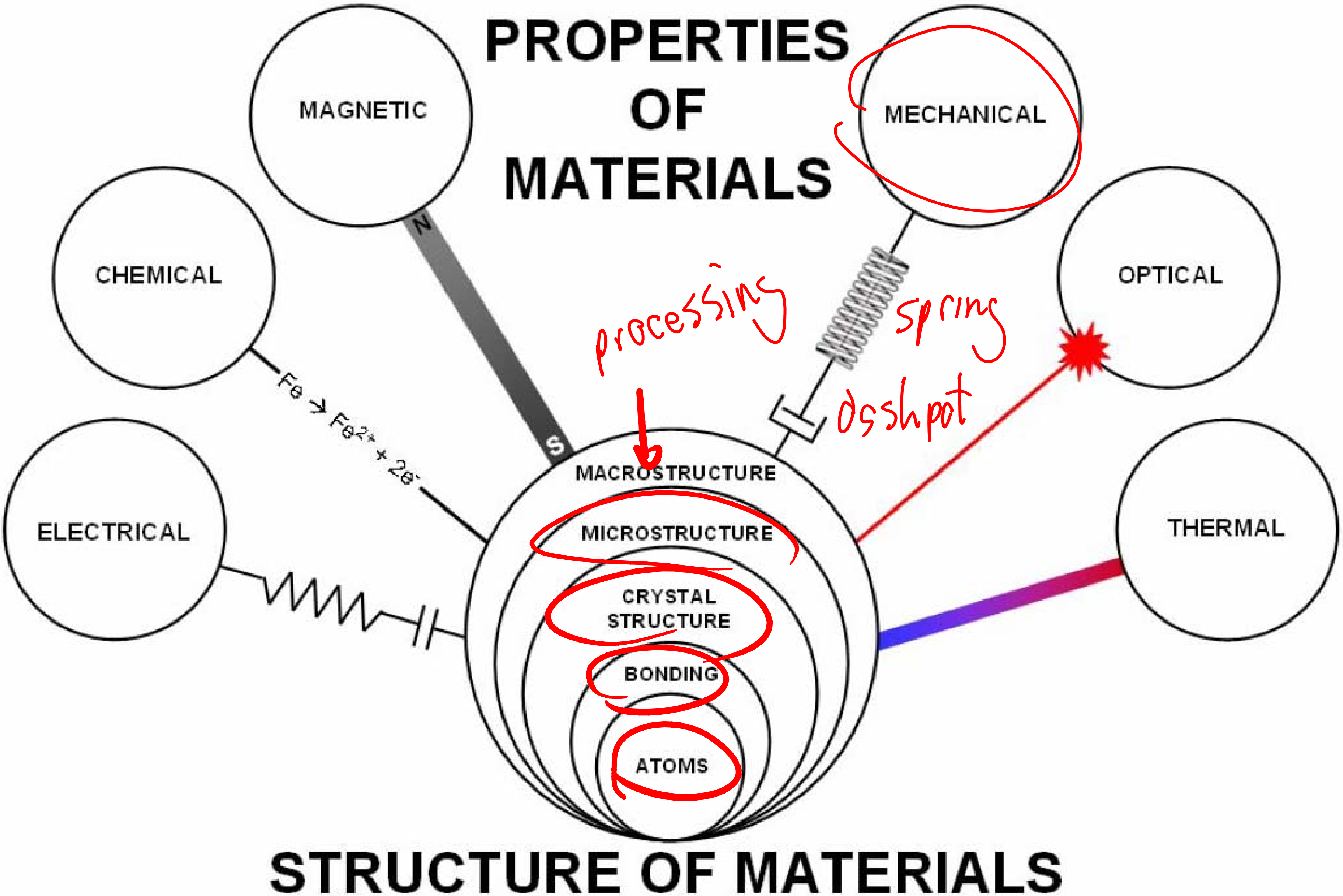
Announcements

- **Mid-term grades should be up on WebCT tomorrow.**
  - **THANK YOU for your work in taking the exam.**
  - **PLEASE be patient!**
  - **The actual content of the exam will be reviewed in the tutorials this week.**
- **WE WILL DO A NEEDS ASSESSMENT (survey) once the grades are out.**
- **Welcome to the second half of the course.**
  - **Moving along to PROPERTIES**
  - **What was the first half?**


PROPERTIES OF MATERIALS
MAGNETIC
N
S
MECHANICAL
CHEMICAL
OPTICAL
ELECTRICAL
THERMAL
$Fe \rightarrow Fe^{2+} + 2e^-$
processing
spring
dashpot
MACROSTRUCTURE
MICROSTRUCTURE
CRYSTAL STRUCTURE
BONDING
ATOMS
STRUCTURE OF MATERIALS

Materials

"non destructively" test them

- **Handle these materials**
- **Find adjectives to describe how the respond mechanically**

TOUCH

Adjectives

ELASTIC

HARD / SOFT

DEFORMABLE

BRITTLE

BOUNCY

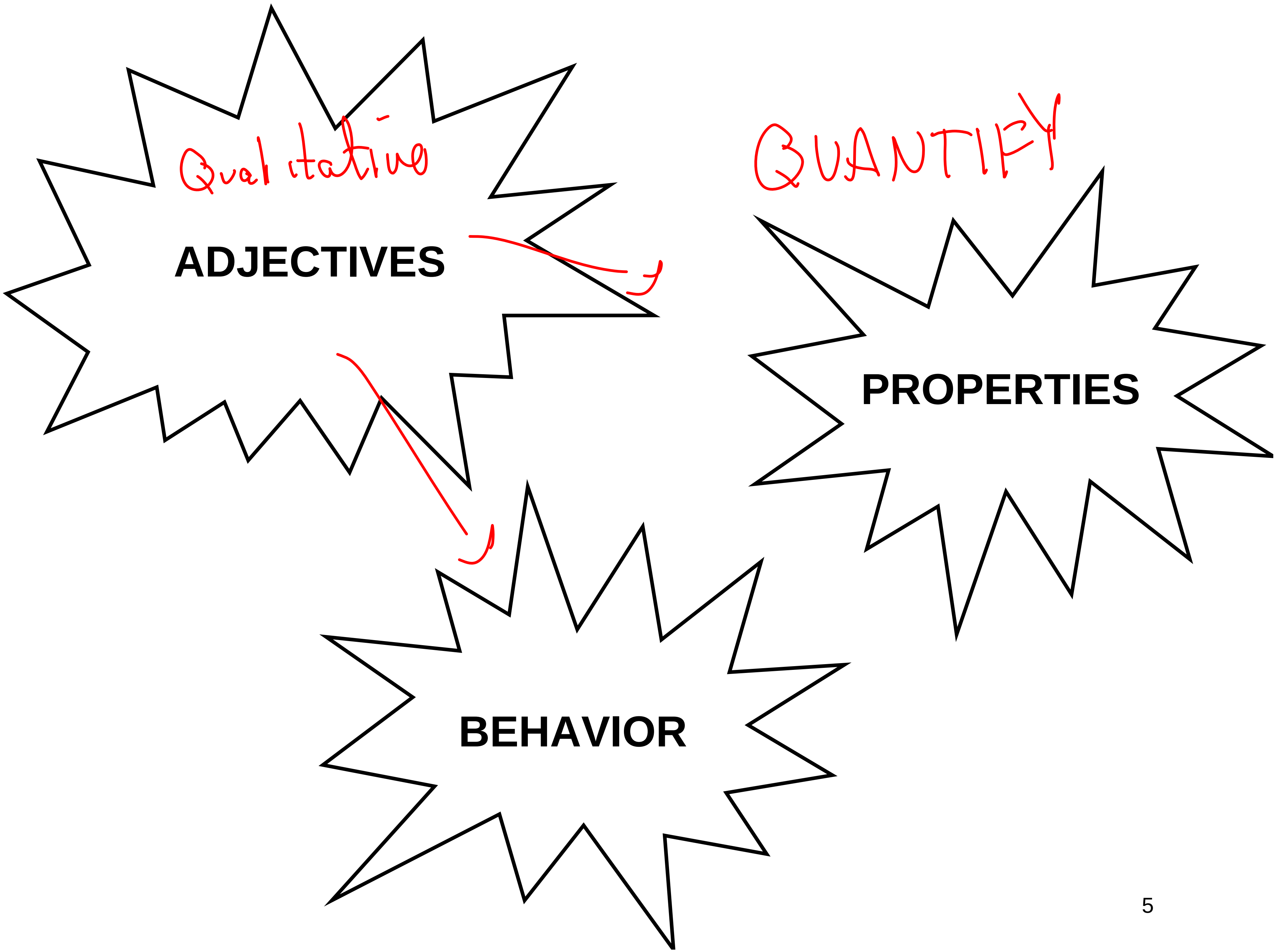
SHINY

STIFF

LIGHT

RIGID

STRONG

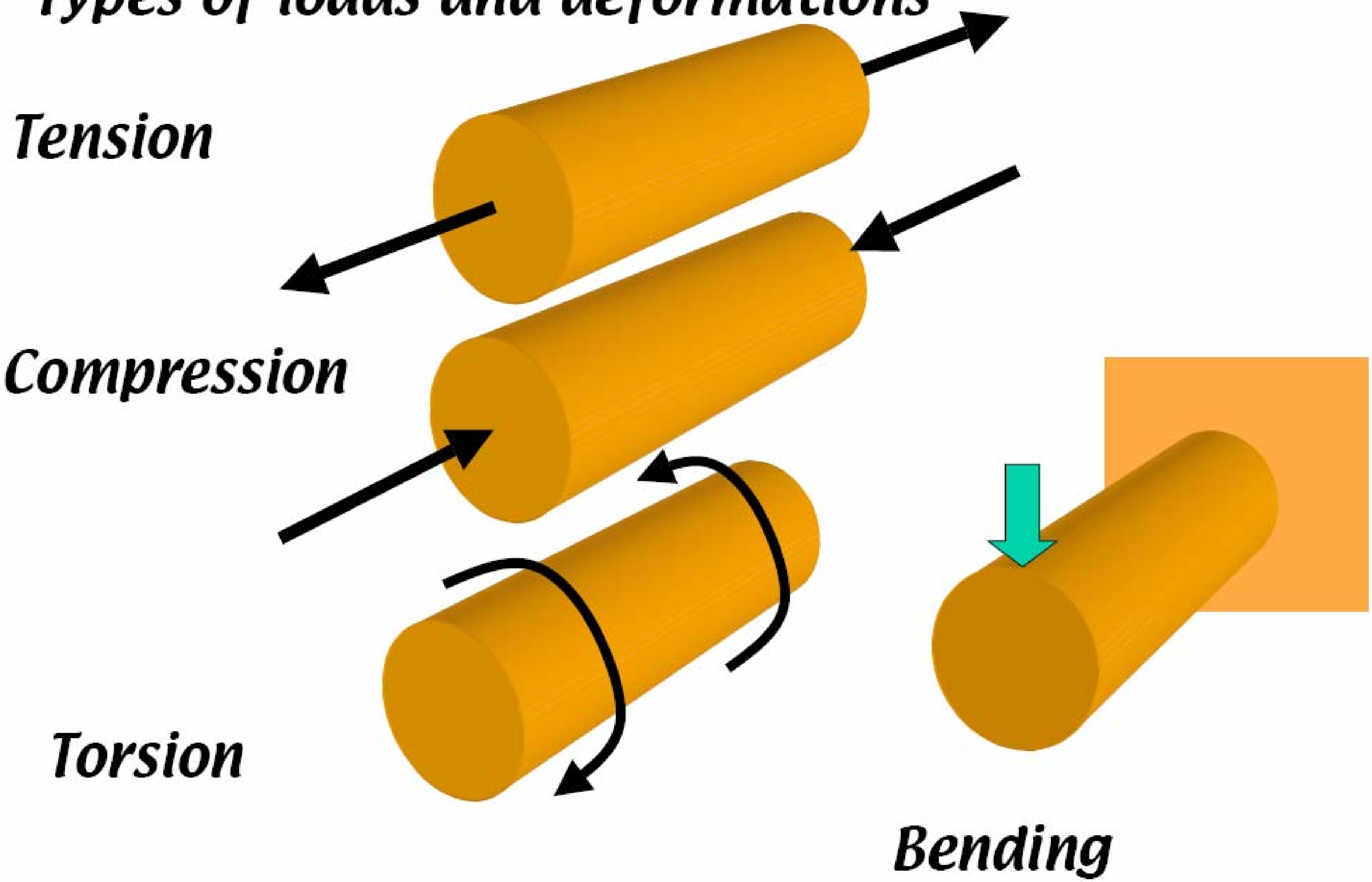

Qualitative
ADJECTIVES
QUANTIFY
PROPERTIES
BEHAVIOR

Chapter 6:
Mechanical Properties

ISSUES TO ADDRESS...

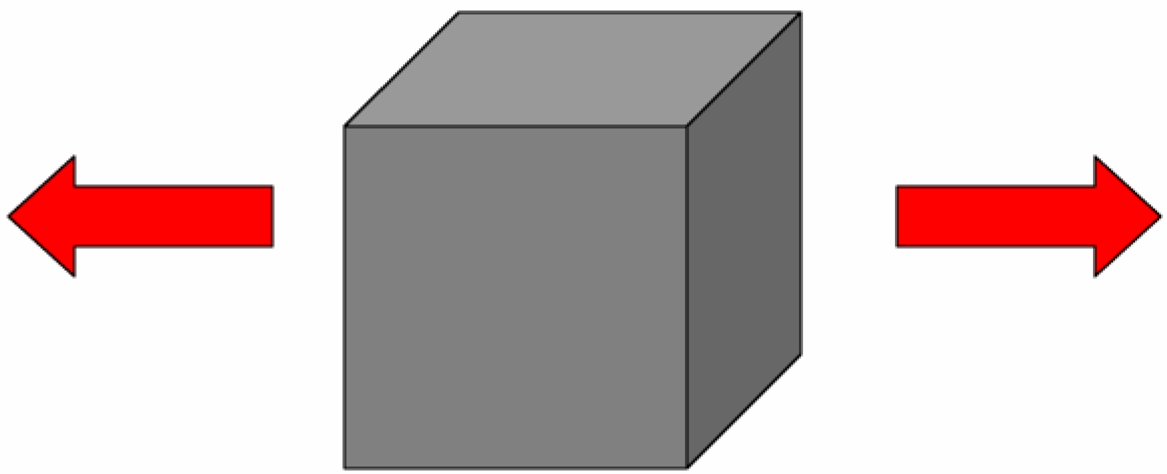
- Stress and strain: What are they and why are they used instead of load and deformation?
- Elastic behavior: When loads are small, how much deformation occurs? What materials deform least?
- Plastic behavior: At what point does permanent deformation occur? What materials are most resistant to permanent deformation?
- Toughness and ductility: What are they and how do we measure them?

Types of loads and deformations



EXTREME example

Tensile loading of iron

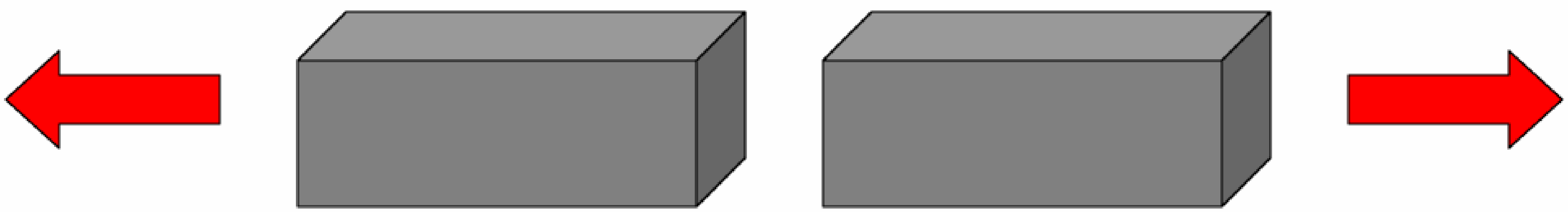


EXTREME example

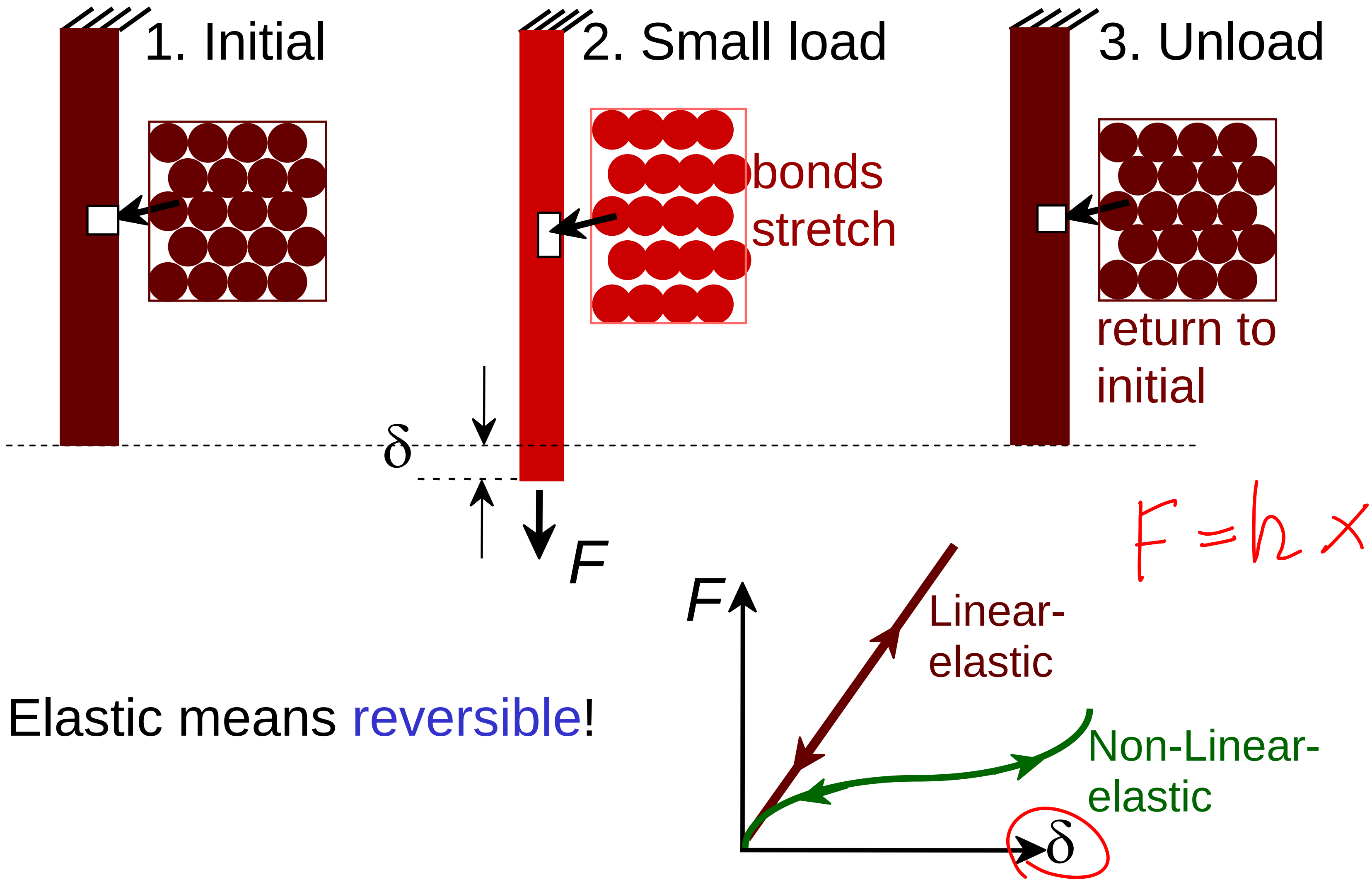
Tensile loading of iron

EXTREME example

Tensile loading of iron

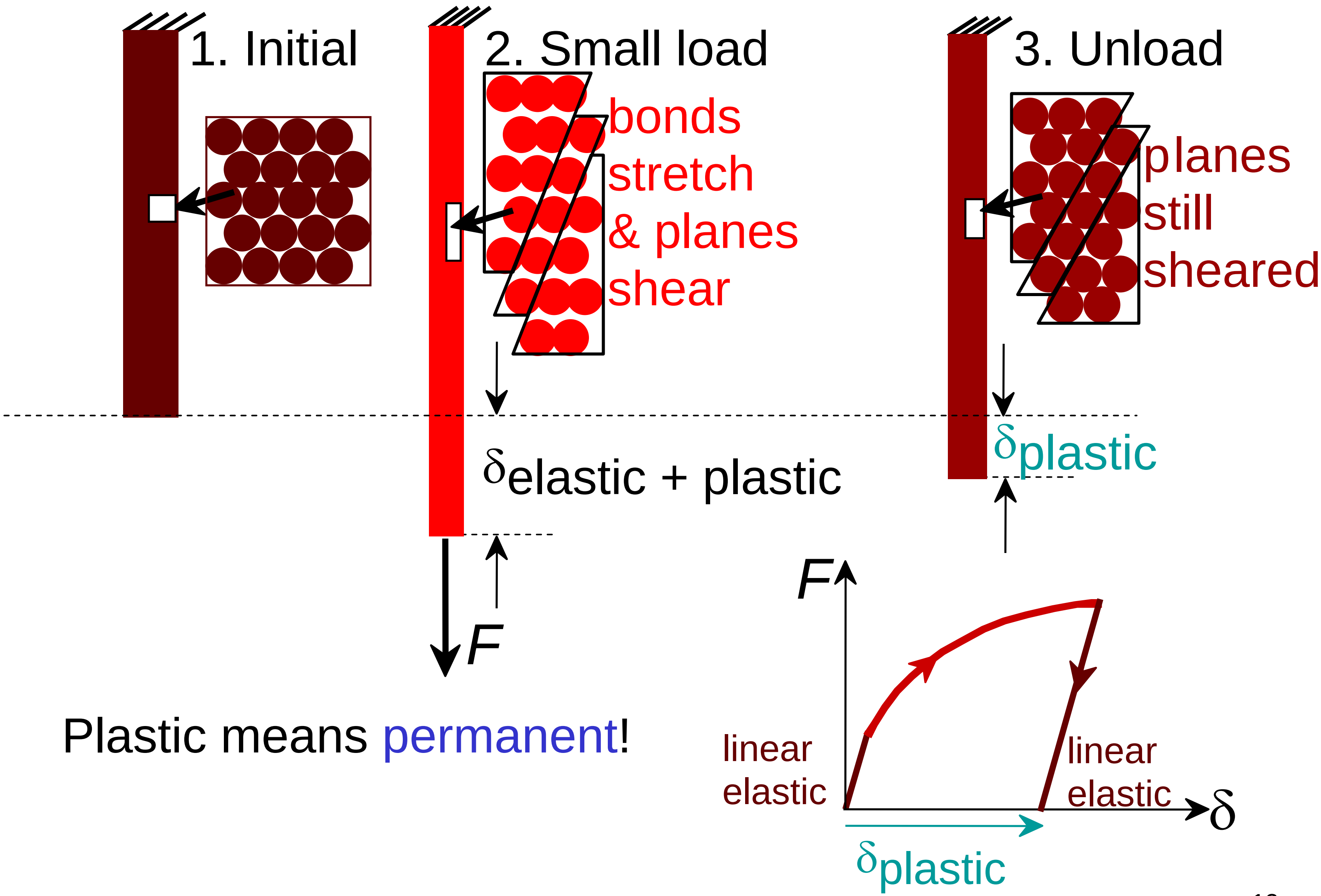


Elastic Deformation



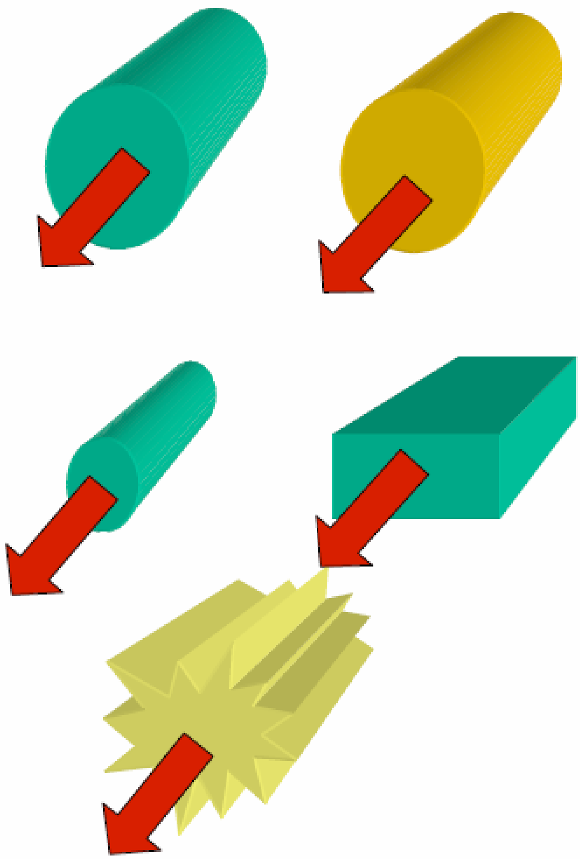
Elastic means reversible!

Plastic Deformation (Metals)



Plastic means permanent!

Material vs. structural properties

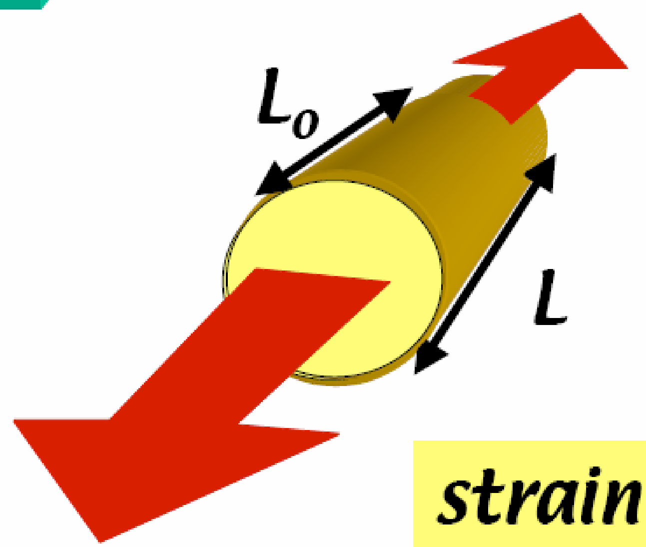


Need to eliminate the effect of size and shape to define material properties.

stress (σ) = Force/Area

σ = F/A

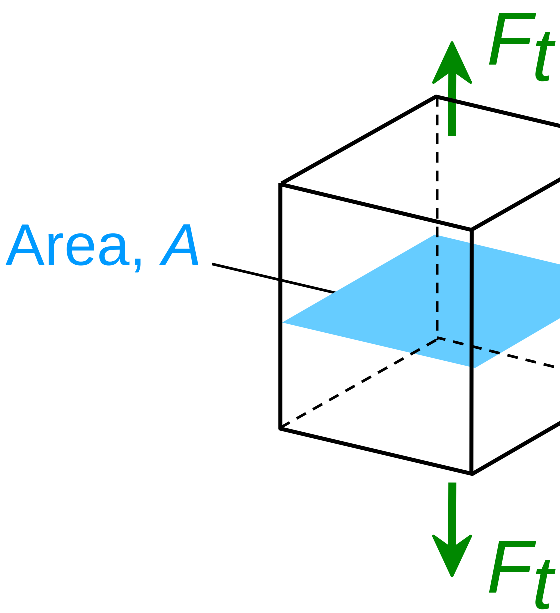
Pa = N/m^2



strain (ε)= $(L - L_o)/L_o$

Engineering Stress

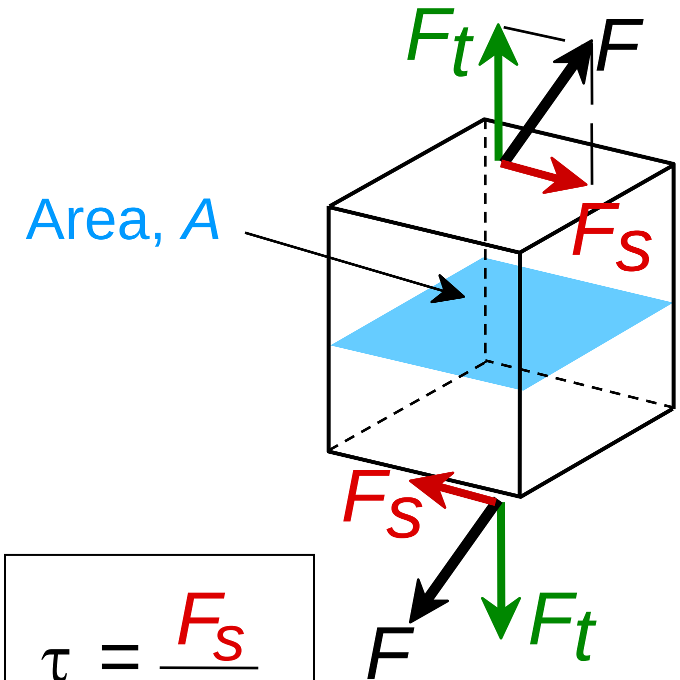
- Tensile stress, σ:



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

original area before loading

- Shear stress, τ:

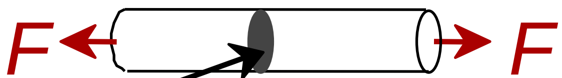


$$\tau = \frac{F_s}{A_o}$$

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

Common States of Stress

- **Simple tension: cable**

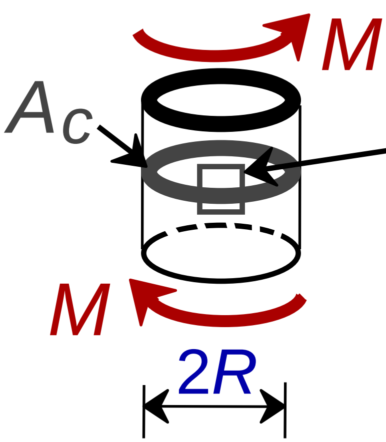


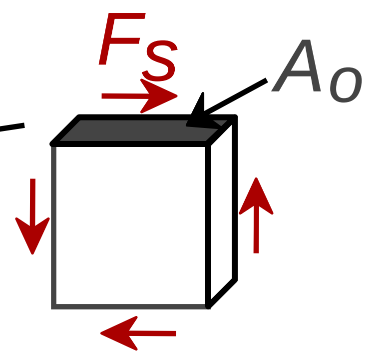
A_o = cross sectional area (when unloaded)

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

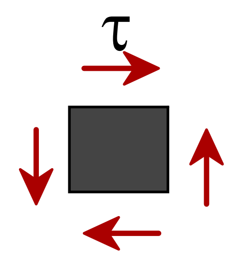
Ski lift (photo courtesy P.M. Anderson)

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





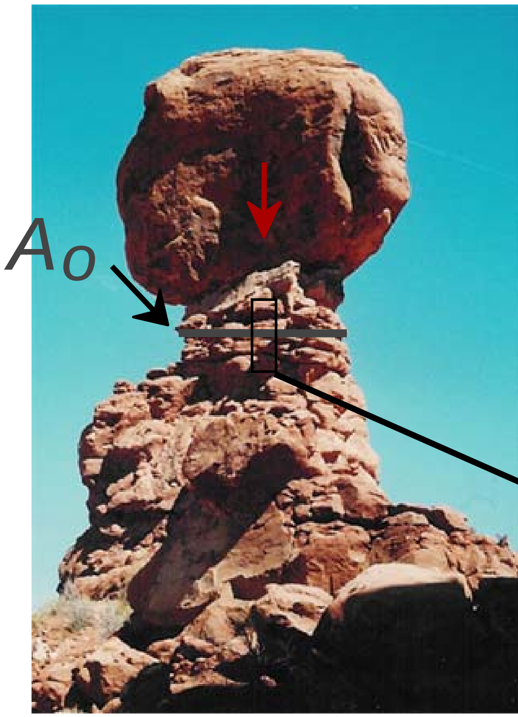
$$\tau = \frac{F_s}{A_o}$$



Note: $\tau = M/A_cR$ here.

OTHER COMMON STRESS STATES (1)

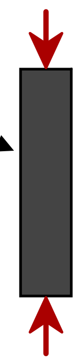
- **Simple compression:**



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

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

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



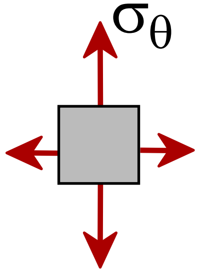
Note: compressive structure member ($\sigma < 0$ here).

OTHER COMMON STRESS STATES (2)

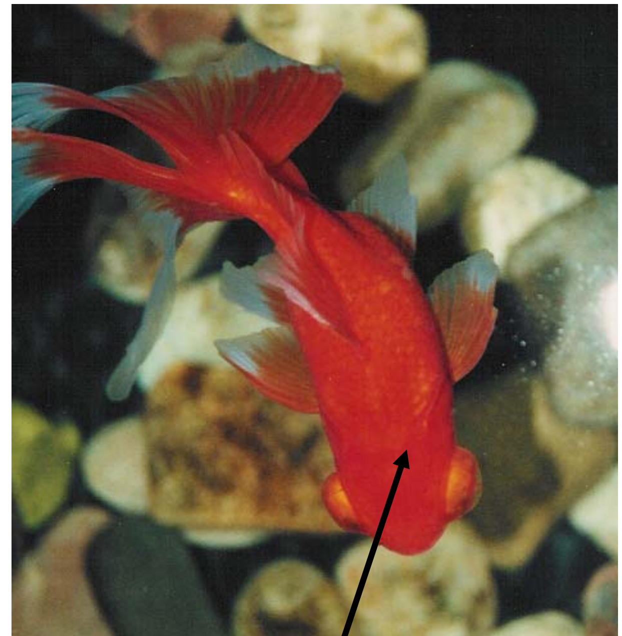
- **Bi-axial tension:**
- **Hydrostatic compression:**

Pressurized tank
(photo courtesy
P.M. Anderson)

σ_θ **> 0**



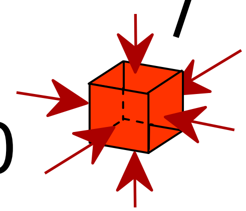
σ_z **> 0**



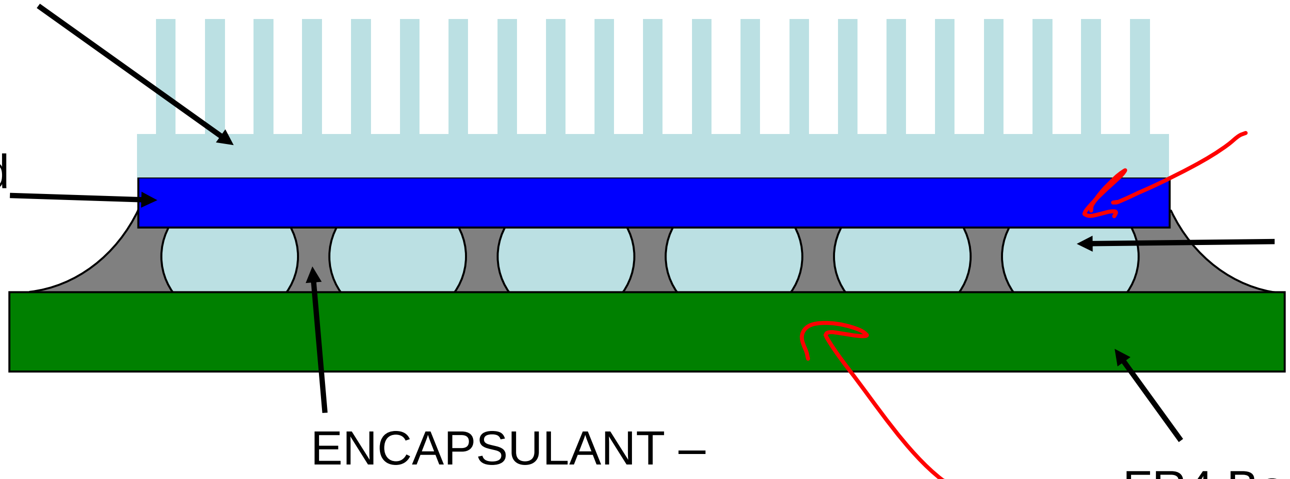
Fish under water

(photo courtesy
P.M. Anderson)

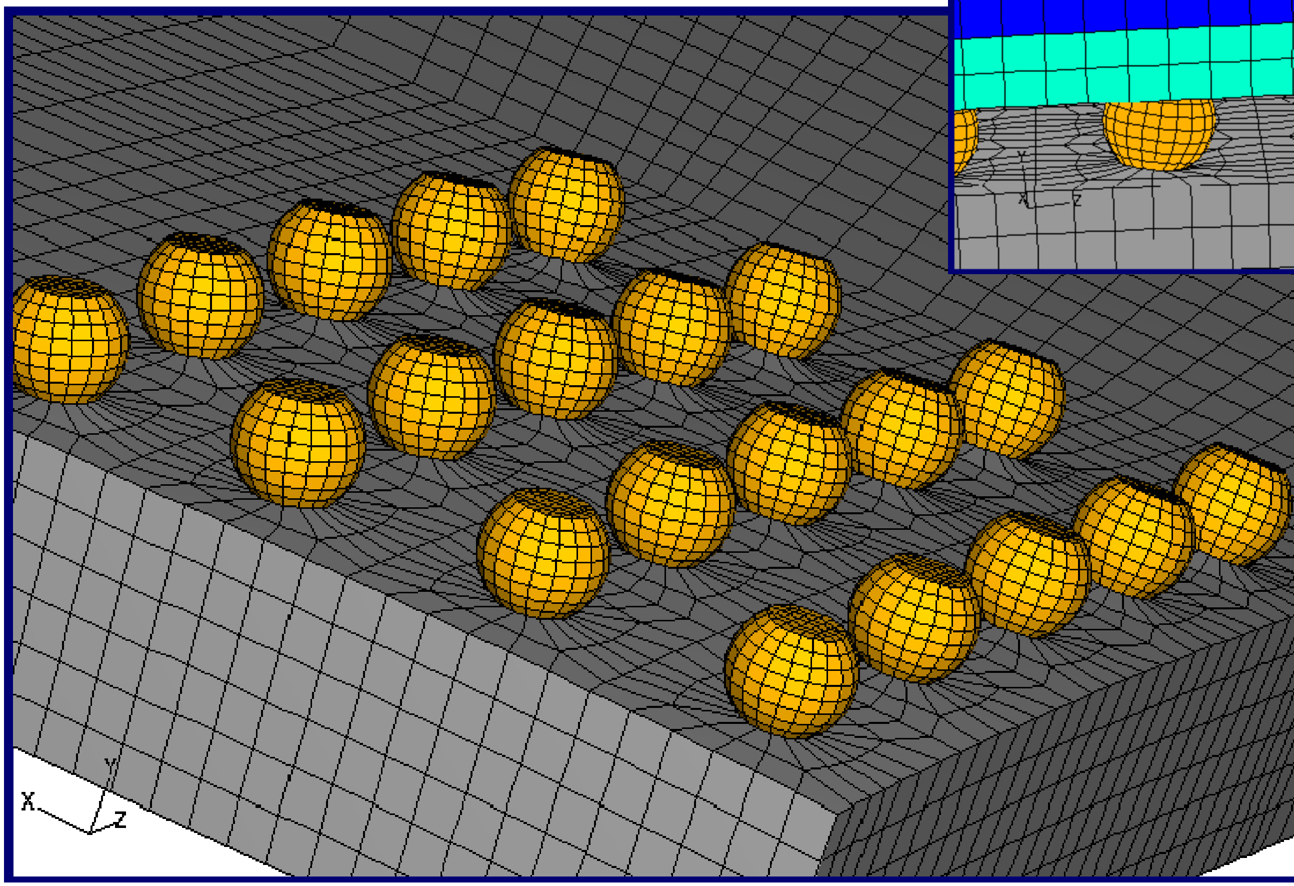
$\sigma_h < 0$

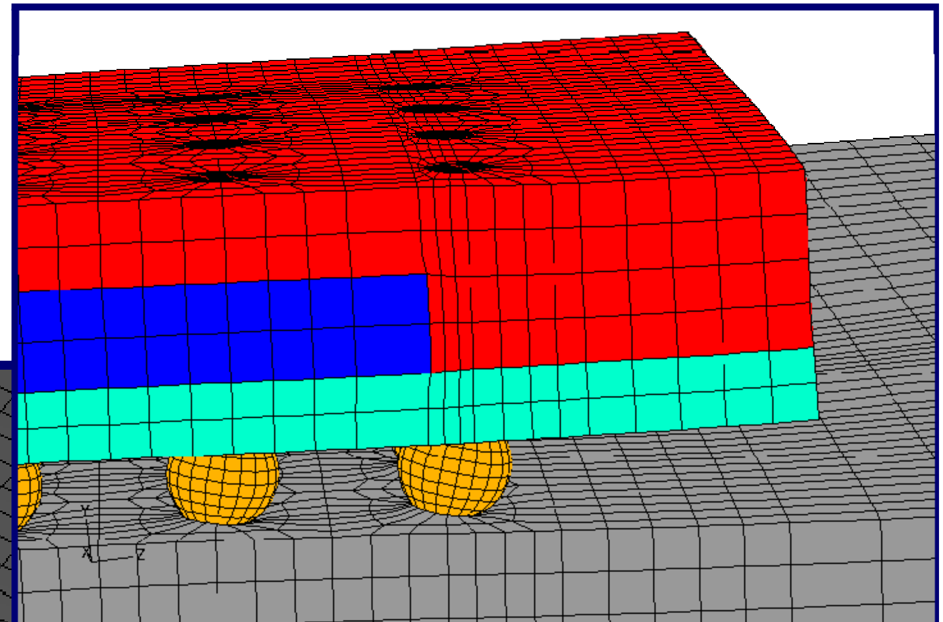


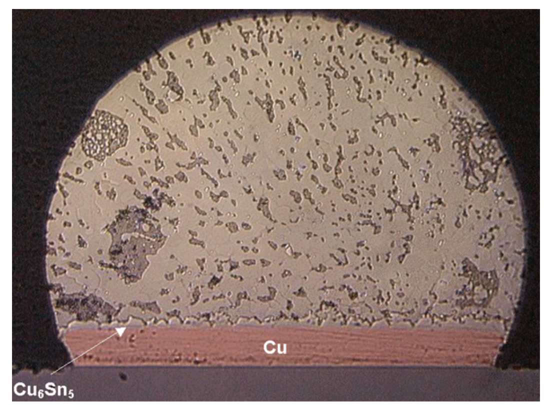
FLIP CHIP
BALL GRID ARRAY



Reliability Modeling
Pb-Sn Solders







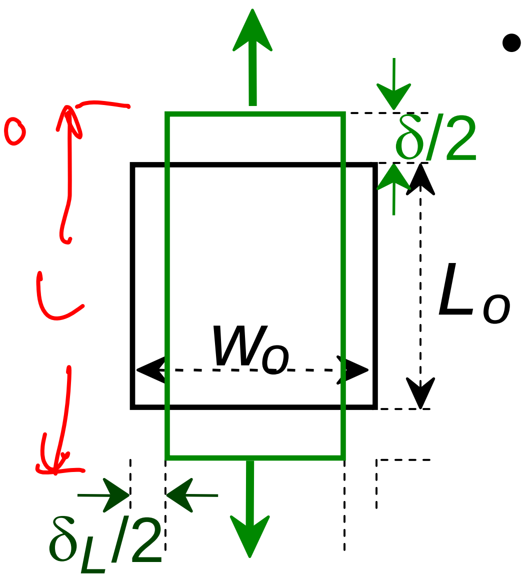
H. Nied and M. Ozturk
Mechanical Engineering
Lehigh Univ.

Engineering Strain

- **Tensile strain:**

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

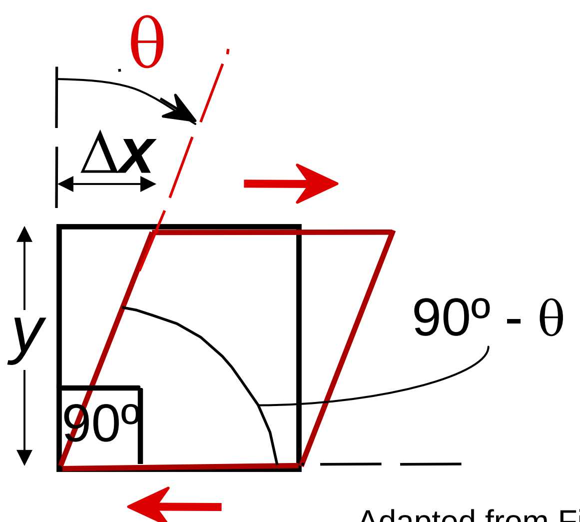
strain



- **Lateral strain:**

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

- **Shear strain:**



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

Strain is always dimensionless.

Adapted from Fig. 6.1 (a) and (c), *Callister 7e.*

Material vs. structural properties

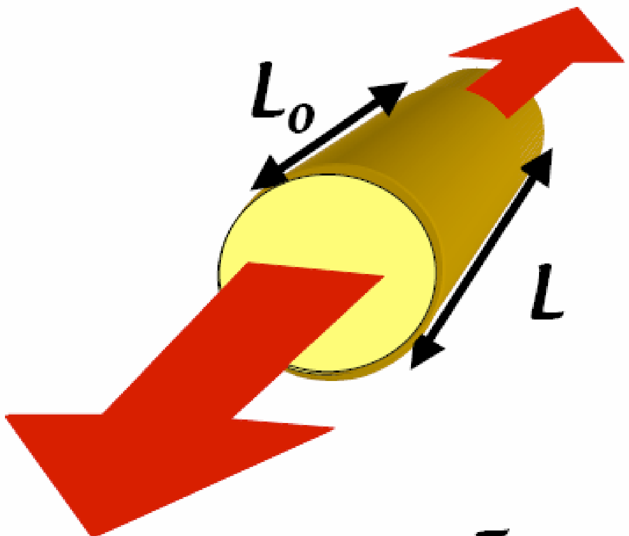
stress (σ) = Force/Area

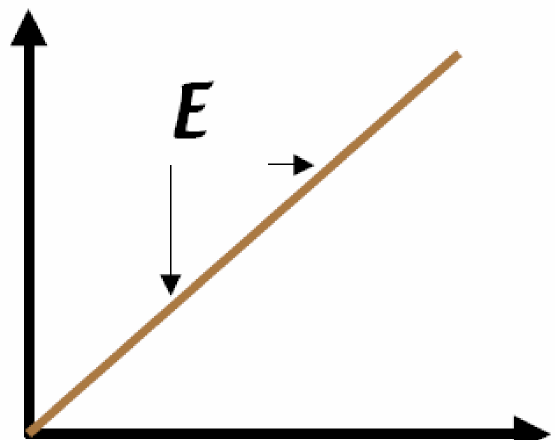
$$\sigma = F/A$$

strain (ε) = $(L - L_o)/L_o$

$$\varepsilon_T = \int dL/L = \ln(L)$$

$$\lambda = L/L_o$$





$$\sigma = \frac{\text{Force}}{\text{Area}}$$

$$\varepsilon = \Delta L / L_o$$

$$\sigma = E\varepsilon \leftarrow$$

Hooke's Law

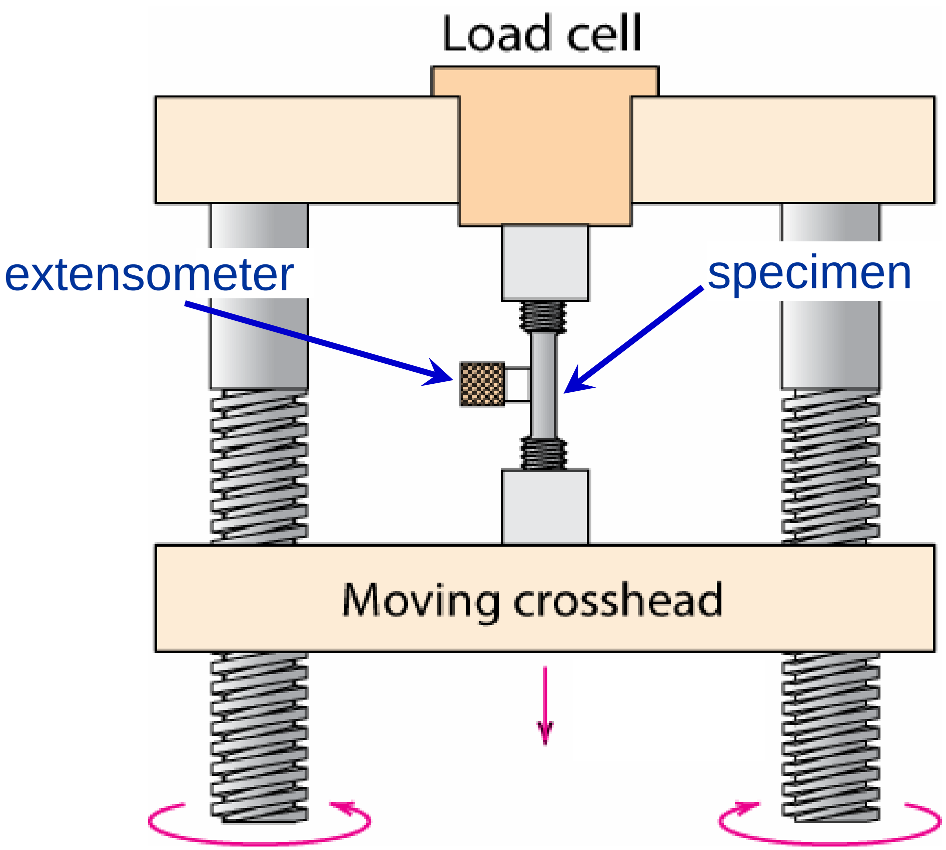
$$F = k\,\Delta L$$

Young's modulus (E) measures the stiffness of a *material*

$$E = \sigma/\varepsilon$$

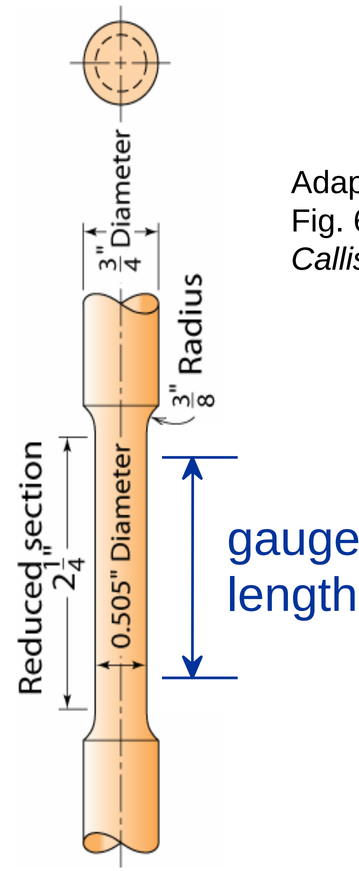
Stress-Strain Testing

• **Typical tensile test machine**

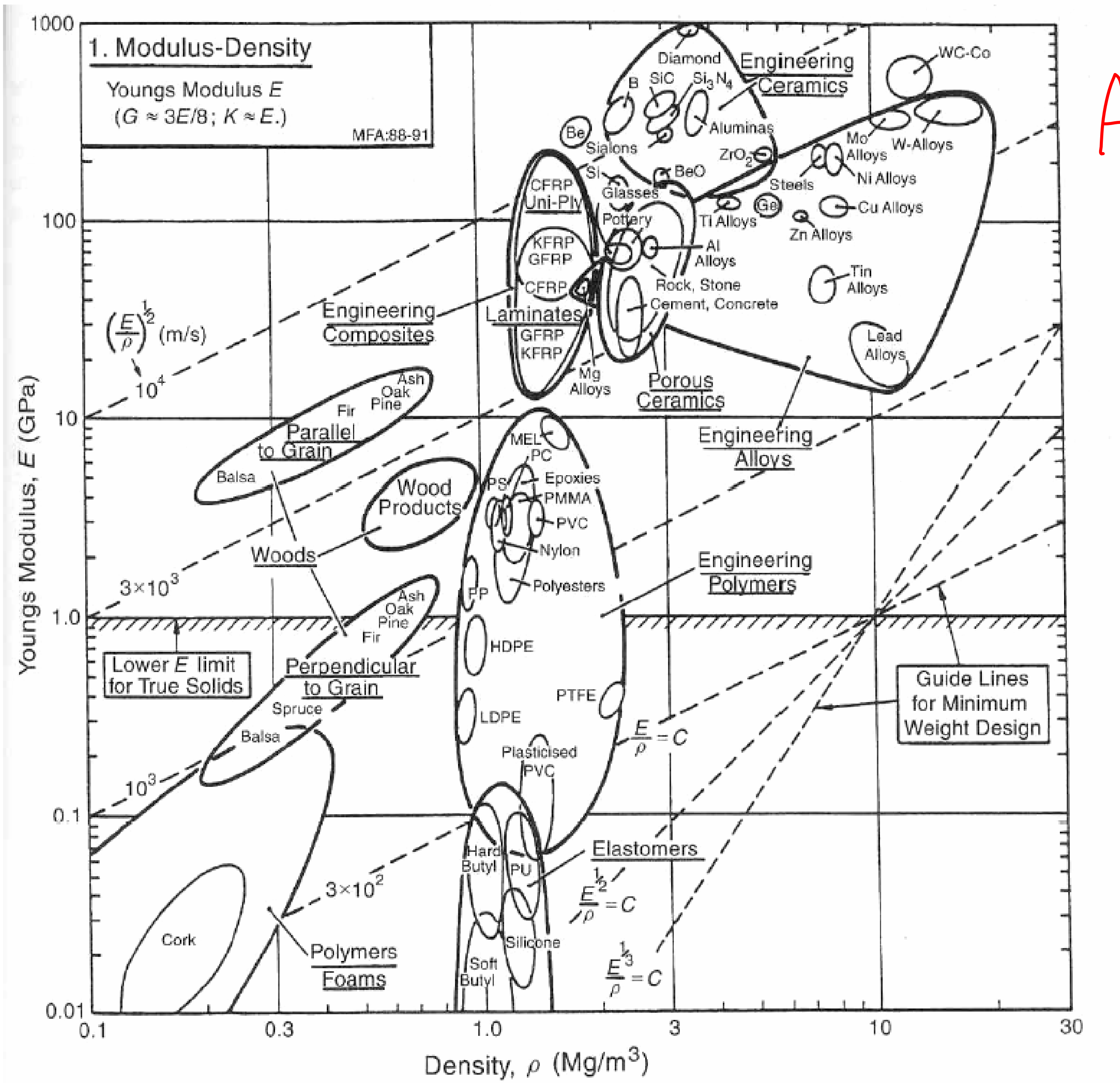


Adapted from Fig. 6.3, *Callister 7e.* (Fig. 6.3 is taken from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, p. 2, John Wiley and Sons, New York, 1965.)

• **Typical tensile specimen**

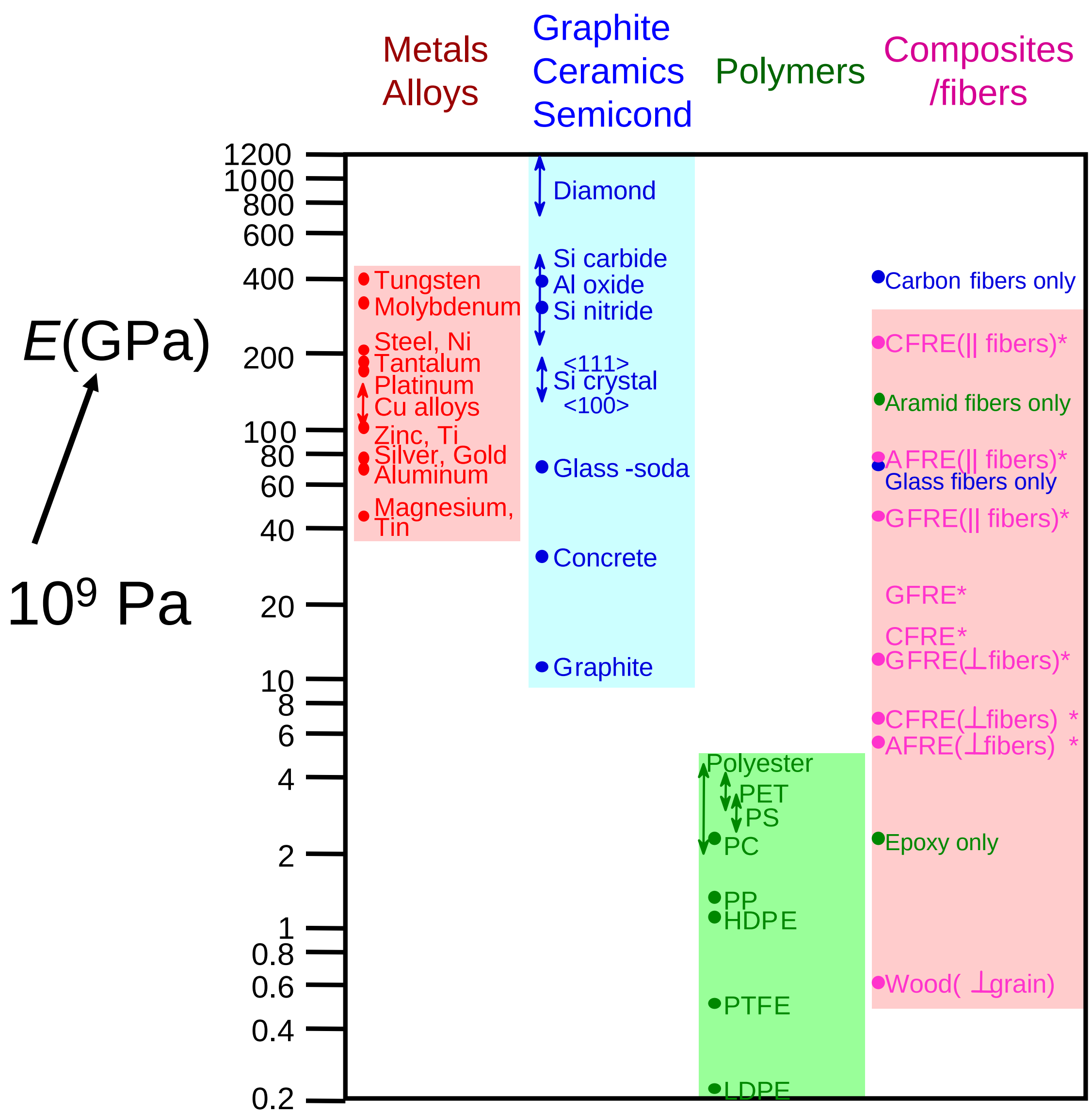


Adapted from Fig. 6.2, *Callister 7e.*


1. Modulus-Density
Youngs Modulus E
(G ≈ 3E/8; K ≈ E.)
MFA:88-91
Engineering Ceramics
Diamond
WC-Co
Engineering Composites
Laminates
Porous Ceramics
Engineering Alloys
Wood Products
Woods
Parallel to Grain
Perpendicular to Grain
Engineering Polymers
Lower E limit for True Solids
Elastomers
Polymers Foams
Guide Lines for Minimum Weight Design
Youngs Modulus, E (GPa)
Density, ρ (Mg/m3)

Ashby Plot

Young's Moduli: Comparison



Based on data in Table B2, *Callister 7e*.

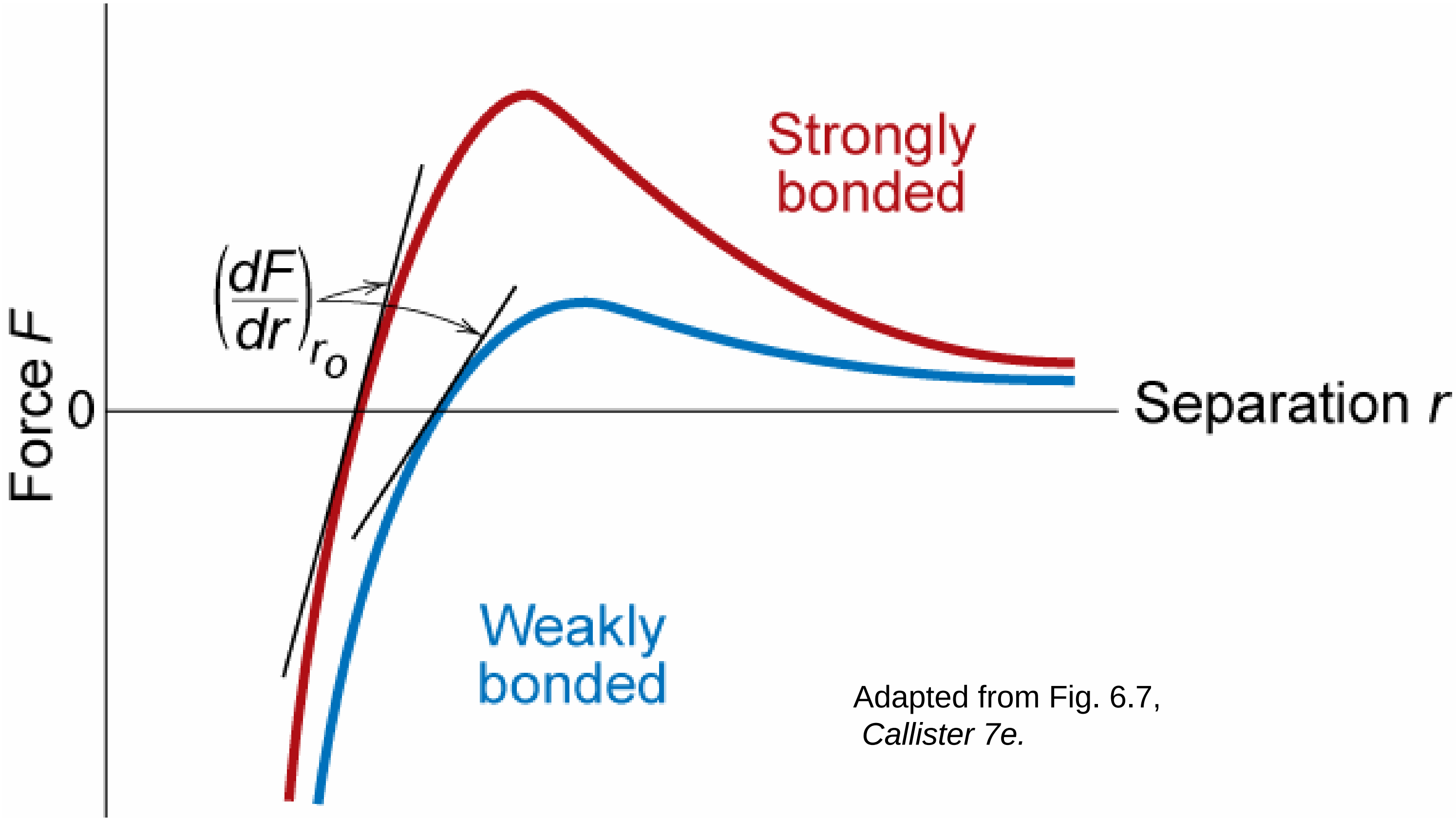
Composite data based on reinforced epoxy with 60 vol% of aligned carbon (CFRE), aramid (AFRE), or glass (GFRE) fibers.

Useful reference values

Diamond	700-1200 GPa
Carbon fibre	230-400 GPa
Steel	200 GPa
Aluminium	70 GPa
Glass	70 GPa
Polyethylene	0.1-1 GPa

Mechanical Properties

- Slope of stress strain plot (which is proportional to the elastic modulus) depends on bond strength of metal



Adapted from Fig. 6.7, *Callister 7e.*

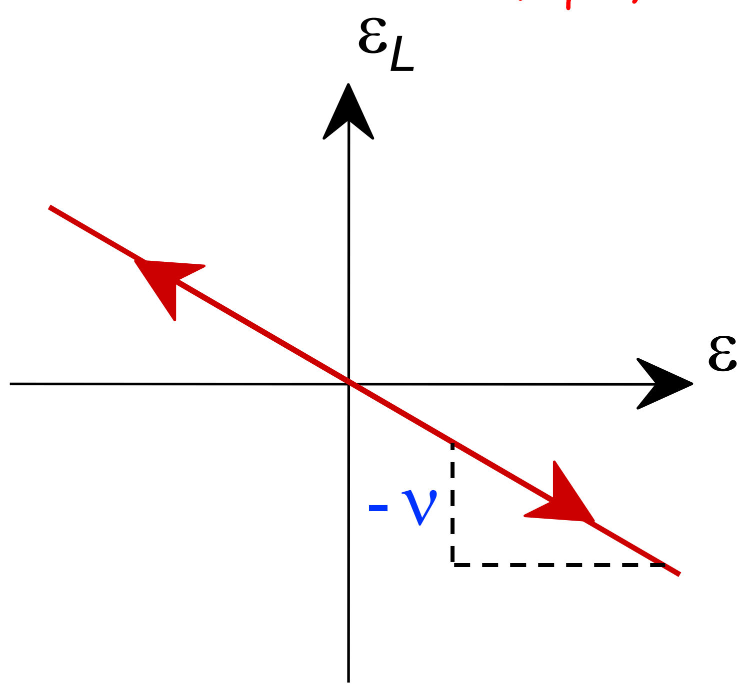
Poisson's ratio, ν

Auxetic

- **Poisson's ratio, ν:**

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

lateral



metals: ν ~ 0.33
ceramics: ν ~ 0.25
polymers: ν ~ 0.40

Units:
E: [GPa] or [psi]
ν: dimensionless

–ν > 0.50 density increases

–ν < 0.50 density decreases (voids form)

Next time

- More about what actually happens in the material
- Strengthening (Ch. 7)
- More on behavior for specific materials
- Failure (Ch. 8)
  - Fracture
  - Creep
  - Fatigue