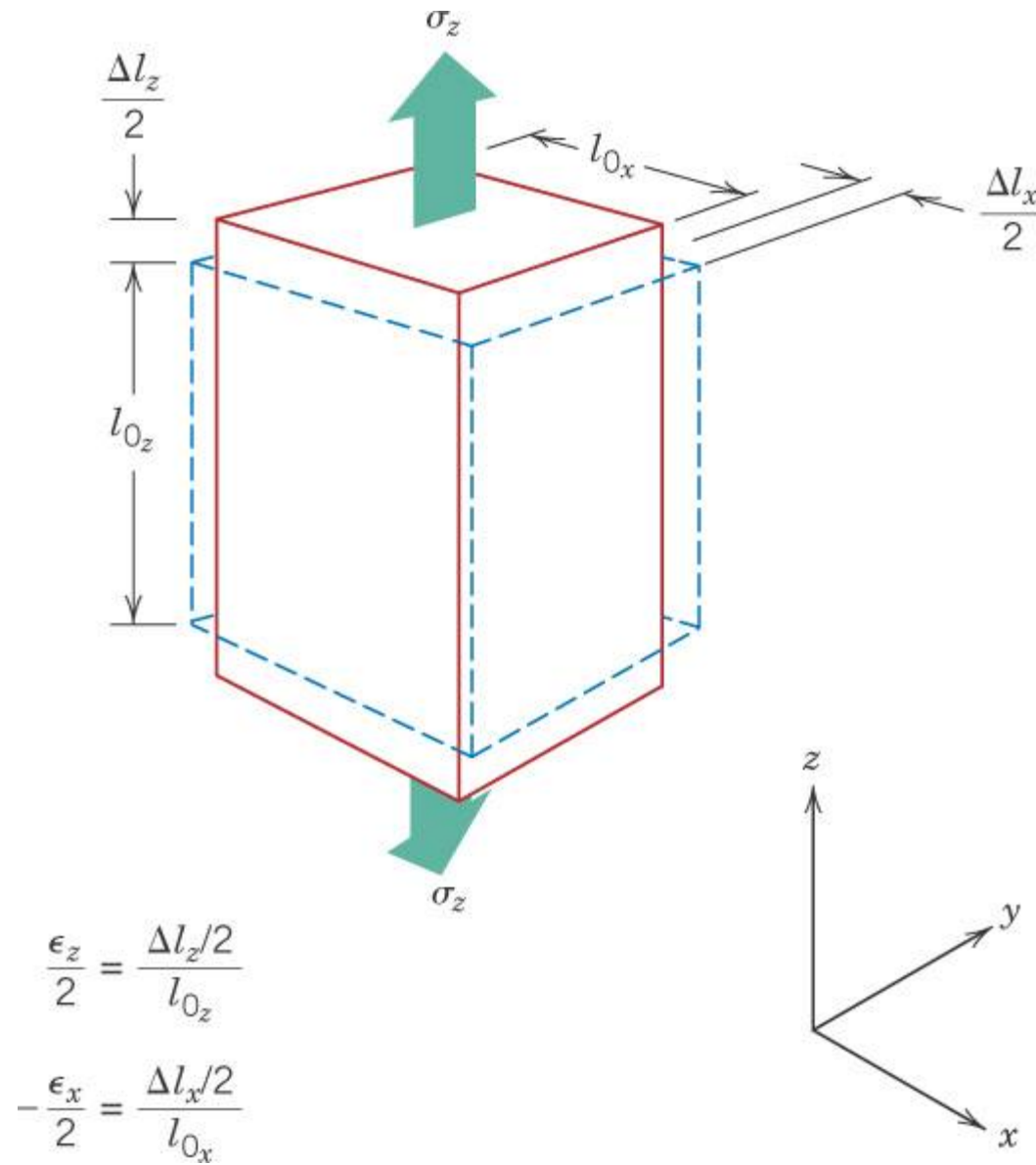
Plastic Deformation (Metals)



Plastic means **permanent**!



7.5(Poisson's Ratio)



c07f09

Poisson's Ratio, ν

- **Poisson's ratio, ν :**

$$\nu = -\frac{\varepsilon_L}{\varepsilon}$$

metals: $\nu \sim 0.33$

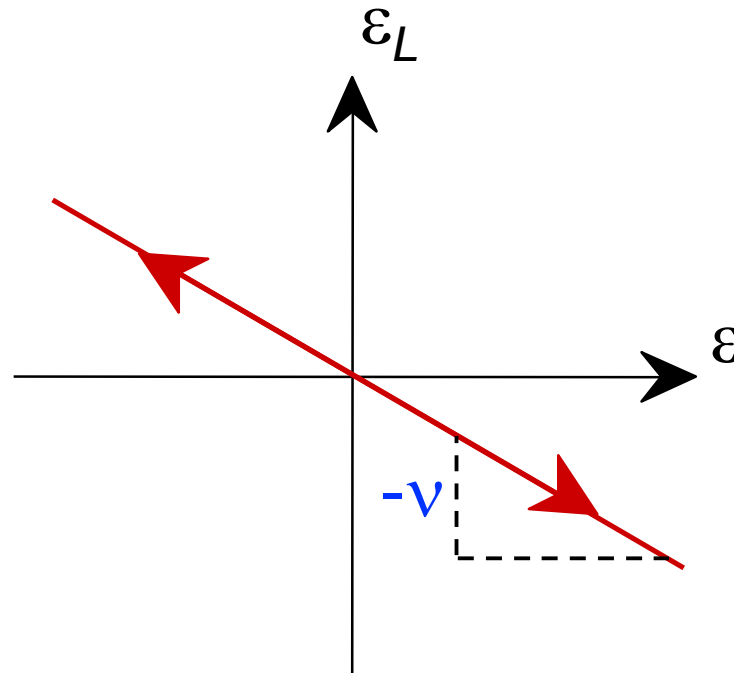
ceramics: $\nu \sim 0.25$

polymers: $\nu \sim 0.40$

Units:

E : [GPa] or [psi]

ν : Dimensionless



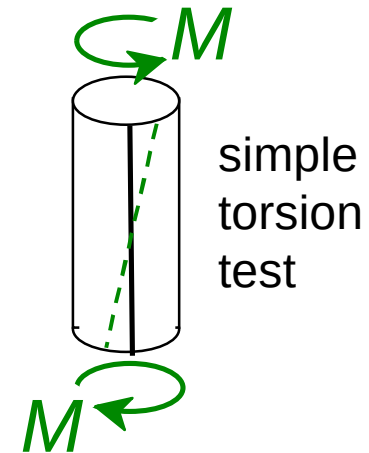
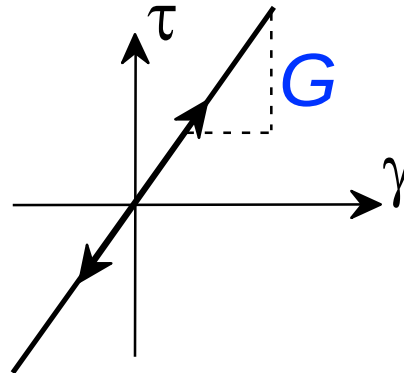
$\nu > 0.50$ density increases

$\nu < 0.50$ density decreases
(voids form)

Other Elastic Properties

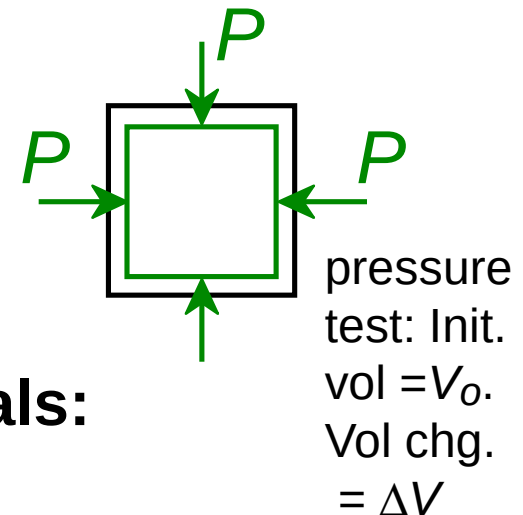
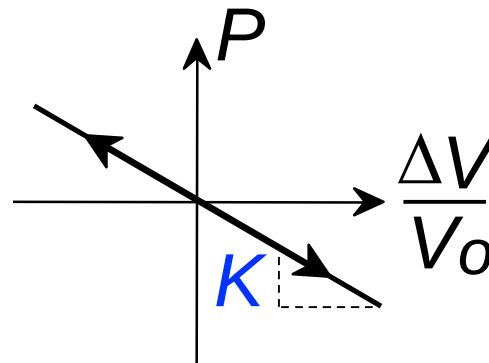
- Elastic Shear modulus, G :

$$\tau = G \gamma$$



- Elastic Bulk modulus, K :

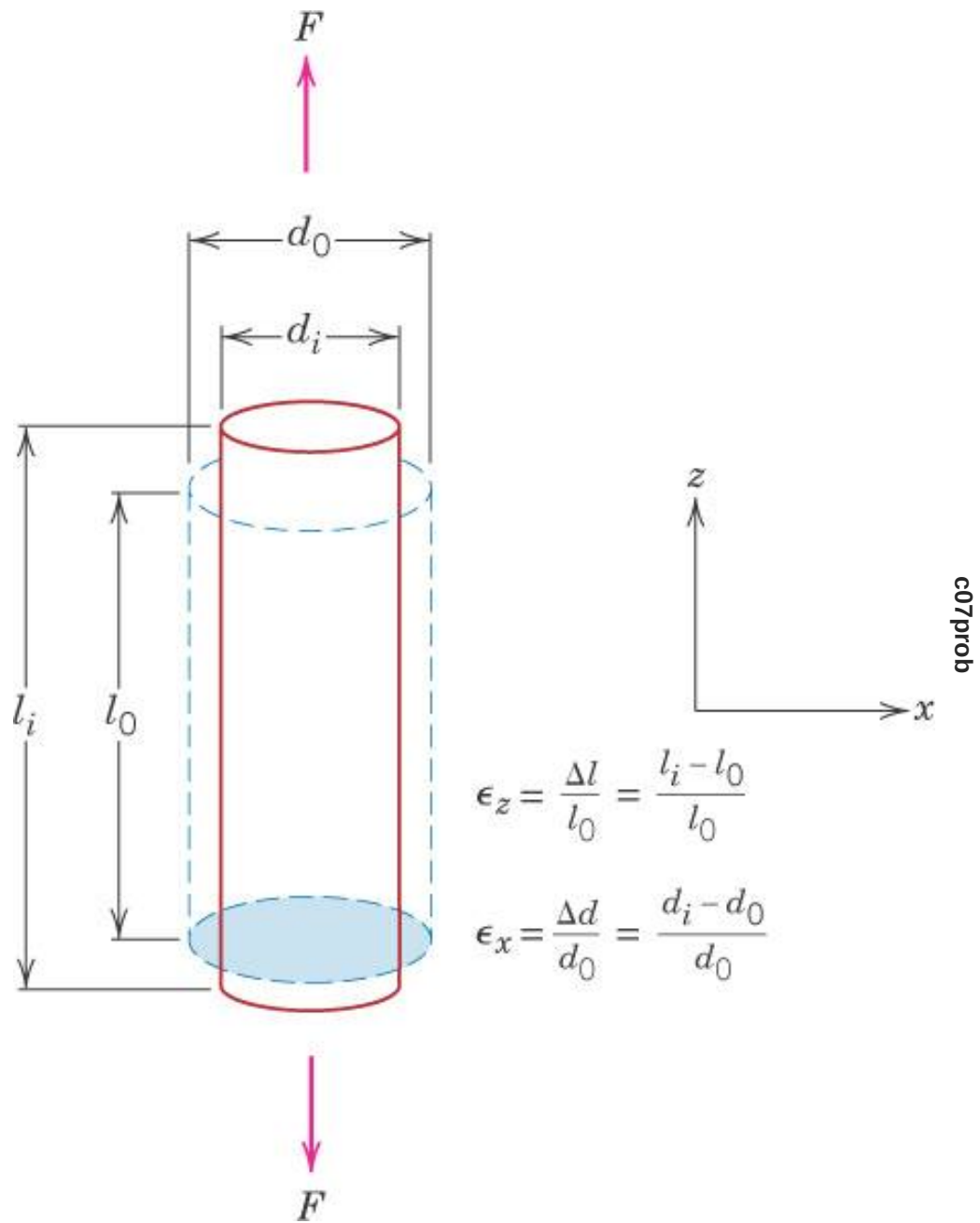
$$P = -K \frac{\Delta V}{V_0}$$



- Special relations for isotropic materials:

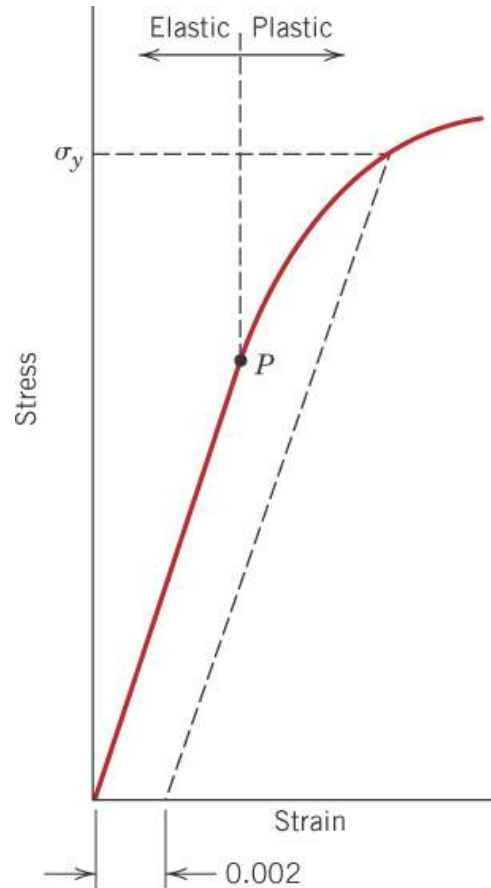
$$G = \frac{E}{2(1+\nu)}$$

$$K = \frac{E}{3(1-2\nu)}$$

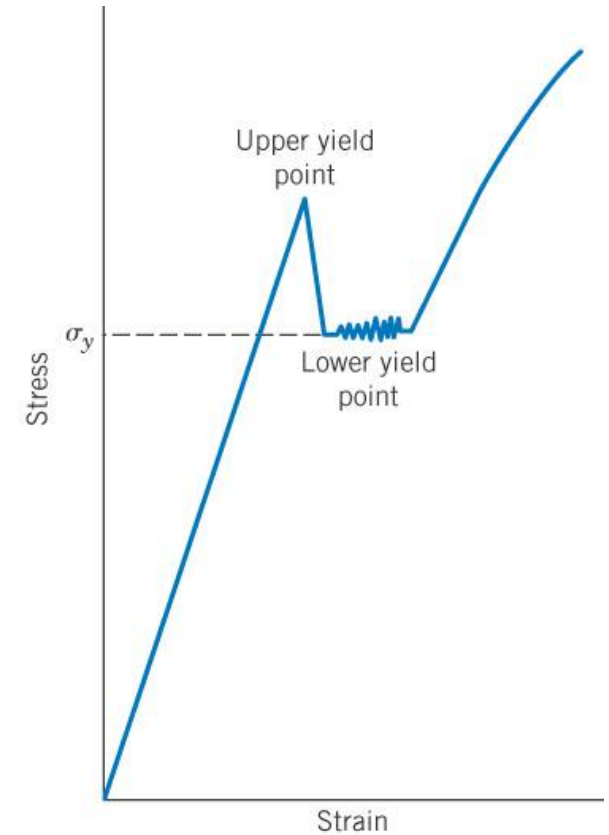


Mechanical Properties:

- Macroscopic Behavior;
- Elastic Deformation;
- Elastic Modulus;
- Proportional Limit;
- Poisson's Ratio;
- Plastic deformation;
- Yielding and Yielding Strength;
- Tensile Strength;
- Fracture Strength;
- Ductility;
- Resilience;
- Toughness.



(a)

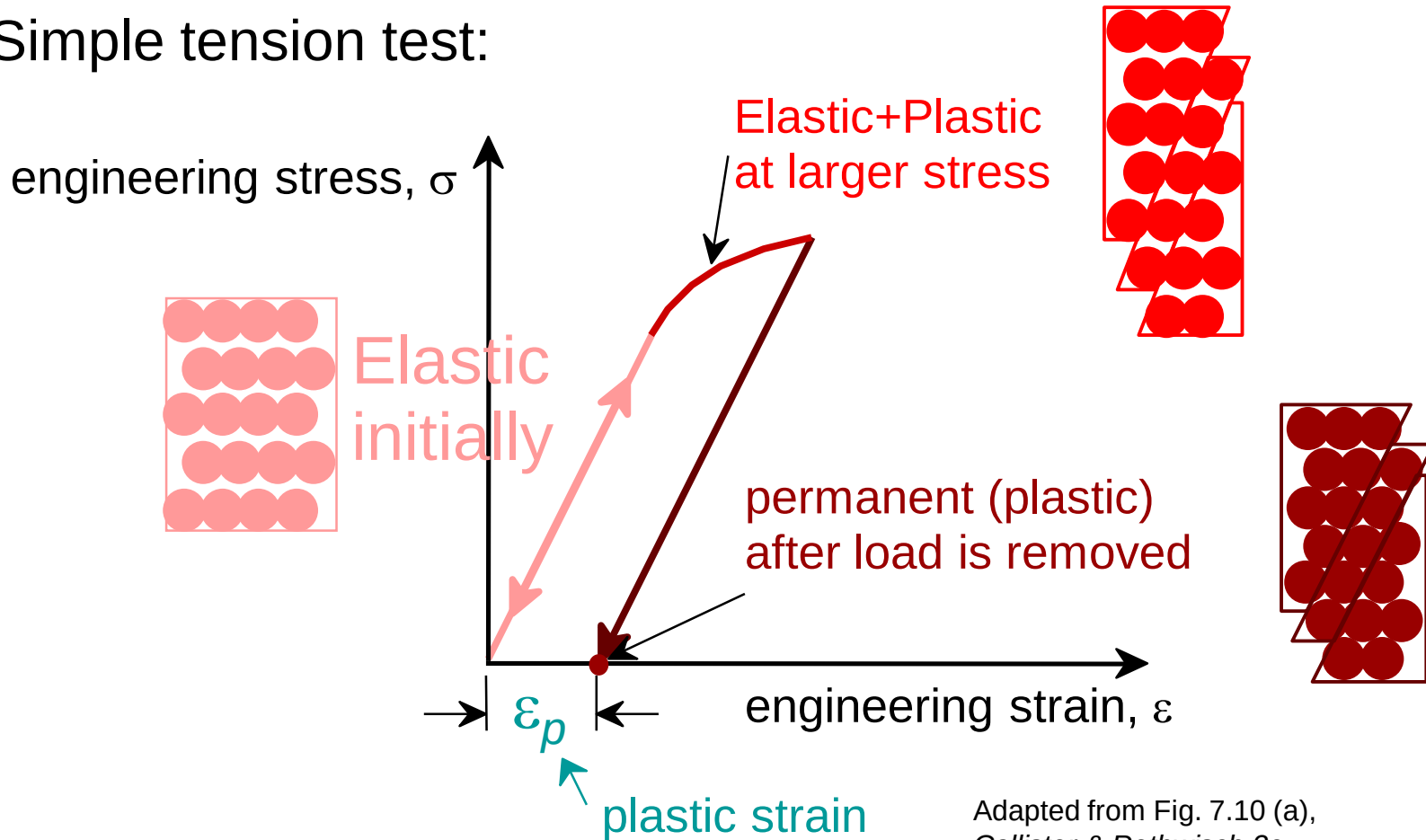


(b)

Plastic (Permanent) Deformation

(at lower temperatures, i.e. $T < T_{melt}/3$)

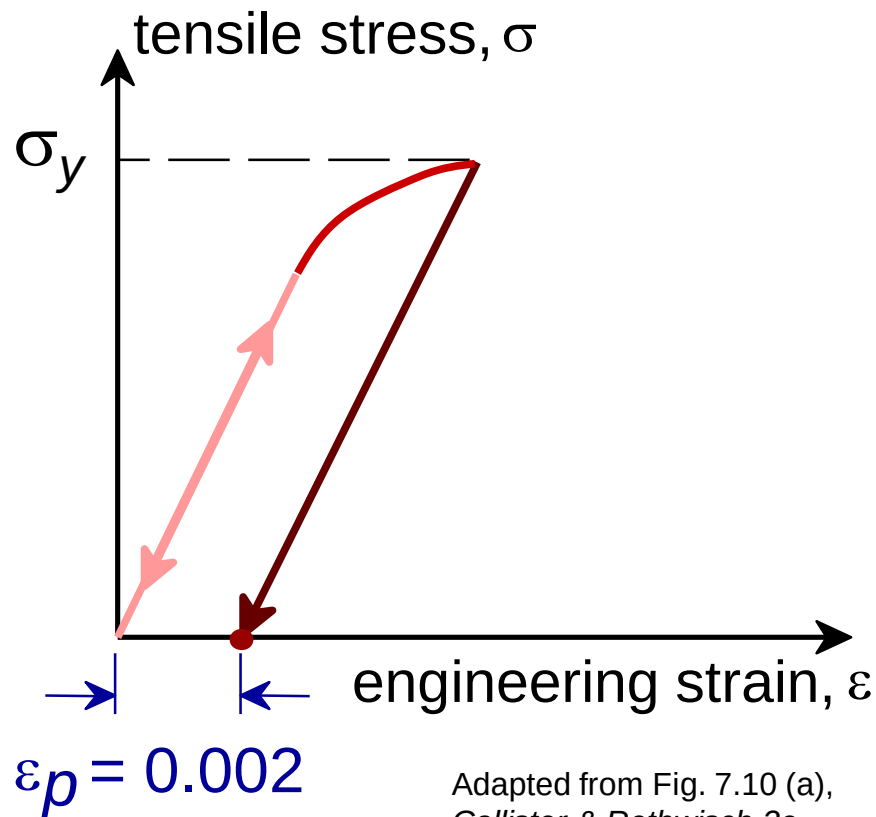
- Simple tension test:



Yielding and Yield Strength, σ_y

- Stress at which *noticeable* plastic deformation has occurred.

when $\varepsilon_p = 0.002$



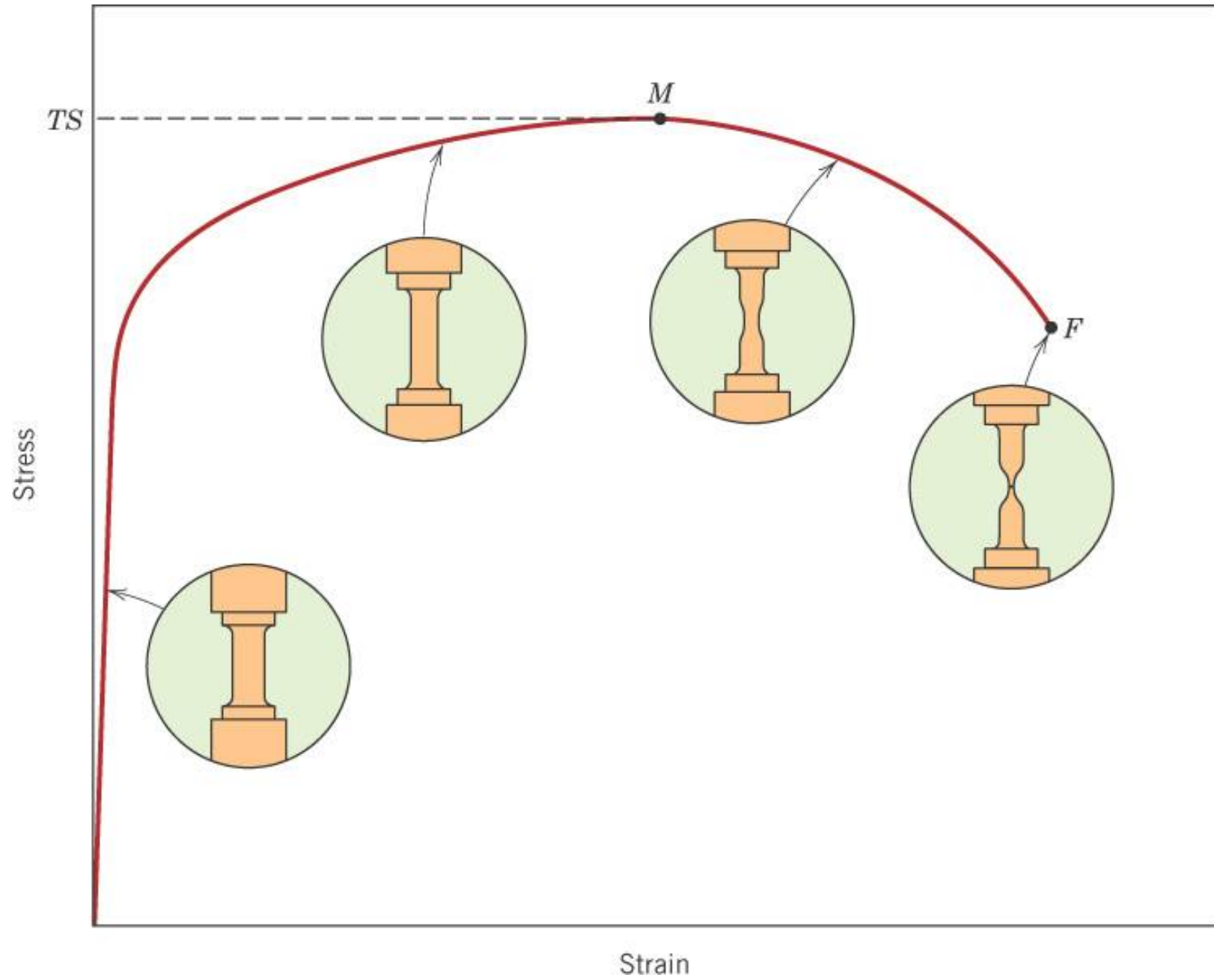
σ_y = yield strength

Note: for 2 inch sample

$$\varepsilon = 0.002 = \Delta z / z$$

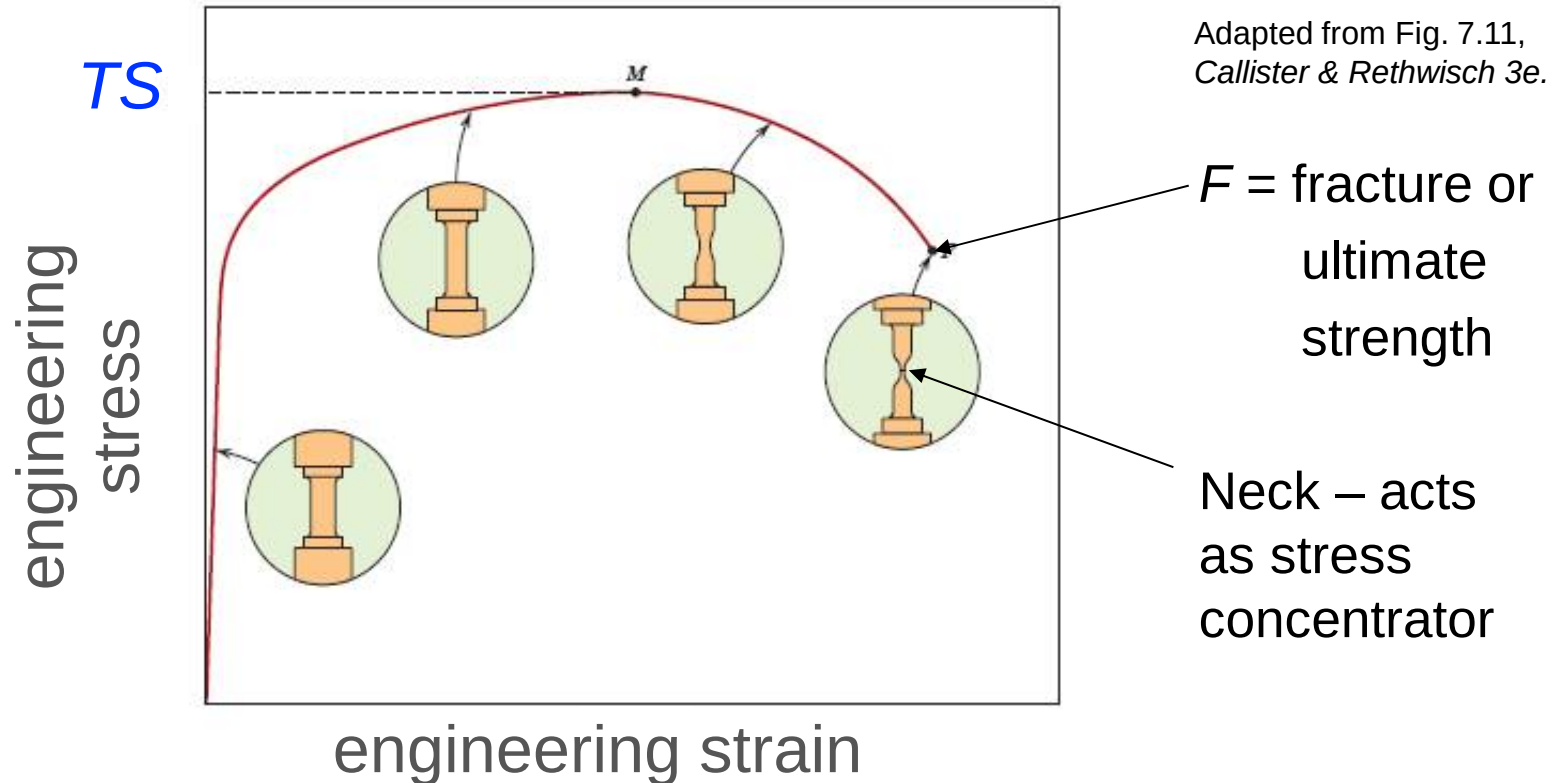
$$\therefore \Delta z = 0.004 \text{ in}$$

Adapted from Fig. 7.10 (a),
Callister & Rethwisch 3e.



Tensile Strength, TS

- Maximum stress on engineering stress-strain curve.

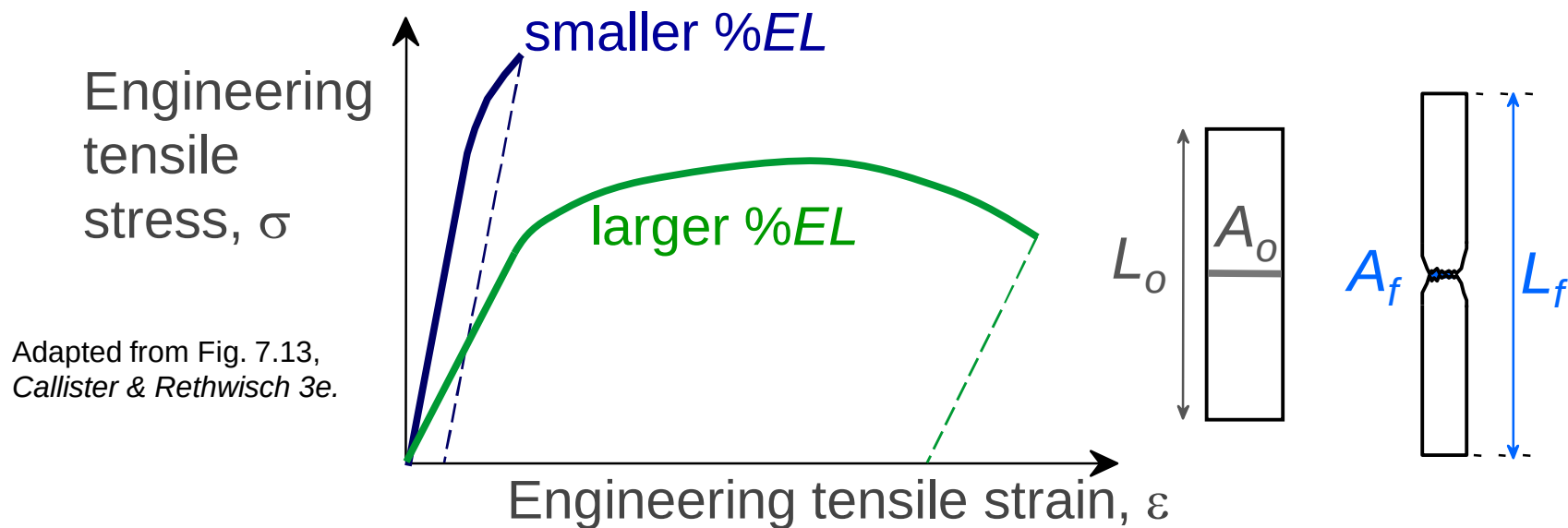


- Metals:** occurs when noticeable **necking** starts.
- Polymers:** occurs when **polymer backbone chains** are aligned and about to break.

Ductility

- Plastic tensile strain at failure:

$$\%EL = \frac{L_f - L_o}{L_o} \times 100$$

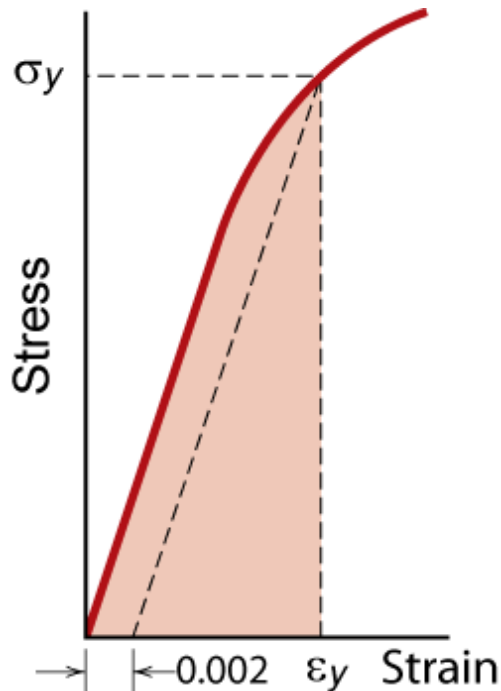


- Another ductility measure:

$$\%RA = \frac{A_o - A_f}{A_o} \times 100$$

Resilience, U_r

- Ability of a material to store energy
 - Energy stored best in elastic region



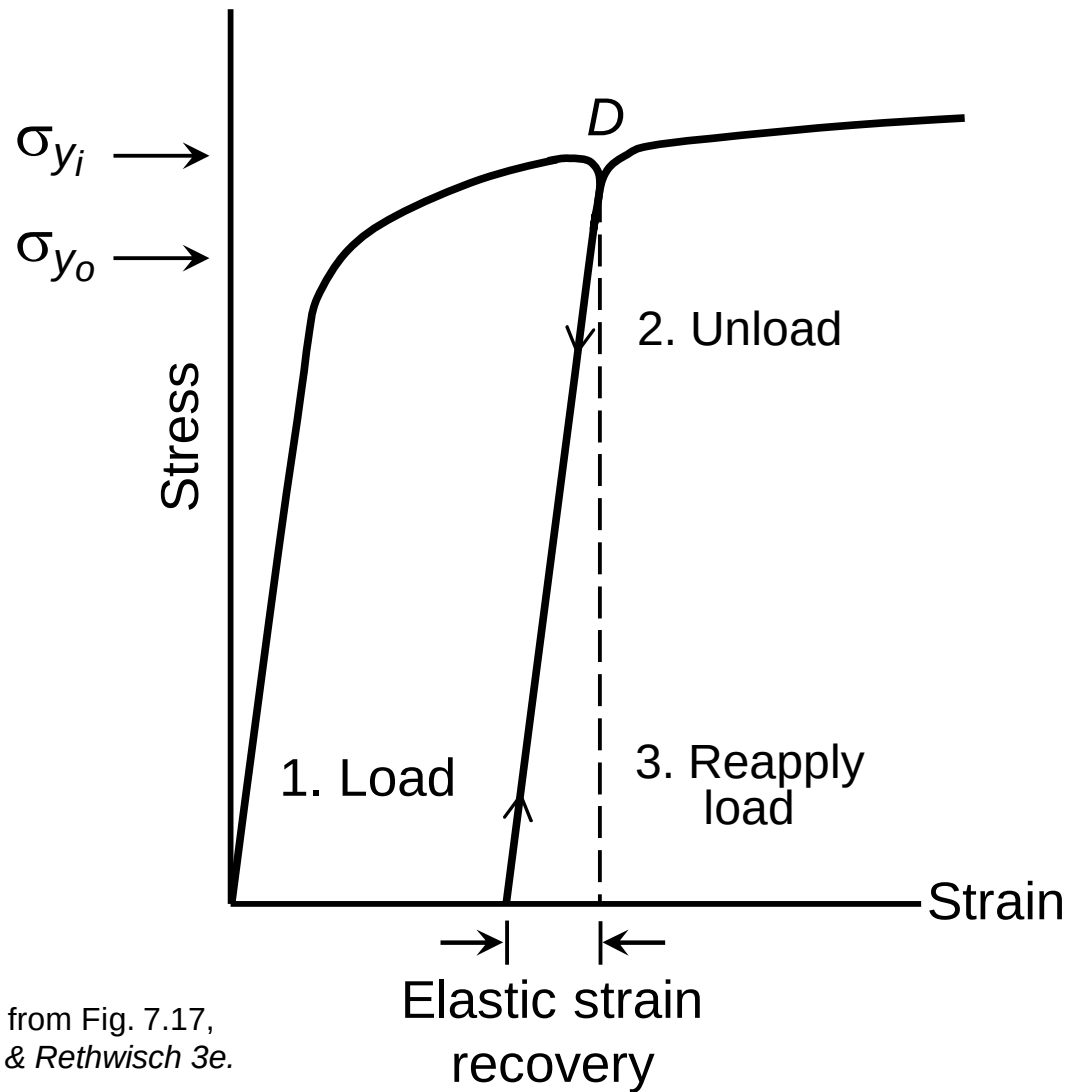
$$U_r = \int_0^{\epsilon_y} \sigma d\epsilon$$

If we assume a linear stress-strain curve this simplifies to

$$U_r \approx \frac{1}{2} \sigma_y \epsilon_y$$

Adapted from Fig. 7.15,
Callister & Rethwisch 3e.

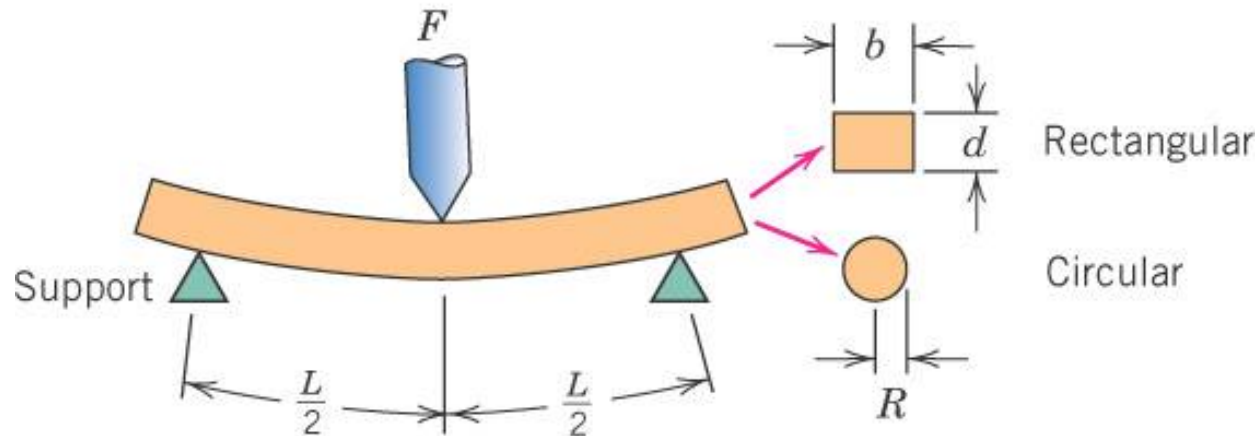
Elastic Strain Recovery



Adapted from Fig. 7.17,
Callister & Rethwisch 3e.

7.10 Flexural Strength of Ceramics)

Possible cross sections



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

where M = maximum bending moment

c = distance from center of specimen to outer surface

I = moment of inertia of cross section

F = applied load

	$\frac{M}{}$	$\frac{c}{}$	$\frac{I}{}$	$\frac{\sigma}{}$
Rectangular	$\frac{FL}{4}$	$\frac{d}{2}$	$\frac{bd^3}{12}$	$\frac{3FL}{2bd^2}$
Circular	$\frac{FL}{4}$	R	$\frac{\pi R^4}{4}$	$\frac{FL}{\pi R^3}$

Mechanical Properties of Ceramics

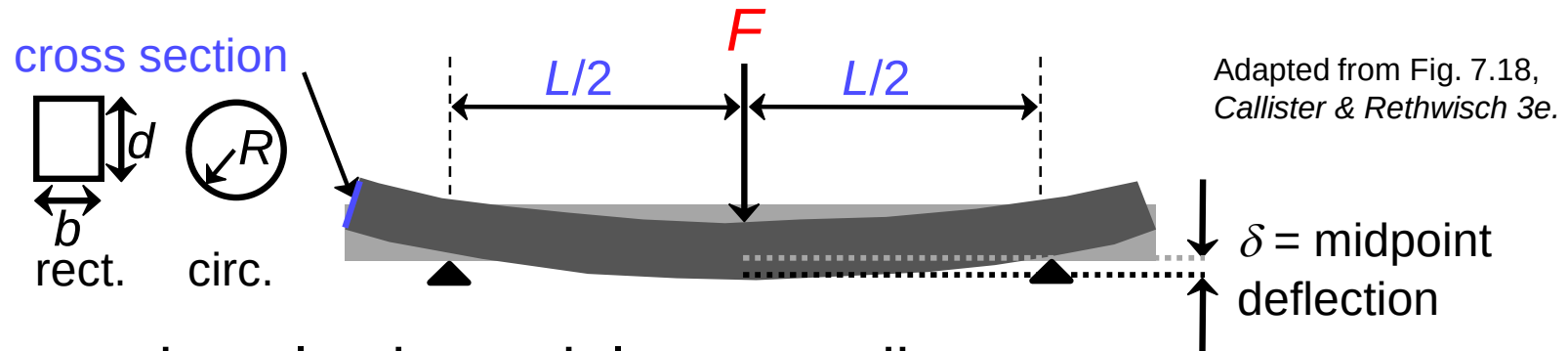
Ceramic materials are more brittle than metals.

Why is this so?

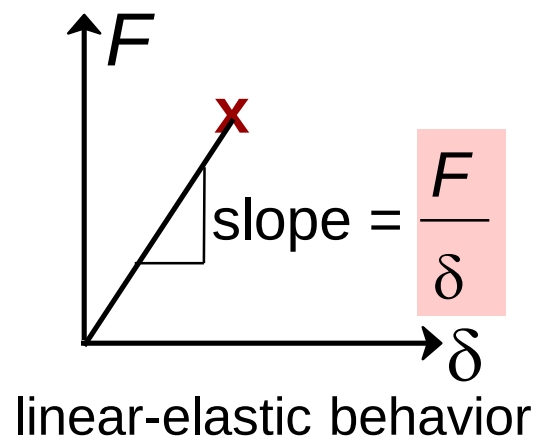
- **Consider mechanism of deformation**
 - In crystalline, by dislocation motion
 - In highly ionic solids, dislocation motion is difficult
 - few slip systems
 - resistance to motion of ions of like charge (e.g., anions) past one another

Flexural Tests – Measurement of Elastic Modulus

- Room T behavior is usually elastic, with brittle failure.
- 3-Point Bend Testing often used.
 - tensile tests are difficult for brittle materials.



- Determine elastic modulus according to:

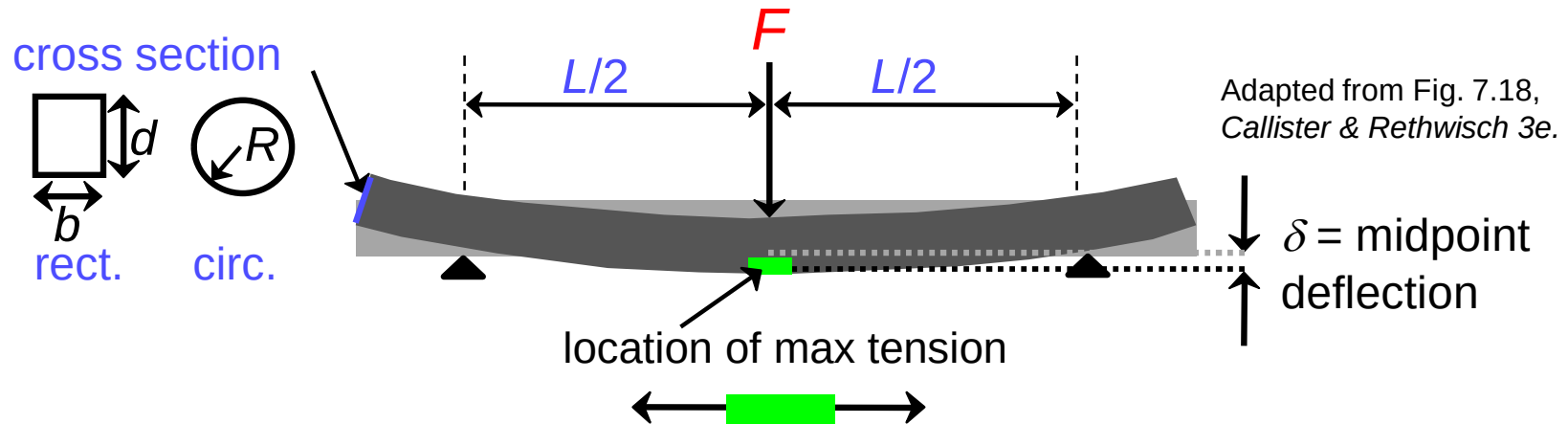


$$E = \frac{F}{\delta} \frac{L^3}{4bd^3} \quad (\text{rect. cross section})$$

$$E = \frac{F}{\delta} \frac{L^3}{12\pi R^4} \quad (\text{circ. cross section})$$

Flexural Tests – Measurement of Flexural Strength

- 3-point bend test to measure room-*T* flexural strength.



- Flexural strength:

$$\sigma_{fs} = \frac{3F_f L}{2bd^2} \quad (\text{rect. cross section})$$

$$\sigma_{fs} = \frac{F_f L}{\pi R^3} \quad (\text{circ. cross section})$$

- Typical values:

Material	σ_{fs} (MPa)	E (GPa)
Si nitride	250-1000	304
Si carbide	100-820	345
Al oxide	275-700	393
glass (soda-lime)	69	69

Data from Table 7.2, Callister & Rethwisch 3e.

Summary

- **Stress** and **strain**: These are size-independent measures of load and displacement, respectively.
- **Elastic** behavior: This reversible behavior often shows a linear relation between stress and strain. To minimize deformation, select a material with a large elastic modulus (E or G).
- **Plastic** behavior: This permanent deformation behavior occurs when the tensile (or compressive) uniaxial stress reaches σ_y .
- **Toughness**: The energy needed to break a unit volume of material.
- **Ductility**: The plastic strain at failure.