EGN 3365
Review on Metals, Ceramics, & Polymers, and Composites

Expectations on Chapter 11

❑Chapter 11

- Understand metals are generally categorized as ferrous alloys and non-ferrous alloys and ferrous alloys are further categorized by carbon content as steel and cast iron and understand the concept of each
- Understand steel is categorized by carbon content as low carbon, mid-carbon, and high carbon steels. Be able to briefly describe the impacts of carbon content on mechanical properties (especially hardness, strength, and ductility) of steels
- Understand the benefits of cast iron and that the mechanical property of cast iron
- Be able to use iron-carbon (Fe-C) and iron-cementite (Fe-Fe3C) phase diagram to determine the phases present, the composition of each phase, and the relative amount of each phase
- Understand how microstructure of steel and cast iron impacts their mechanical properties significantly
- Understand the major limitations with ferrous alloys are poor corrosion resistance and, in some cases, high density.
- Understand stainless steel typically include significant concentration of chromium (Cr) as well as other elements into iron to improve corrosion resistance

Expectations on Chapter 11

❑Chapter 11 (continued)

- Be able to describe briefly major characteristics of different categories of non-ferrous alloys including aluminum alloys, copper alloys, titanium alloys, precious metals, and refractory metals.
- Understand the metal processing include refining and forming
- Understand the major categories of forming including casting, forming such as rolling, forging, extrusion, and others such as plating, welding, and powder metallurgy
- Understand the difference between cold forming and hot forming
- Understand the importance of heat treatment or annealing in controlling mechanical properties of steels
- Understand the concepts of aging and precipitation hardening for alloys such as aluminum alloys and how mechanical property change in those processes

Expectations on Chapter 12 & 13

❑Chapter 12 & 13

- Understand the structure of ceramics typically involve oppositely charged ions (or atoms sharing electrons via covalent bonds) that touch each other, and amorphous glass lacks long-range translational order in its structure
- Understand the stable crystalline structure of ceramics is often determined by two factors: one is charge neutrality and the other is the maximization of coordination number for atoms
- For a given unit cell of ceramics, be able to determine coordination number(s), number of atoms present, chemical formula, and molecular weight (or formula weight)
- Understand point defects in ceramics involve more complex structure such as cation-anion vacancy pair (Shottky defect) and interstitial cation-cation vacancy pair (Frenkel defect) and understand the requirement of charge balance (or neutrality) when defects are created
- Understand the same principle in phase diagrams apply for ceramic phase diagrams and be able to use it to determine phases present, composition, and the relative amount of each phase

Expectations on Chapter 12 & 13

❑Chapter 12 & 13 (continued)

- Understand why ceramics typically display no plastic deformation. Understand the mechanical properties of ceramics are often measured in 3-point bending test. Be able to use testing data to determine modulus for ceramics
- Using the example of carbon, understand the properties of materials is significantly influenced by structure
- For glass, understand the change in viscosity for glass with temperature and the forming technique such as blowing, pressing, drawing fiber, and forming sheets
- For typical ceramics, understand the forming technique can be hydro-plastic such as extrusion, casting (slip or tape) or dry pressing. The hydroplastically formed parts need drying. Finally, all ceramic parts typically require final heat treatment at high temperature for sintering to densify the ceramic body.
- Understand the sintering process is driven by reduction of total surface area, which eliminates pores and excess grain boundaries.

Expectations on Chapter 14 & 15

❑Chapter 14 & 15

- Understand polymers are materials with very large molecules obtained from reactions (polymerization) between many small repeating molecules (also called monomers) that most commonly contain carbon and other elements such as H, O, N, S, etc..
- Understand that different polymers are distinguished by the repeating units (monomers) as well as the structures the repeating units are arranged together. Be able to identify the repeating units for simple polymers.
- Understand that the primary structure for a polymer molecule could be linear, branched, cross-linked and networked
- Understand the complexity in the structure for a single polymer molecule also arises from coiling/twisting, rotation, as well as the relative position of side groups/side chains
- Understand the concept of molecular weight for polymer materials and that it has a wide distribution instead of a single value
- Understand a polymer material can be crystalline or amorphous, while typical plastics contain both crystalline and amorphous regions

Expectations on Chapter 14 & 15

❑Chapter 14 & 15 (continued)

- Understand that polymers display different mechanical behaviors from brittle to plastic (with large plastic deformation possible) and to elastomer (rubbery), depending on structure.
- Understand the similarity and difference in mechanical property between polymers and metals and ceramics
- Understand polymer mechanical behavior also depends highly on testing condition, especially temperature and strain rate. Be able to briefly explain the change in mechanical behavior with respect to temperature for typical plastics such as PMMA
- Understand the concept of viscoelastic behavior unique to polymers and the associated change in "modulus" with time and temperature
- Understand the concept of relaxation, creep, fatigue, and fracture for polymers
- Understand the elastic and plastic deformation mechanism for typical plastics and understand the impacts of molecular weight, degree of crystallinity, and predeformation, and heat treating on modulus of polymers

Expectations on Chapter 14 & 15

❑Chapter 14 & 15 (continued)

- Understand the concepts of melting point and glass transition temperature for polymers and how they impacts the behavior of glassy, semicrystalline, and fully crystalline polymers
- Understand the general difference between plastics and rubber (elastomer)
- Understand polymers form either by addition reaction or condensation reaction
- Understand polymers contain additives such as fillers, plasticizers, stabilizers, colorants (dye and pigments) and others
- Understand typical polymer processing techniques include compression molding, injection molding, extrusion, blow molding, etc.
- Understand polymers may be used as fiber, film, coating, foam, or bulk materials.

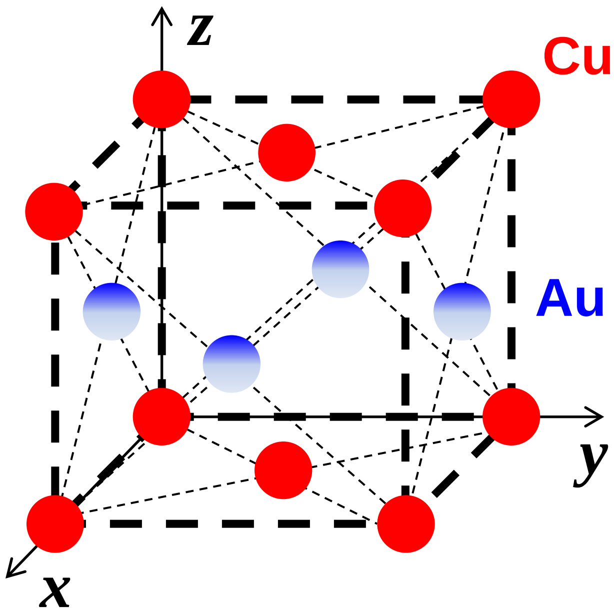
Expectations on Chapter 16

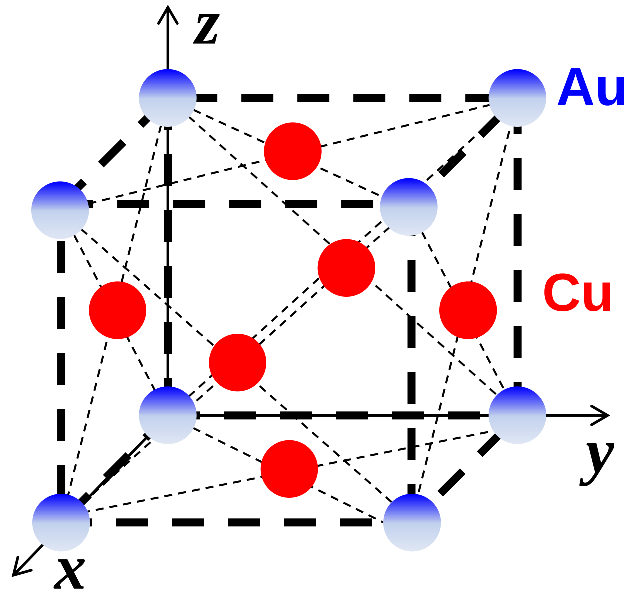
❑Chapter 16

- Understand the concept of composite
- Understand classification of composites by matrix materials
- Understand classification of composites by reinforcement type
- Understand the major improvement in properties of MMC, CMC, and PMC over their respective matrix materials and be able to give simple real world examples for each
- Understand the typical trend of modulus change with respective to reinforcement loading (volume percent) for particle reinforced composites. Understand the impact of fiber alignment and length on reinforcement effect. Be able to use the equations concerning modulus of composite to solve simple problems
- Understand the limitations of composites

Class Exercise

- Given the unit cells for two types of ordered intermetallic compounds between Cu and Au as given below <u>(cubic structure)</u>, please determine the number of Cu and Au atoms per unit cell and the chemical formula for the compounds





2 Cu atoms and 2 Au atoms per unit cell

CuAu

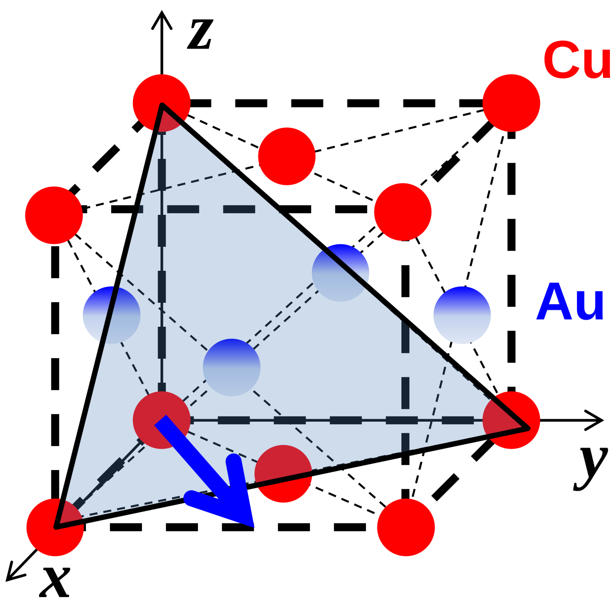
3Cu atoms and 1 Au atoms per unit cell

Cu_3Au

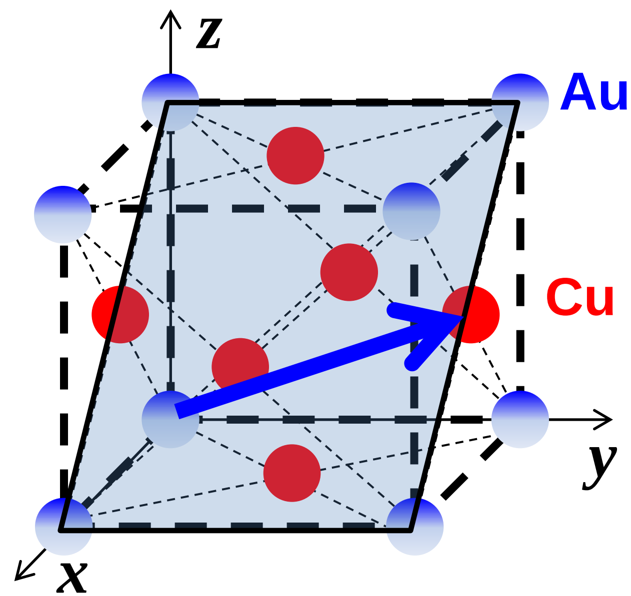
x

Class Exercise

- **Given the unit cell for two types of ordered intermetallic compounds between Cu and Au given below <u>(cubic structure)</u>, please determine the miller indices for the marked crystal planes and directions**



[210] *direction*



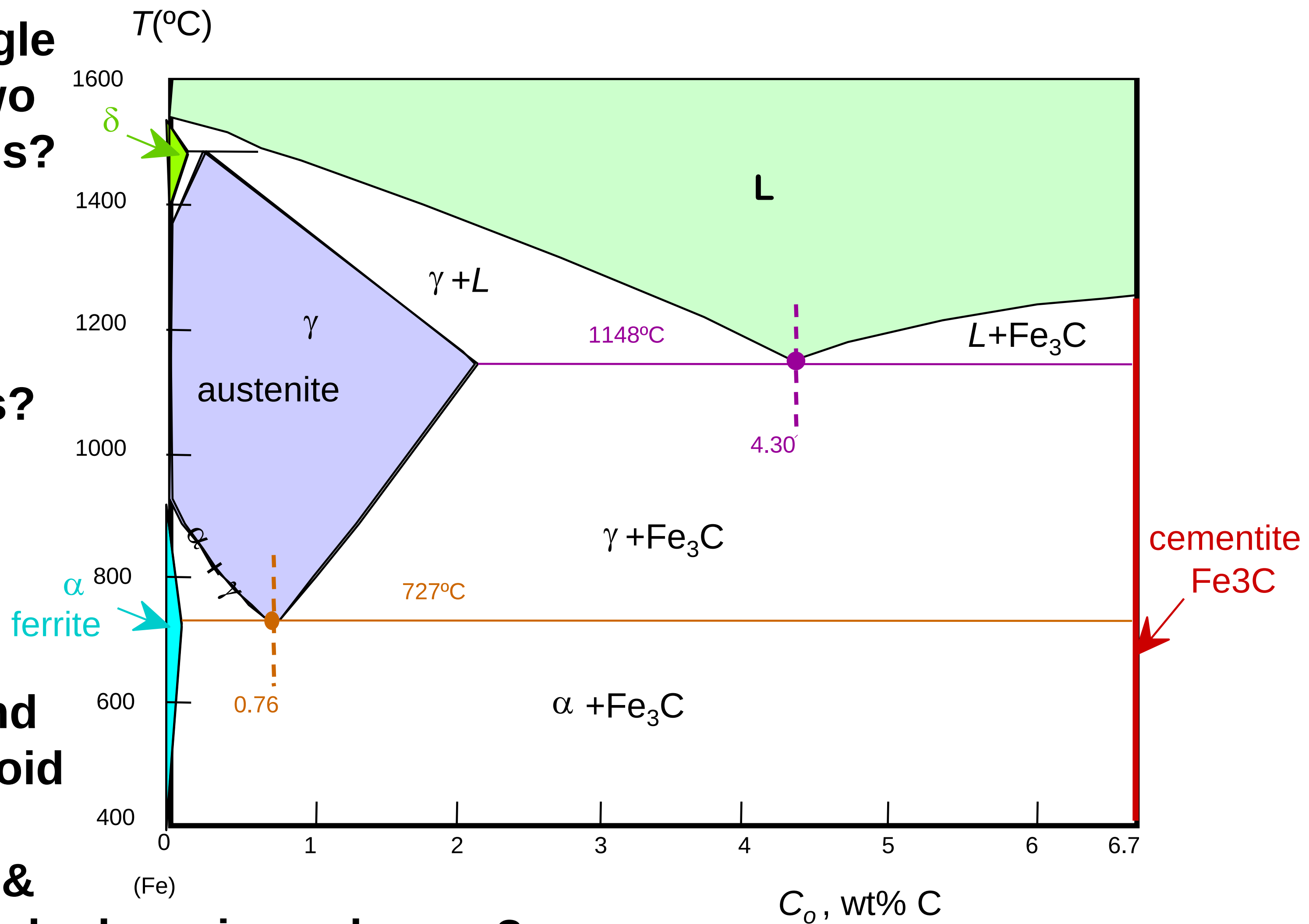
(101) *plane*

[121] *direction*

x

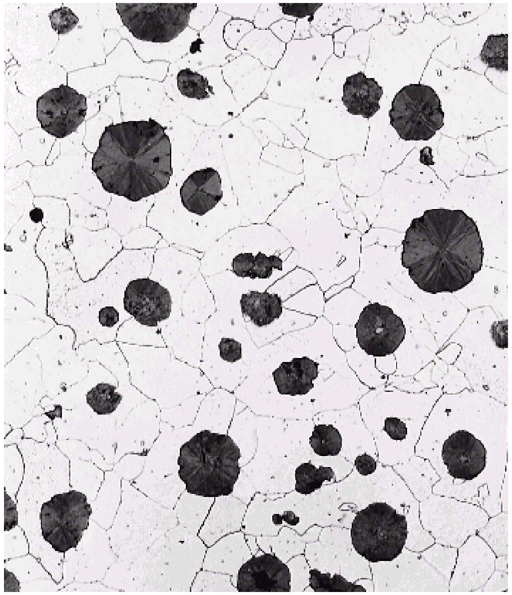
Class Exercise

- What are single phase and two phase regions?
- Eutectic and eutectoid temperatures?
- 0.4wt% C cooled from 1000 ºC to just <u>above</u> and <u>below</u> eutectoid temperature, composition & amount of each phase in each case?



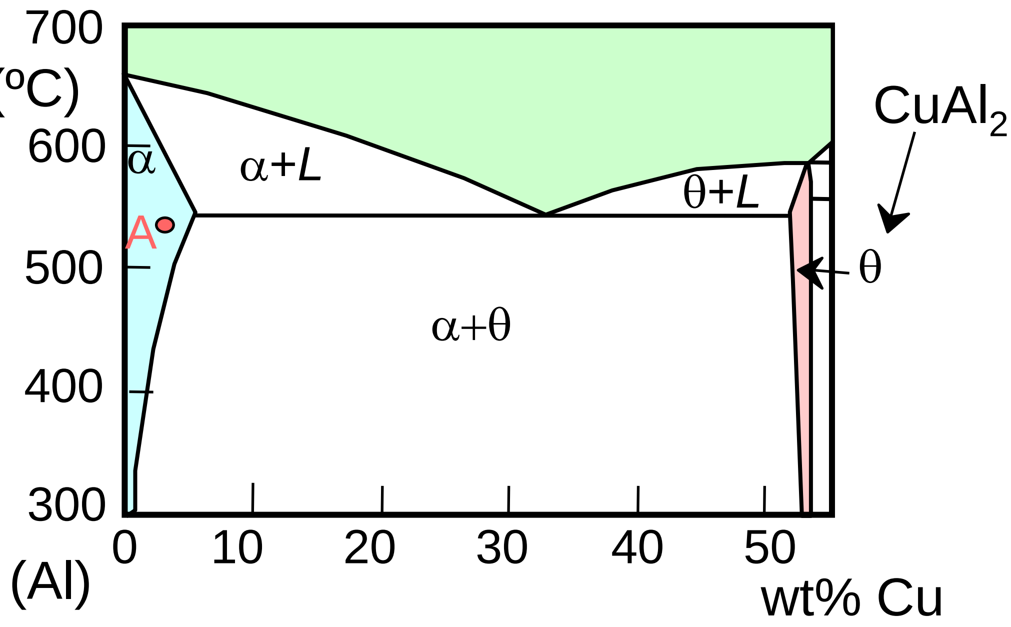
Class Exercise

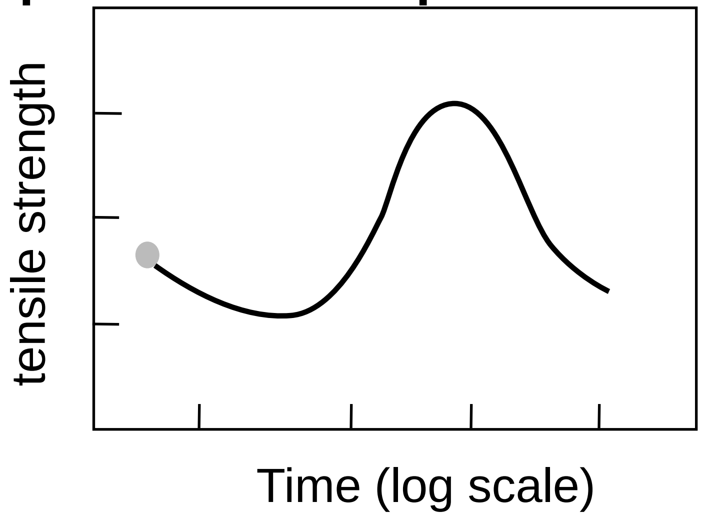
- Two types of cast irons, which one expected to be more brittle and why?



Class Exercise

- Base on part of the Al-Cu phase diagram, if alloy with ~4 wt% of Cu is fast quenched from 550 °C to room temperature and then heated back to ~200 °C and hold, please draw the change of strength with time at that temperature and explain





Class Exercise

❑ **Given the unit cell between compounds between Na and Cl, determine**

- Average number of Na and Cl atoms per unit cell

4 Na and 4 Cl

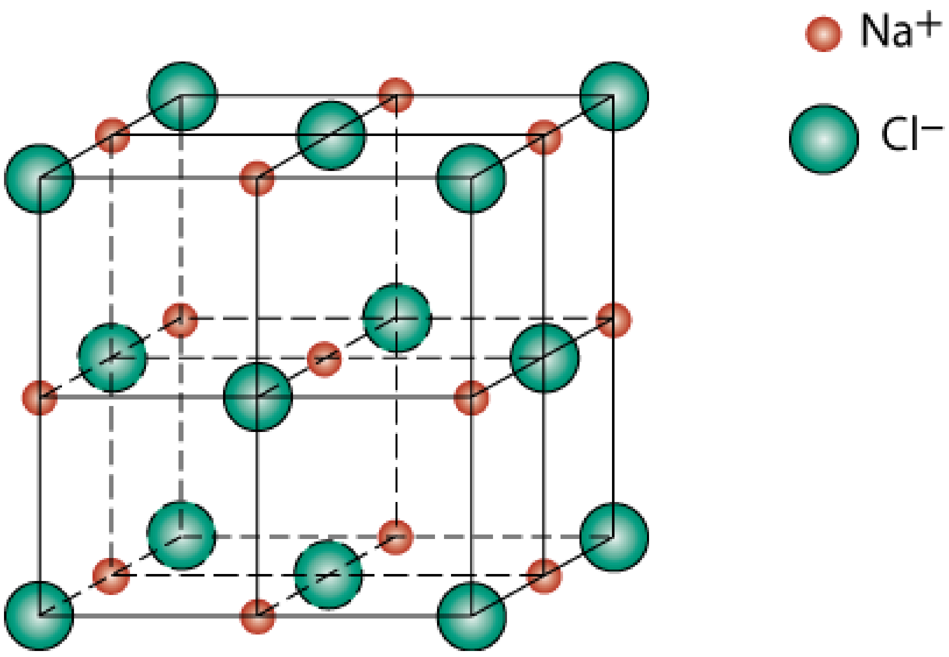
- Coordination number of Na and Cl atoms, respectively

CN (Na) = 6

CN (Cl) = 6

- The chemical formula for the compound

NaCl



Adapted from Fig. 12.2, *Callister & Rethwisch 8e.*

Class Exercise

Based on the phase diagram on the right

❑Identify the components and melting point of each

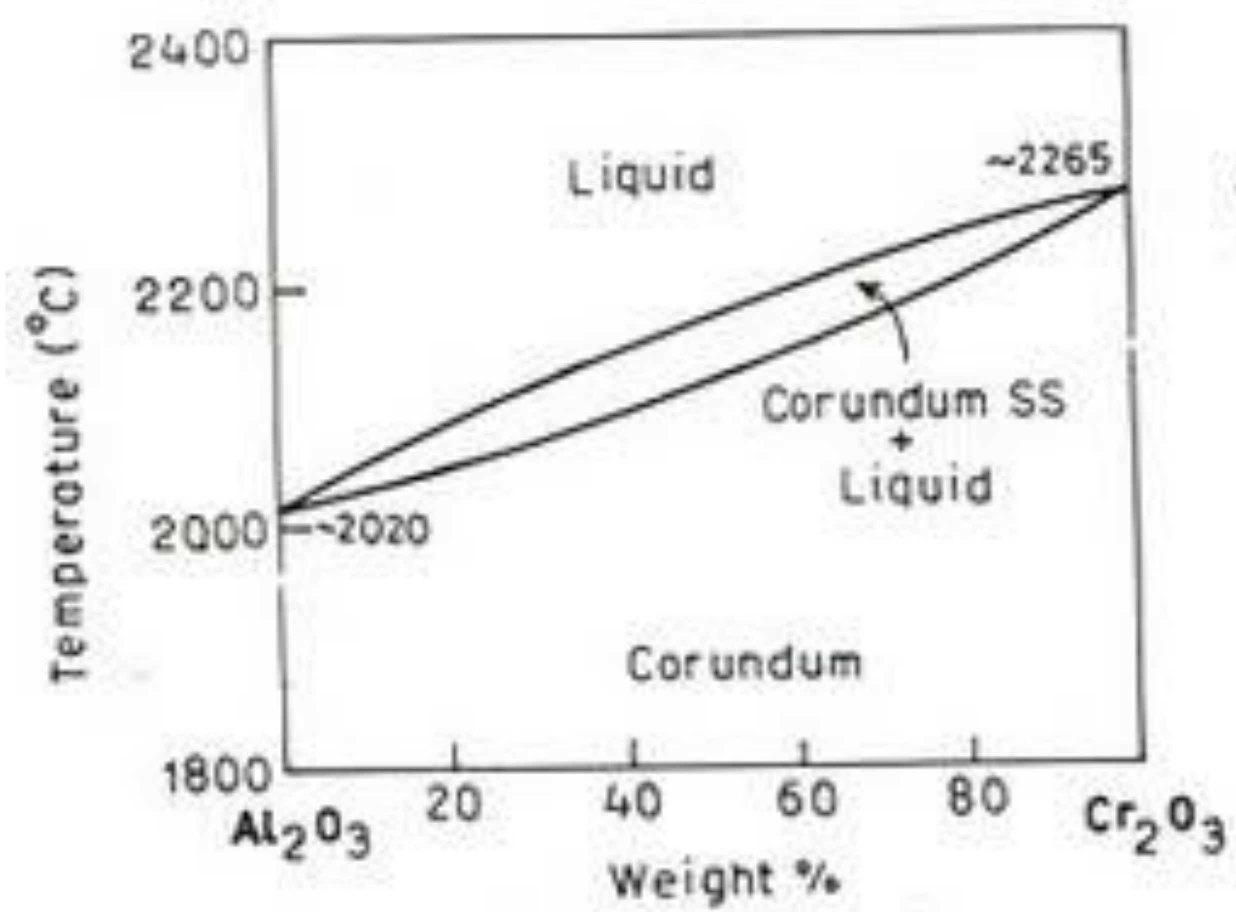
Al_2O_3 (T_m=2020 °C)

Cr_2O_3 (T_m=2265 °C)

❑Identify the single phase and two-phase regions

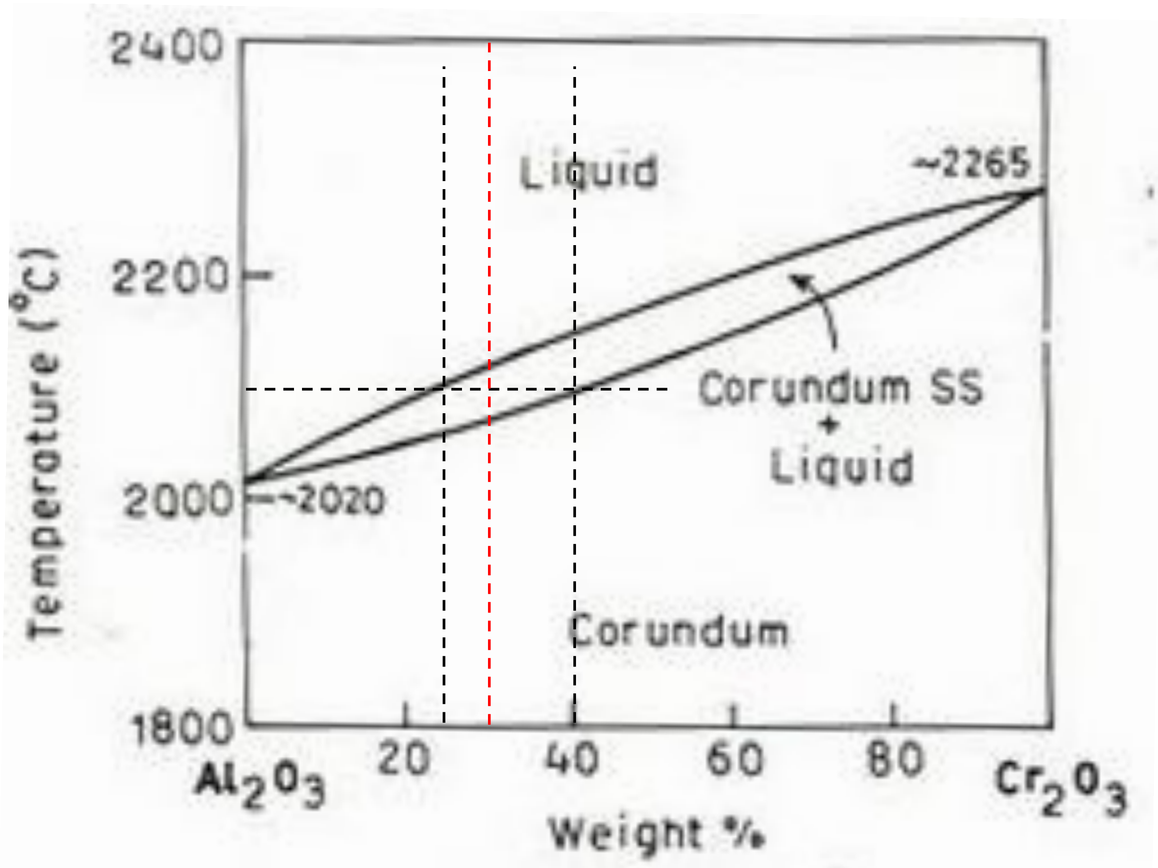
Single phase region: Liquid, Corundum SS;

Two phase region: Liquid + Corundum SS



Class Exercise

- **For a system with 30 wt.% of Cr_2O_3, what are phase(s) present, the composition (in terms of wt.% Cr_2O_3), and weight fraction of each phase at 2400 ^oC and 2100 ^oC?**



2400 ^oC: 100 wt.% Liquid,
C_L= 30 wt.% Cr_2O_3;

2100 ^oC:
C_L= ~24 wt. Cr_2O_3;
C_C= ~40 wt.% Cr_2O_3;

Liquid weight fraction L% = (40-30)/(40-24)=62.5%

Corundum solid solution weigh fraction C% = (30-24)/(40-24) = 37.5%

Class Exercise

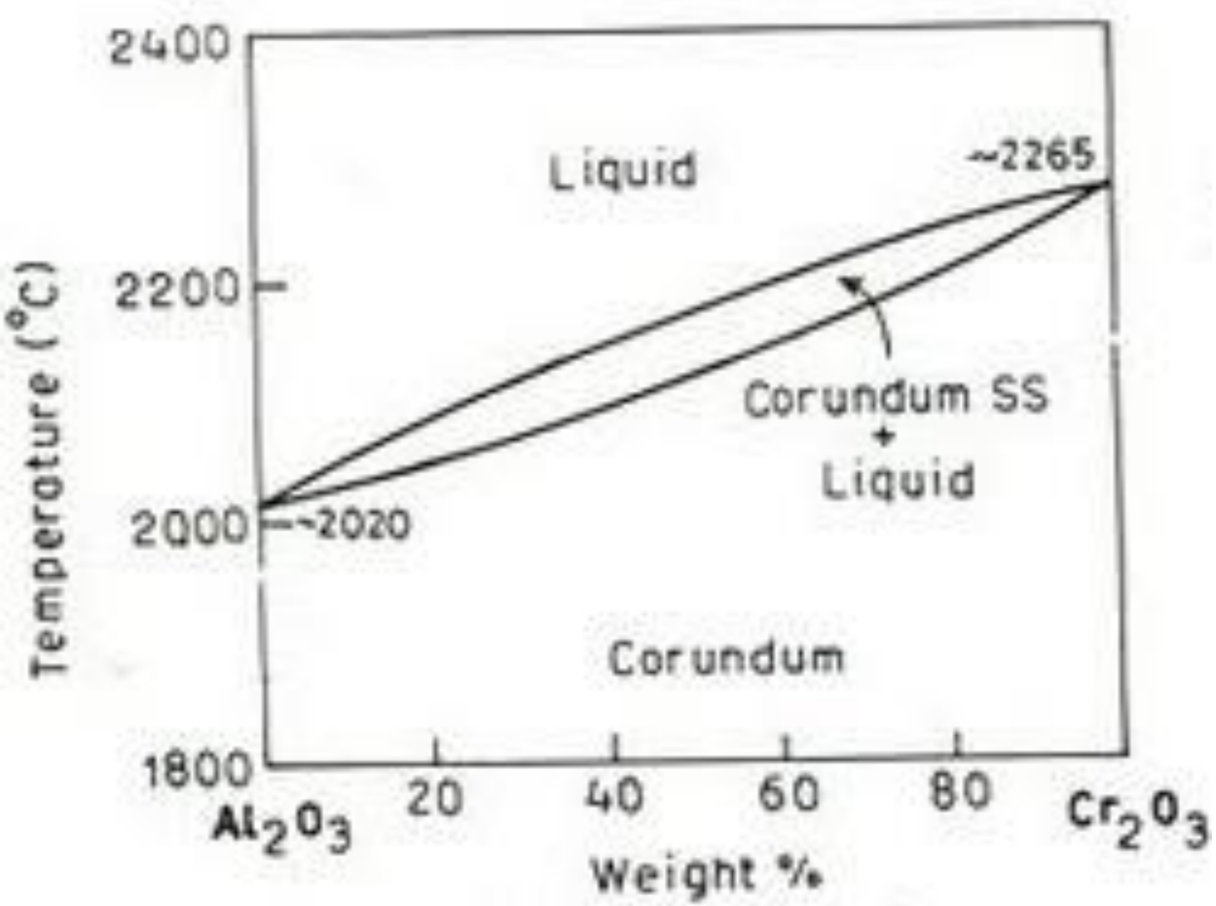
Based on the phase diagram on the right

- ❑**Is the phase diagram eutectic or not? Why?**

NO, it is not eutectic.
It does not have eutectic reaction

- ❑**About the crystal structure of Al_2O_3 and Cr_2O_3, what is your guess of their similarity? Why?**

The crystal structure should be the <u>same</u> because the two components are completely miscible (very high solubility of each other)



Class Exercise

A three-point bending test is performed on a glass specimen having a rectangular cross section of height d = 5 mm (0.2 in.) and width b = 10 mm (0.4 in.); the distance between support points is 45 mm (1.75 in.).

Compute the flexural strength if the load at fracture is 290 N (65 lbf) knowing the flexural strength of

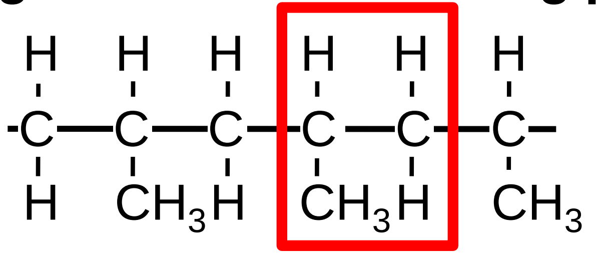
$$\sigma_{fs} = \frac{3F_f L}{2bd^2}$$

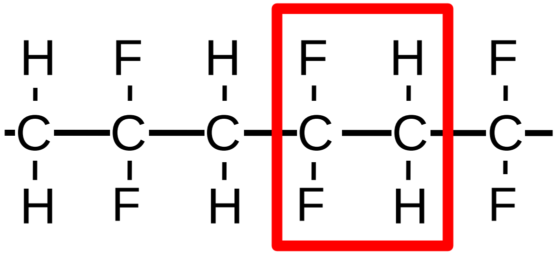
in which F_f is load, L is distance between support points, b and d are cross-section height and width

$$\sigma_{fs} = \frac{(3)(290\ N)(45\times10^{-3} m)}{(2)(10\times10^{-3} m)(5\times10^{-3} m)^2} = 7.83\times10^{7}\ \mathrm{N/m^2} = 78.3\ \mathrm{MPa}$$

Class Exercise

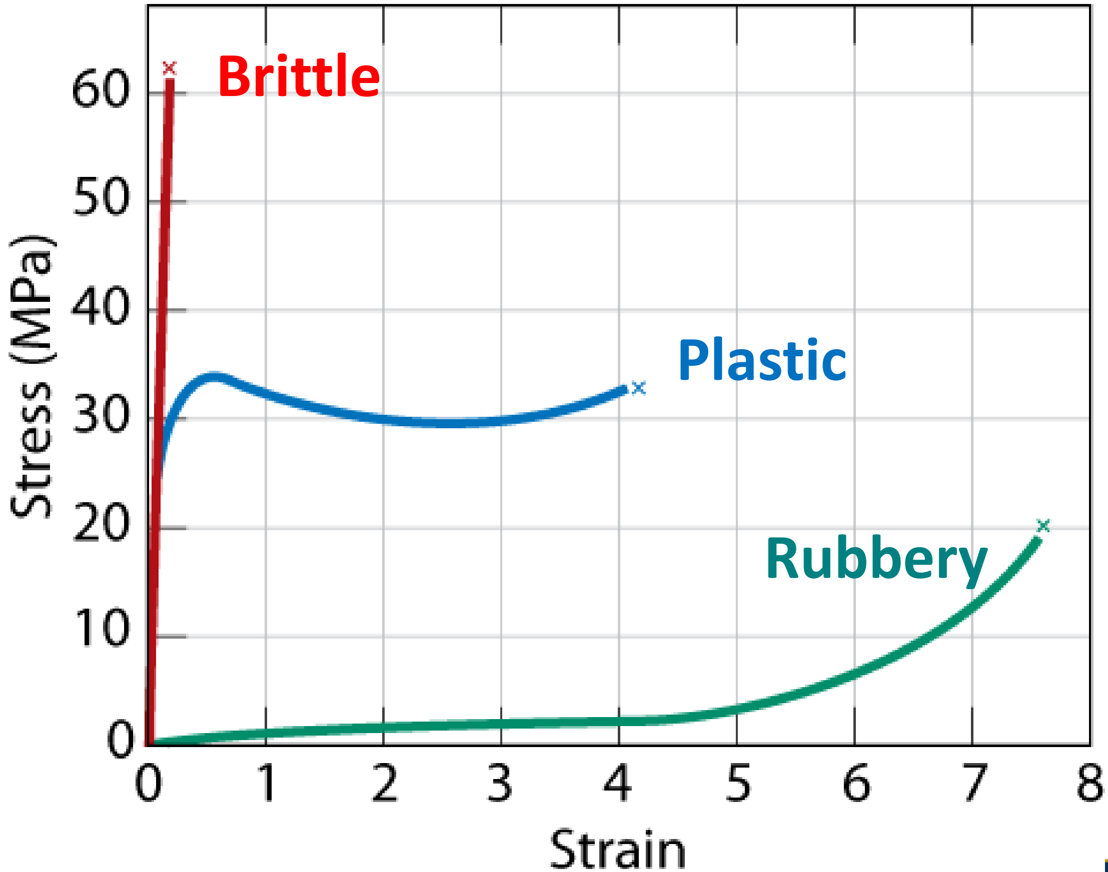
❑Identify the repeating unit for the following polymer molecule





Class Exercise

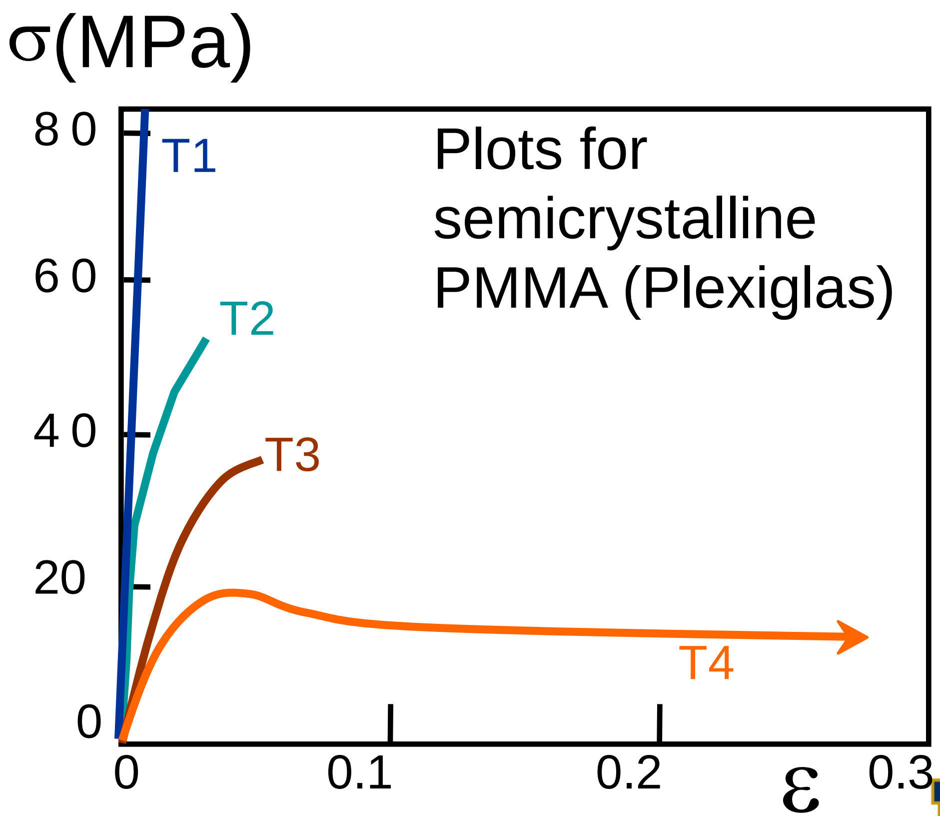
- For the stress-strain behaviors below, which one is brittle, plastic, and rubbery, respectively?



Adapted from Fig. 15.1, *Callister & Rethwisch 8e*.

Class Exercise

- For the stress-strain behavior below obtained at different temperature, determine which is the one is highest and lowest temperatures, respectively?



- $T_1<T_2<T_3<T_4$
- T_1 Lowest temperature
- T_4 Highest temperature

Class Exercise

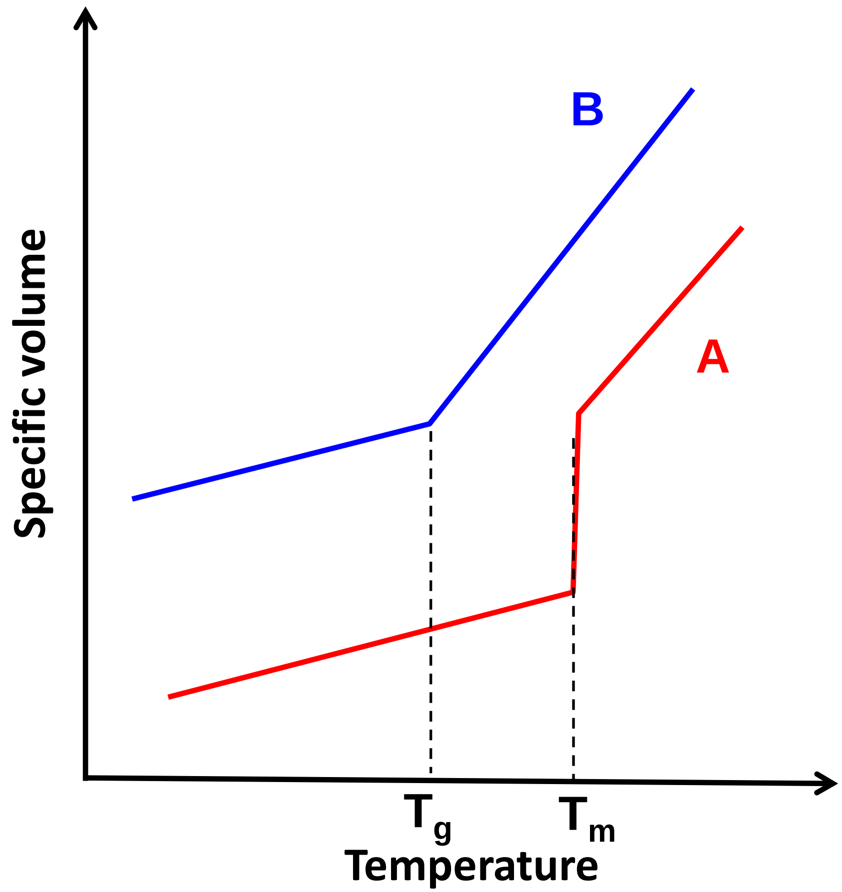
- **Based on the change of specific volume versus temperature curves obtained for two polymers,**

  Decide which is crystalline in the solid state and which is glassy and explain why

  A: crystalline - discontinuity in specific volume at a distinct temperature

  B: amorphous – no discontinuity in *specific volume by with slope change*

  Label melting point for crystalline and glass transition point for amorphous polymer & explain the physical meaning of melting point and glass transition temperature



Melting point T_m: crystalline structure to (free-flowing) liquid transition, and density change is not continuous; Glass transition T_g: the transition from **viscous** liquid to **solid, rigid, brittle** glass. Density continuous but slope (of specific volume vs. T) changes suddenly

Class Exercise

A continuous and aligned fiber-reinforced composite consists of 50 vol.% of glass fiber having modulus of elasticity of 70 GPa and 50 vol% of polyester that, when hardened, display a modulus of 3.5 GPa. (a) Calculate the modulus of elasticity of the composite in the longitude direction. (b) If an external tensile force of 10000 N is applied along the longitude direction, calculate the load carried by each of the fiber and matrix phase assuming isostrain condition and the load along longitude direction bore by each phase satisfy

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$$

Modulus of elasticity for composite with continuous aligned fiber along longitude direction is: $E_{cl} = E_m V_m + E_f V_f$

Therefore, E_{cl} = 3.5 x 50% + 70 x 50% = 36.75 GPa

Load bear by fiber F_f and load bear by matrix F_m satisfy

$$\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m} = \frac{70 \times 0.5}{3.5 \times 0.5} = 20$$

Total load $F_{cl} = F_m + F_f$ → F_{cl}=(20+1)Fm, $F_m = F_{cl}/21$=476N, F_f= 9524N

Class Exercise

- A cylinder shaped composite sample with cross-section of 1cm^2 and an elastic modulus of 30 GPa is subject to tensile force of 3000N. If the composite cylinder is 10cm long, please calculate the elongation of the sample.

$$\varepsilon = \frac{\sigma}{E} = \frac{F}{AE}$$

$$\varepsilon = \frac{3000N}{1cm^2 \times 30 \times 10^9 Pa} = 0.001$$

$$\delta = \varepsilon L_0 = 0.001 \times 10cm = 0.01cm = 100\mu m$$

Class Exercise

Determine if the following statements are right or wrong

- ❑**Ferrous alloys with higher carbon content are termed "steel" while those with lower carbon content are termed "cast iron"**

Wrong

- ❑**Stainless steels will not corrode under any circumstances**

Wrong

- ❑**In cast iron, some carbon atoms are present as dissolved carbon solute atoms in ferrite (α-Fe) phase while some other carbon atoms are present as cementite (Fe_3C) or graphite phase**

Right

- ❑**For steel, the hardness is typically lower if the quenching medium is water than when the quenching medium is oil**

Wrong

Class Exercise

Determine if the following statements are right or wrong

- ❑ **For ceramics with ionic bonding such as NaCl, the cations (e.g., Na^+ here) are usually much smaller than anions (e.g., Cl^- here)**

Right

- ❑ **Ceramics of chemical formula in the form AB (e.g., NaCl) can only have one type of crystal structure**

Wrong

- ❑ **Mechanical properties such as elastic modulus and strength for ceramics are typically obtained through three-point bending/flextural tests instead of traditional tensile tests**

Right

- ❑ **Polymer molecule structure and shape are usually extremely simple**

Wrong

Class Exercise

Determine if the following statements are right or wrong

- ❑ **For a polymer material, all molecules within it have the same length and molecular weight**

Wrong

- ❑ **Typical polymers contain both crystalline and amorphous regions under ambient condition**

Right

- ❑ **Similar to metals, under mechanical load, polymers also display phenomena such as creep, relaxation, and fatigue**

Right

- ❑ **Metal matrix composites are typically made to achieve improved toughness over the metal matrix**

Wrong

Class Exercise

Determine if the following statements are right or wrong

- ❑**Rubbers are polymers**

Right

- ❑**Polymers form from small repeating molecules through either addition reaction or condensation reaction**

Right