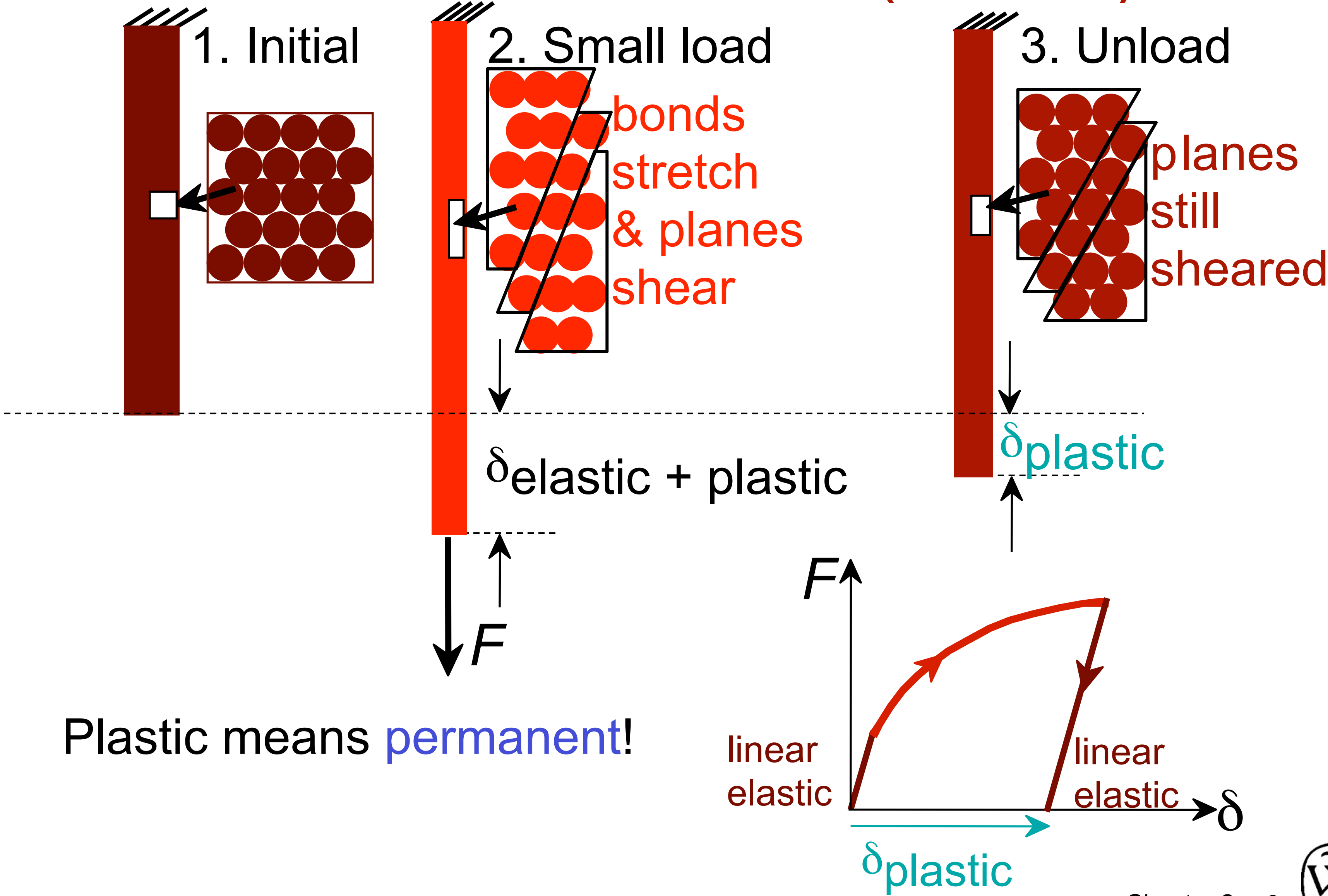
MSE 170 Final review part 2

- Exam date: 12/9/2008 Tues, 8:30-10:20
- Place: Here!
- Closed book, no notes and no collaborations
- Two sheets of letter-sized paper with double-sided notes is allowed
- Exam is comprehensive: material on the exam will be taken from the text book reading, lecture notes, homework, and lab
- Bring a calculator and straight edge/triangle
- The review materials are not comprehensive, there may be questions on the exam on topics not listed here

Plastic deformation

- Slip plane, direction and system, resolved shear stress
- Mechanism of plastic deformation
- Strengthening mechanisms
- Recovery, recrystallization, and grain growth

Plastic Deformation (Metals)

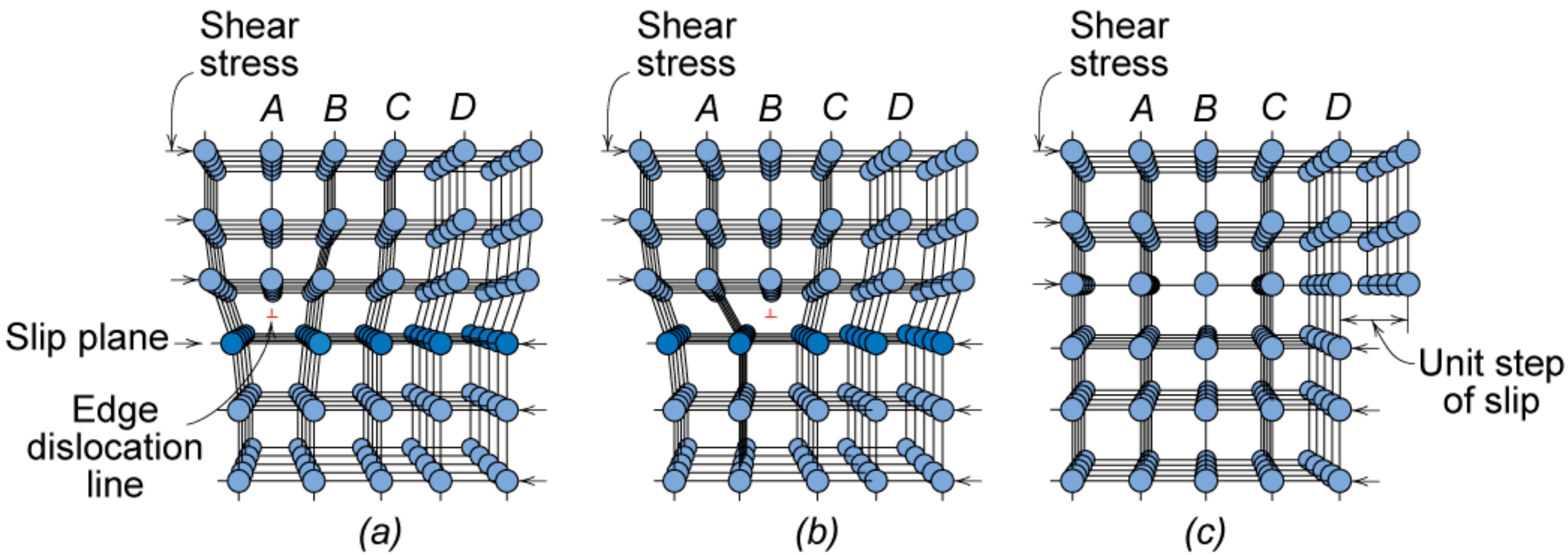


Plastic means permanent!

Dislocation Motion

Dislocations & plastic deformation

- Cubic & hexagonal metals - plastic deformation by plastic shear or slip where one plane of atoms slides over adjacent plane by defect motion (dislocations).



- If dislocations don't move, deformation doesn't occur!

Adapted from Fig. 7.1, *Callister 7e.*

Failure

- Ductile vs brittle fracture
- Stress concentrations and fracture toughness
- Creep and fatigue failure

Phase diagram

- Solubility limits, solidus, liquidus
- Binary isomorphic and eutectic phase diagrams
- Eutectic, peritectic, eutectoid reactions
- Lever law, weight fraction of phases
- Composition and microstructure of equilibrium phases

Aside: a touch of Thermodynamics

Entalpy~ Internal Energy

$$\Delta G = \Delta H - T\Delta S$$

Gibb's free Energy

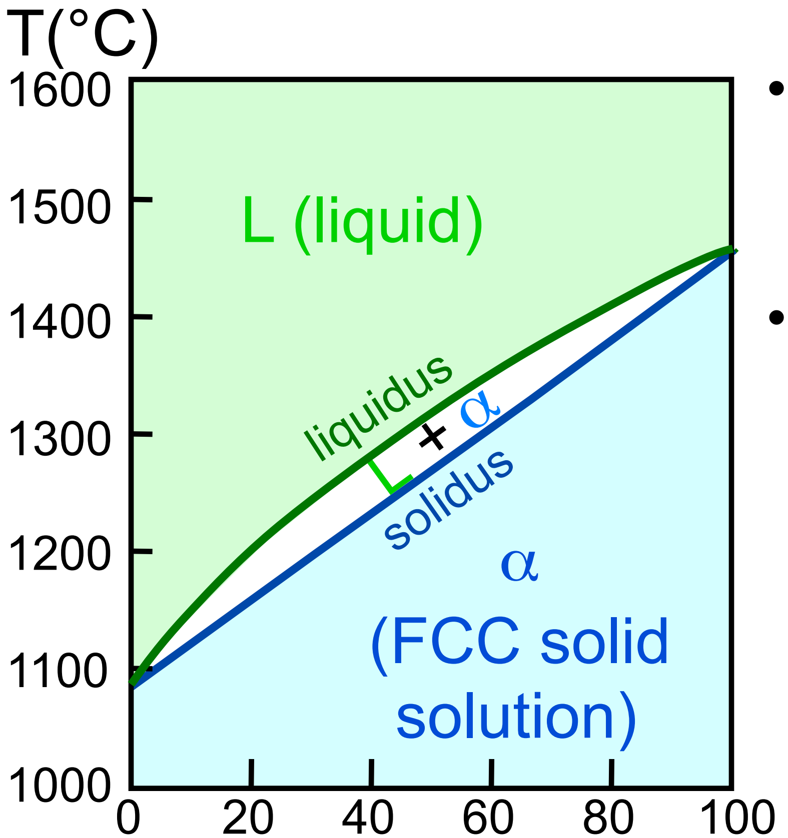
Entropy~ disorder~ probability

A transformation will occur spontaneously if ΔG is negative.

Phase Diagrams

- Indicate phases as function of T, C_o, and P.
- For this course:
  - -binary systems: just 2 components.
  - -independent variables: T and C_o (P = 1 atm is almost always used).

- Phase Diagram for Cu-Ni system



- 2 phases:
  - L (liquid)
  - α (FCC solid solution)
- 3 phase fields:
  - L
  - L + α
  - α

Adapted from Fig. 9.3(a), Callister 7e. (Fig. 9.3(a) is adapted from Phase Diagrams of Binary Nickel Alloys, P. Nash (Ed.), ASM International, Materials Park, OH (1991).

Eutectoid & Peritectic

- Eutectic - liquid in equilibrium with two solids

$$L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$

- Eutectoid - solid phase in equation with two solid phases

$$S_2 \rightleftharpoons S_1 + S_3$$

intermetallic compound
- cementite

$$\gamma \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + Fe_3C \qquad (727^oC)$$

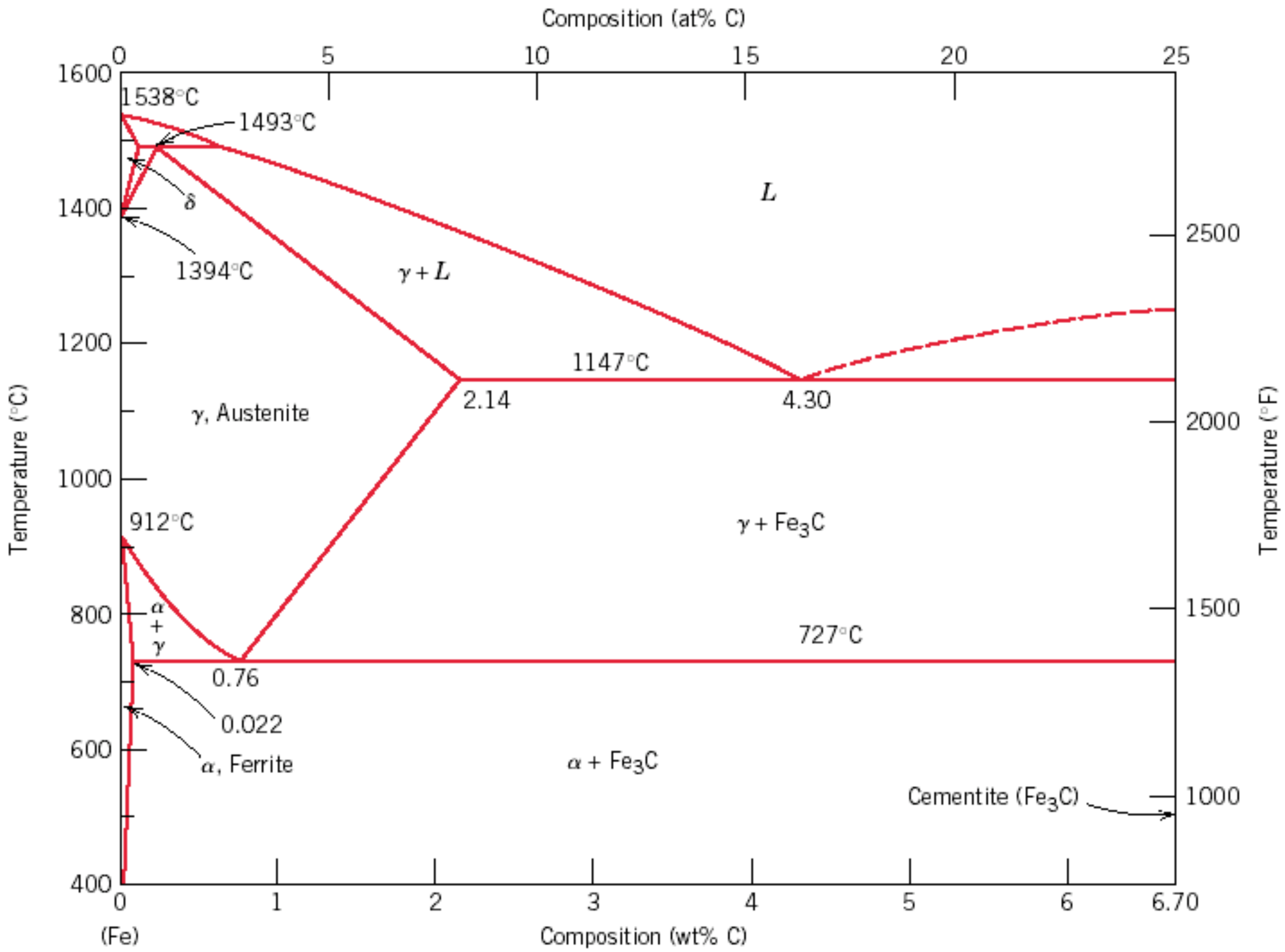
- Peritectic - liquid + solid 1 → solid 2 (Fig 9.21)

$$S_1 + L \rightleftharpoons S_2$$

$$\delta + L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \gamma \qquad (1493^oC)$$

The iron-iron carbide (Fe-Fe_3C) phase diagram

- Ferrite-α -BCC, low C solubility(0.022%wt), magnetic
- Austenite-γ-FCC, high C solubility(2.14%wt), nonmagnetic
- Ferrite-δ-BCC
- Cementite (Fe_3C)
- Eutectic, peritectic, eutectoid
- Iron, ferrite (C<0.008wt%)
- Stainless steel, α +Fe_3C (0.008-2.14wt %)



Phase transformation

- Nucleation/growth controlled phase transformation
- Diffusional vs diffusionless
- Rate of transformation
- Isothermal transformation diagrams

Phase Transformations

Nucleation

– nuclei (seeds) act as template to grow crystals

Driving force to nucleate increases as we increase ΔT

In Δ T range close to T_m, rate of nucleation higher with higher Δ T

– supercooling (eutectic, eutectoid)

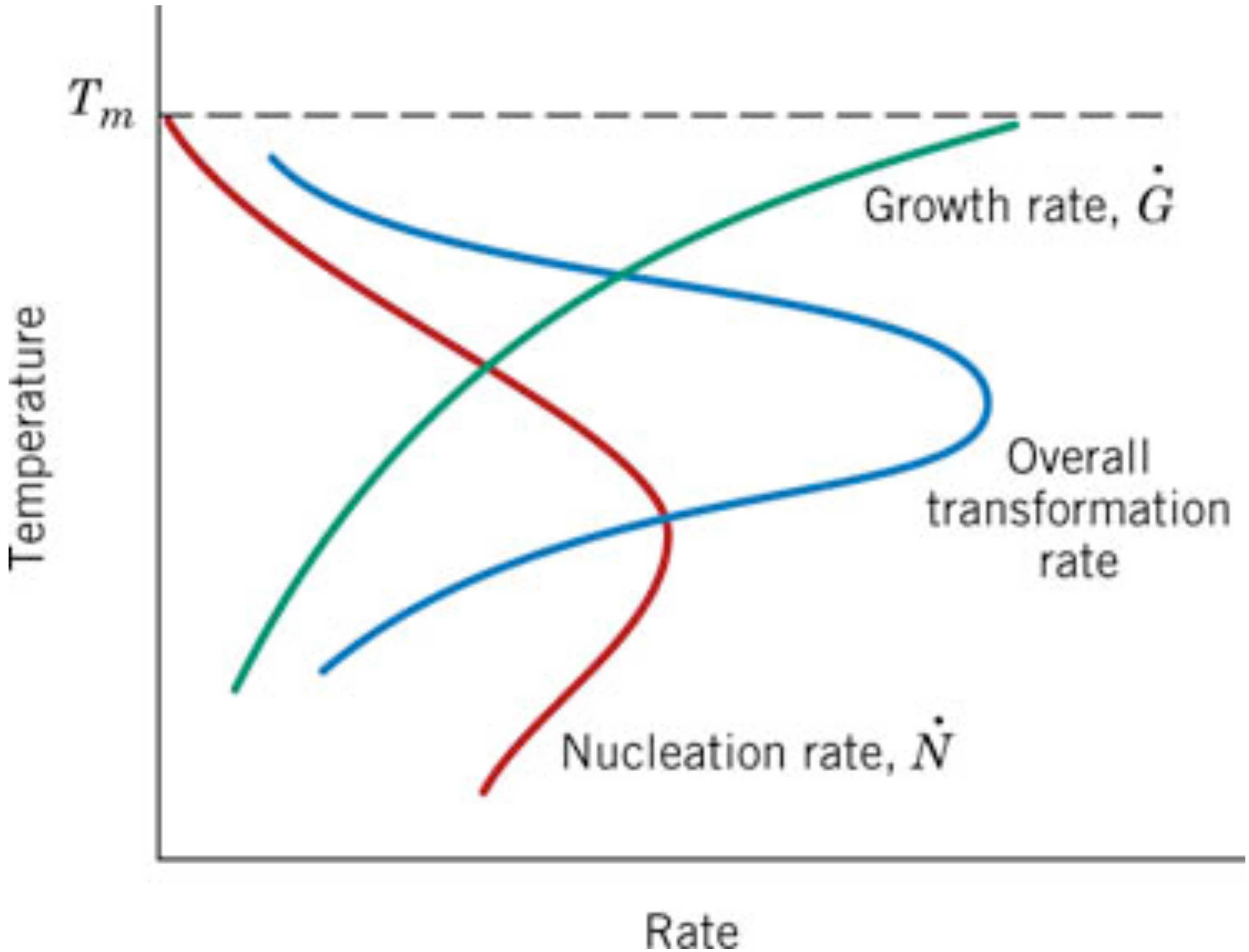
Growth

Growth rate increases with T (thermally activated)

$$dG/dt = C \exp(-Q/kT)$$

Small supercooling → few nuclei - large crystals

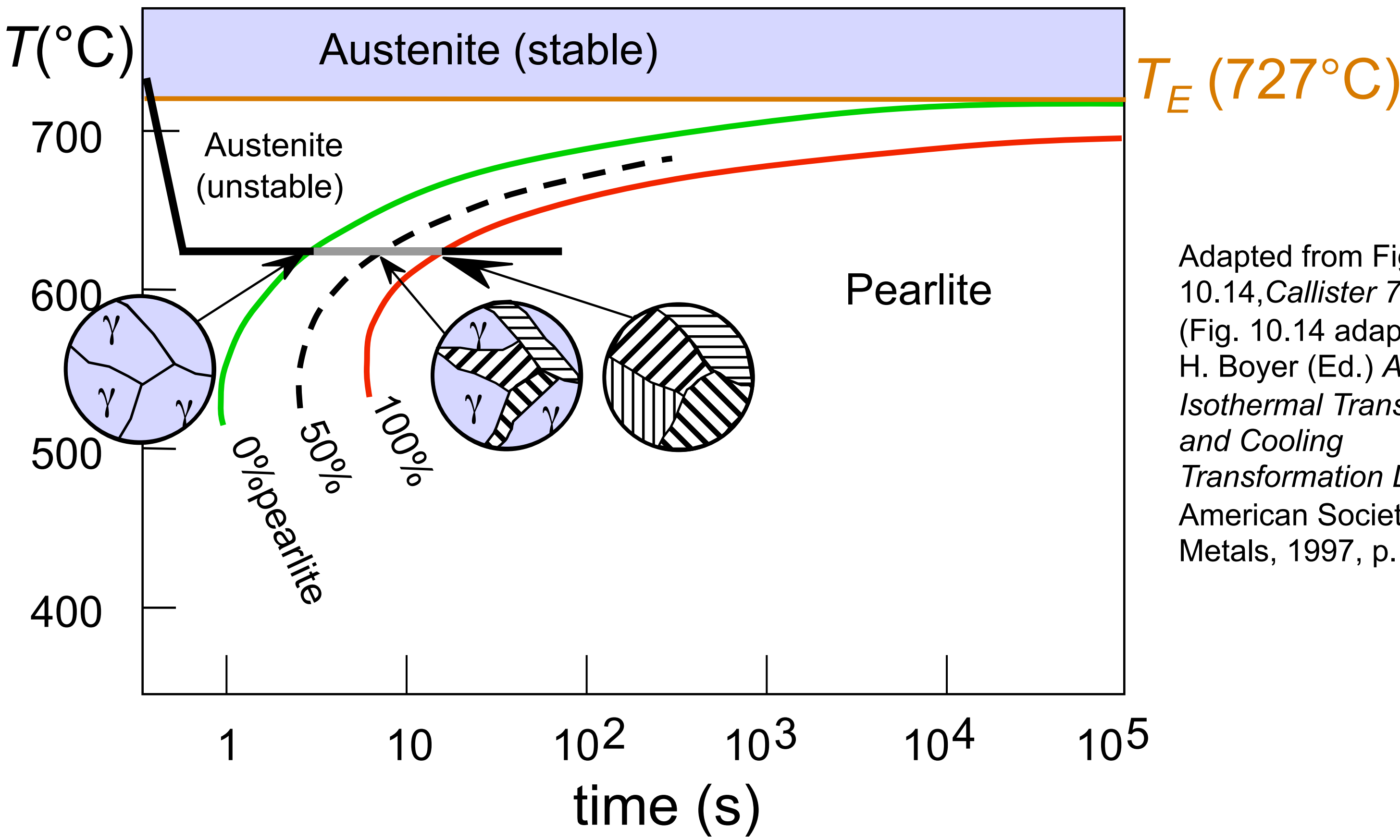
Large supercooling → rapid nucleation - many nuclei, small crystals



T_m
Growth rate, $\dot{G}$
Overall transformation rate
Nucleation rate, $\dot{N}$
Temperature
Rate

Effect of Cooling History in Fe-C System

- Eutectoid composition, C_o = 0.76 wt% C
- Begin at T > 727°C
- Rapidly cool to 625°C and hold isothermally.



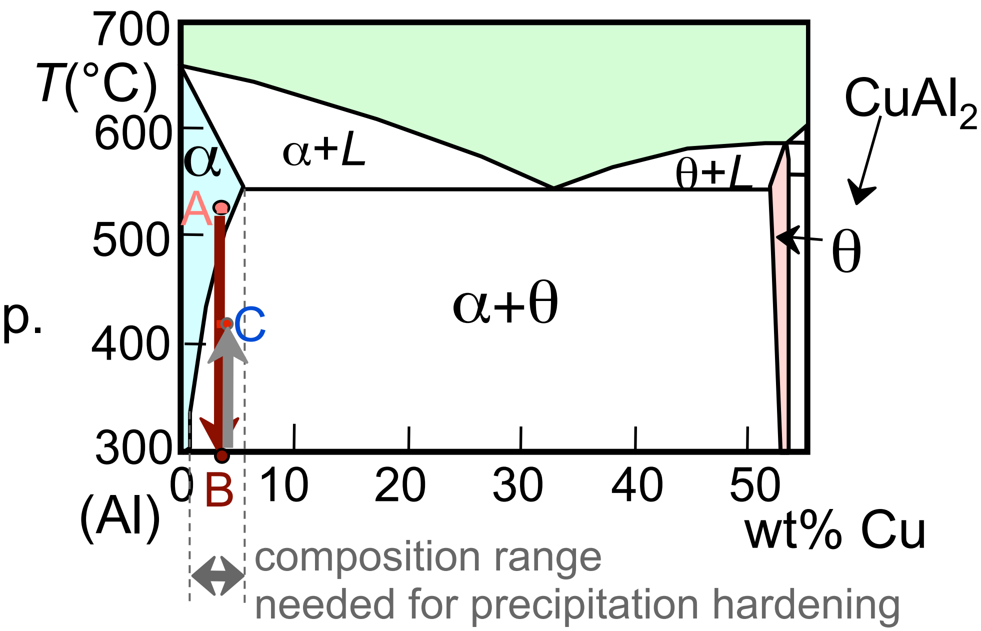
Adapted from Fig. 10.14, *Callister 7e*. (Fig. 10.14 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1997, p. 28.)

Thermal processing of metals and alloys

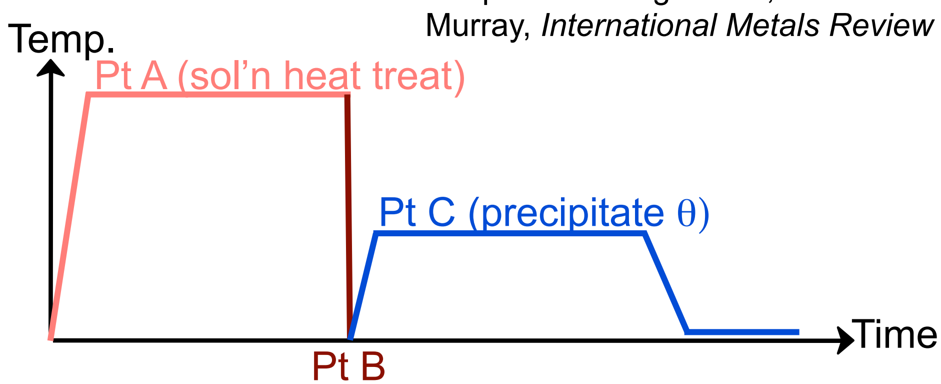
- Quenching & tempering, annealing, precipitation
- Precipitation hardening
- Factors that influence quenching
- Hardenability

Precipitation Hardening

- Particles impede dislocations.
- Ex: Al-Cu system
- Procedure:
  --Pt A: solution heat treat (get α solid solution)
  --Pt B: quench to room temp.
  --Pt C: reheat to nucleate small θ crystals within α crystals.
- Other precipitation systems:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



Adapted from Fig. 11.24, *Callister 7e*. (Fig. 11.24 adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985.)



Adapted from Fig. 11.22, *Callister 7e*.

Structures and properties of ceramics

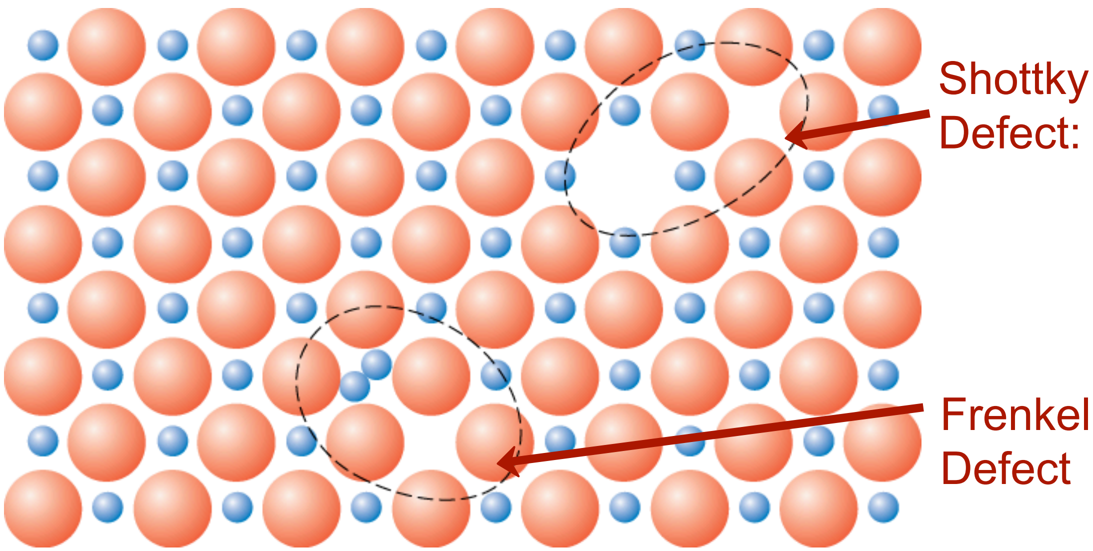
- Imperfection in ceramics
- Ceramic phase diagrams
- Mechanical properties of ceramics

Defects in Ceramic Structures

- Frenkel Defect

  --a cation is out of place.
- Shottky Defect

  --a paired set of cation and anion vacancies.



Adapted from Fig. 12.21, *Callister 7e.* (Fig. 12.21 is from W.G. Moffatt, G.W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, John Wiley and Sons, Inc., p. 78.)

- Equilibrium concentration of defects $\sim e^{-Q_D/2kT}$

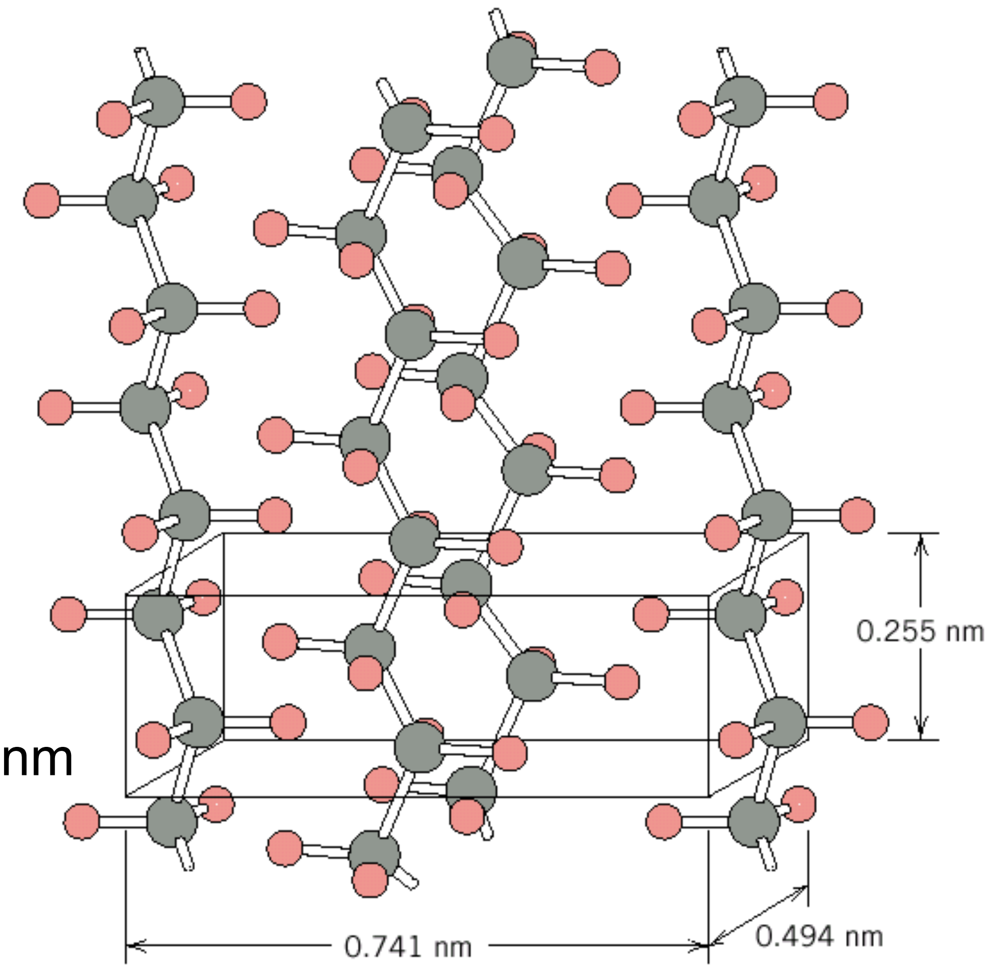
Polymer properties

- Hydrocarbon molecules
  - Saturated and unsaturated
  - Bonding
  - Melting point
  - Isomerism
  - mer, monomer, polymer
- copolymer, homopolymer, blockpolymer
- molecular structures of polymers, molecular weight
- Mechanical properties of polymers
- Crystallization, melting, and glass transition phenomena
- Thermoplastic and thermosetting polymers

Polymer Crystallinity

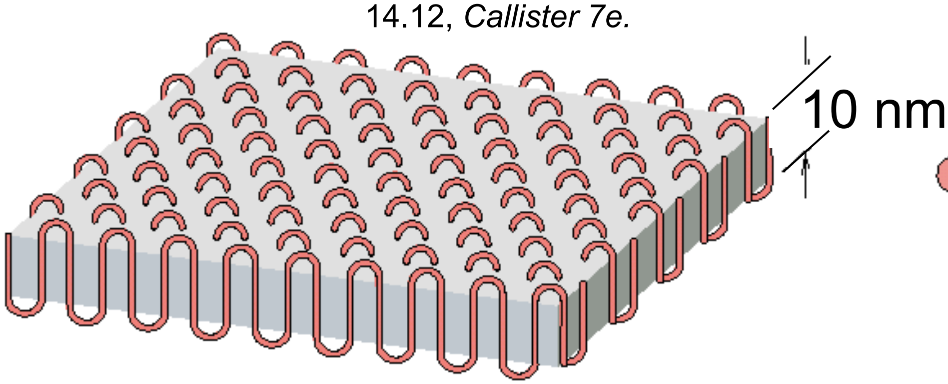
Adapted from Fig. 14.10, *Callister 7e.*

Ex: polyethylene unit cell



- Crystals must contain the polymer chains in some way
  - Chain folded structure

Adapted from Fig. 14.12, *Callister 7e.*

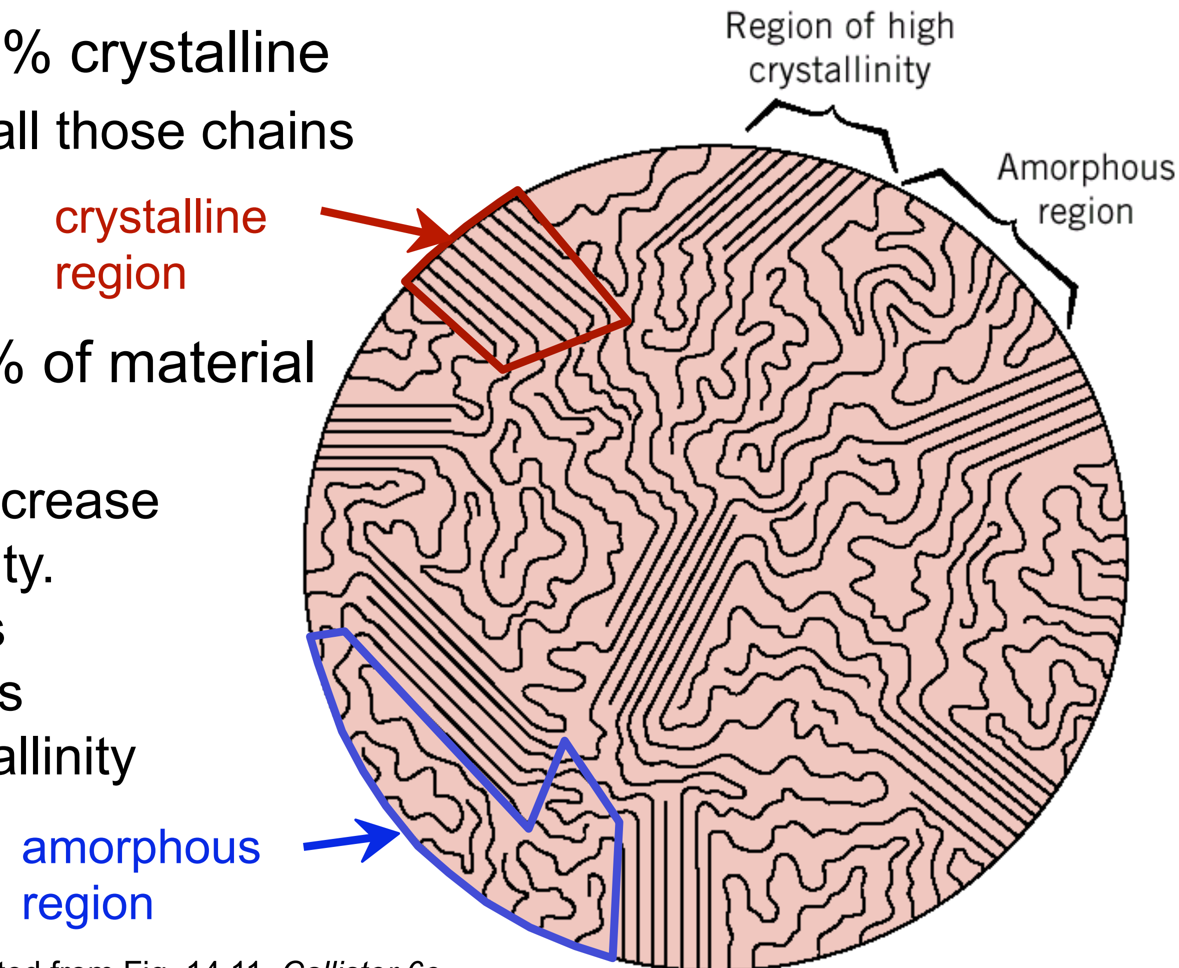


Polymer Crystallinity

Polymers rarely 100% crystalline

- Too difficult to get all those chains aligned

- % Crystallinity: % of material that is crystalline.
  - -- *TS* and *E* often increase with % crystallinity.
  - -- Annealing causes crystalline regions to grow. % crystallinity increases.



Adapted from Fig. 14.11, *Callister 6e.*
(Fig. 14.11 is from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, John Wiley and Sons, Inc., 1965.)

Polymers

- General drawbacks to polymers:
  - -- E, σ_y, K_c, $T_{\text{application}}$ are generally small.
  - -- Deformation is often T and time dependent.
  - -- Result: polymers benefit from composite reinforcement.
- Thermoplastics (PE, PS, PP, PC):
  - -- Smaller E, σ_y, $T_{\text{application}}$
  - -- Larger K_c
  - -- Easier to form and recycle
- Elastomers (rubber):
  - -- Large reversible strains!
- Thermosets (epoxies, polyesters):
  - -- Larger E, σ_y, $T_{\text{application}}$
  - -- Smaller K_c

Table 15.3 *Callister 7e*:

Good overview of applications and trade names of polymers.

Composites

- Composites, matrix, dispersed phase
- Types of composites and characteristics of each
- Mechanical properties of composites including upper bound and lower bound of elastic modulus

Composite Survey

- Composites
  - Particle-reinforced
    - Large-particle
    - Dispersion-strengthened
  - Fiber-reinforced
    - Continuous (aligned)
    - Discontinuous (short)
      - Aligned
      - Randomly oriented
  - Structural
    - Laminates
    - Sandwich panels

Adapted from Fig. 16.2, *Callister 7e*.

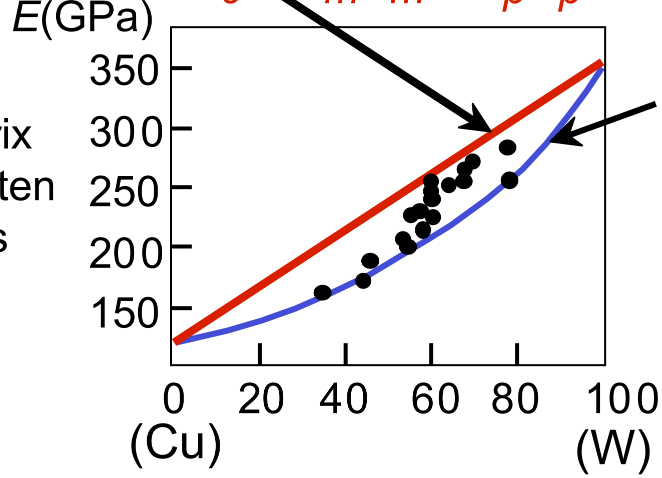
Composite Survey: Particle-III

Particle-reinforced | Fiber-reinforced | Structural

- Elastic modulus, E_c, of composites:
  - -- two approaches.

upper limit: "rule of mixtures"

$$E_c = V_m E_m + V_p E_p$$



Data:
Cu matrix
w/tungsten
particles

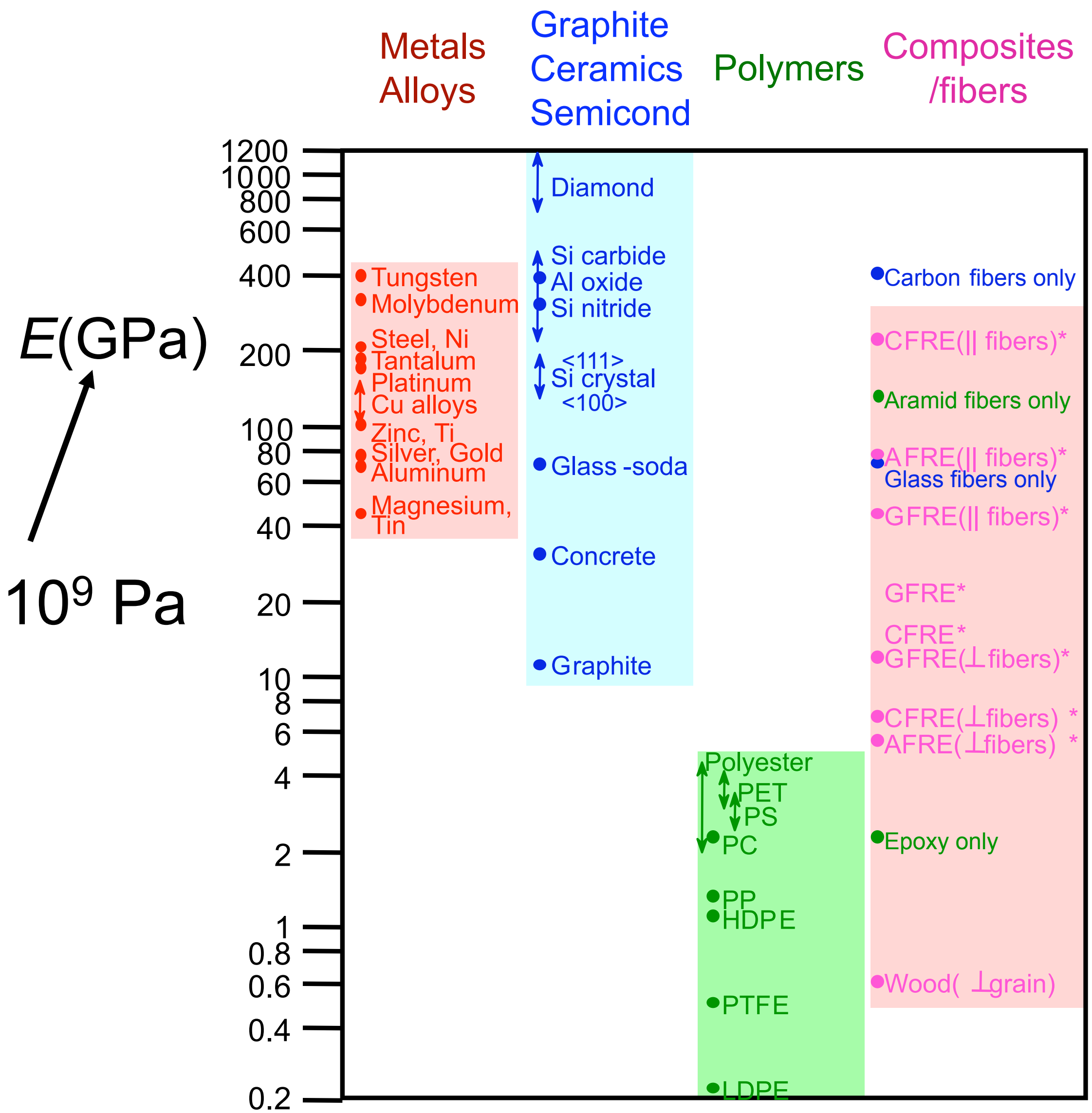
lower limit:

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_p}{E_p}$$

Adapted from Fig. 16.3, *Callister 7e*. (Fig. 16.3 is from R.H. Krock, *ASTM Proc*, Vol. 63, 1963.)

- Application to other properties:
  - -- Electrical conductivity, σ_e: Replace E in equations with σ_e.
  - -- Thermal conductivity, k: Replace E in equations with k.

Young's Moduli: Comparison



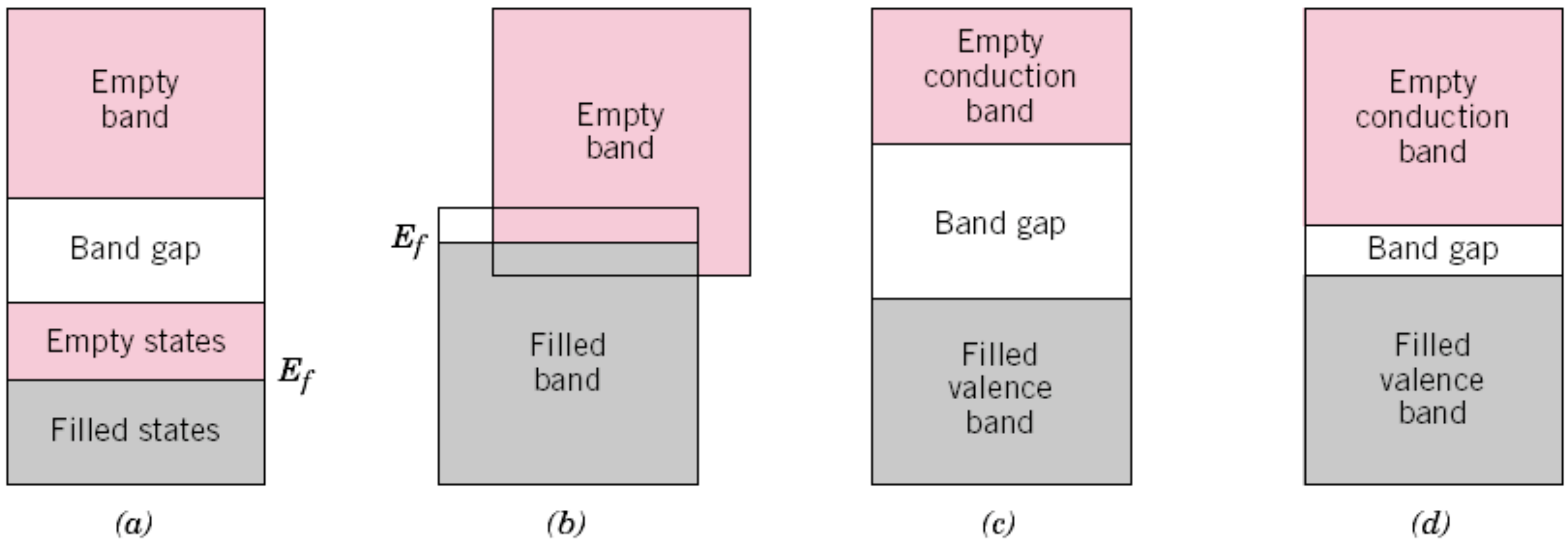
Based on data in Table B2, *Callister 7e*.
Composite data based on reinforced epoxy with 60 vol% of aligned carbon (CFRE), aramid (AFRE), or glass (GFRE) fibers.

Electrical properties

- Intrinsic semiconductors
- Extrinsic semiconductors
- Energy band structure
- Electric conductivity, resistivity and mobility
- Carrier concentration
- P-N junctions and diodes

Various possible electron band structures

- Fermi energy E_f: the energy corresponding to the highest filled state at 0 K



Metal (Cu) **Metal (Mg)** **Insulator** **Semiconductor**

Ohm's Law

Further definitions

$\boxed{J = \sigma\, \varepsilon}$ <= another way to state Ohm's law

$J \equiv$ current density $= \dfrac{\text{current}}{\text{surface area}} = \dfrac{I}{A}$ like a flux

$\varepsilon \equiv$ electric field potential $= V/\ell$ or $(\Delta V/\Delta \ell)$

$$J = \sigma\, (\Delta V/\Delta \ell)$$

Electron flux conductivity voltage gradient

<u>Current carriers</u>

- electrons in most solids
- ions can also carry (particularly in liquid solutions)

Electrical Properties

- Electrical conductivity and resistivity are:
  -- material parameters.
  -- geometry independent.
- Electrical resistance is:
  -- a geometry and material dependent parameter.
- Conductors, semiconductors, and insulators...
  -- differ in accessibility of energy states for conductance electrons.
- For metals, conductivity is increased by
  -- reducing deformation
  -- reducing imperfections
  -- decreasing temperature.
- For pure semiconductors, conductivity is increased by
  -- increasing temperature
  -- doping (e.g., adding B to Si (*p*-type) or P to Si (*n*-type).

Good Luck!