

## Self-review Questions for Module 1

### 1-1 Name and briefly describe the following terms and recall their meaning in Chinese:

(1) materials 材料;

**Materials are defined as these substances have properties that make them useful in structures, machines, devices, products, and systems.**

(2) materials science 材料科学;

**Materials science focuses on discovering the nature of materials, which in turn leads to theories or descriptions that explain how structure relates to composition, properties and behavior.**

(3) materials engineering; 材料工程

**Materials engineering deals with the use of science in order to develop, prepare, modify, and apply materials to meet specific needs.**

(4) materials science and engineering (MSE); 材料科学与工程

MSE involves the generation and application of knowledge relating the composition, structure, and processing of materials to their properties and uses.

(5) structure; 结构

**The structure of a material usually relates to the arrangement of its internal components.**

(6) properties; 性能

**The term of properties describes the behavior of materials when subjected to some external force or condition.**

(7) advanced materials; 先进材料

**Materials utilized in high-technology(or high-tech) applications are sometimes termed advanced materials, it usually refer to those materials used as semiconductors, biomaterials, smart materials, and nanomaterials.**

(8) the materials cycle; 材料环

**All the materials will experience from raw materials extraction, synthesis, processing, production, use, disposal or recycle, we call this as materials cycle.**

(9) engineered materials; 工程材料

These raw materials are purified, refined, and converted into bulk forms such as metals, cements, petroleum, rubber, and fibers. Further synthesis and processing results in products that are what may be termed *engineered materials*, such as metal alloys, ceramic powders, glass, plastics, composites, semiconductors, and elastomers.

(10) life cycle analysis/assessment; 材料生命周期性评价

One approach that is given to the cradle-to-grave environmental assessment of the product, from material extraction to product manufacture to product use and, finally, to recycling and disposal; sometimes this approach is also labeled green design

(11) sustainability; 可持续发展

Sustainability represents the ability to maintain an acceptable lifestyle at the present level and into the indefinite future while preserving the environment. This means that over time and as populations increase in size, the Earth's resources must be used at a rate such that they can be replenished naturally and that emission levels of pollutants are maintained at acceptable levels.

(12) recyclability; 可循环使用

Recyclability means that a material, after completing its life cycle in one component, could be reprocessed, could reenter the materials cycle, and could be reused in another component—a process that could be

repeated an indefinite number of times.

**(13) biodegradability; 生物可降解**

Biodegradation is that by interactions with the environment (natural chemicals, microorganisms, oxygen, heat, sunlight, etc.) the material deteriorates and returns to virtually the same state in which it existed prior to the initial processing.

**(14) green design; 绿色设计**

Consideration is given to the cradle-to-grave environmental assessment of the product, from material extraction to product manufacture to product use and, finally, to recycling and disposal; sometimes this approach is also labeled green design

**(15) design for assembly; 为组装而设计**

Emphasizes easy product assembly by robots and other automated equipment

**(16) design for disassembly. 为拆卸而设计**

A concept that places recycling at the beginning or design stage of the materials cycle to ensure that waste going into municipal landfills will be minimized.

**1-2 What are the four levels of structure of solid materials?**

subatomic, atomic or molecular, microscopic and macroscopic structures

**1-3 What are six different categories of properties that solid materials may be grouped into?**

mechanical, electrical, thermal, deteriorative, magnetic, and optical

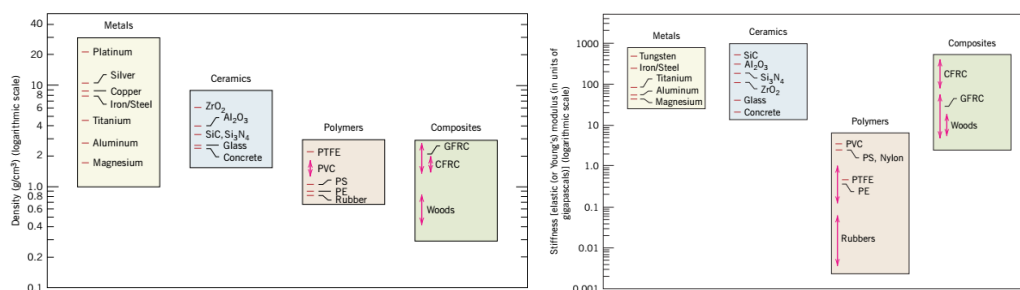
**1-4 What are the four components of the discipline of materials science and engineering and interrelationships between these components?**

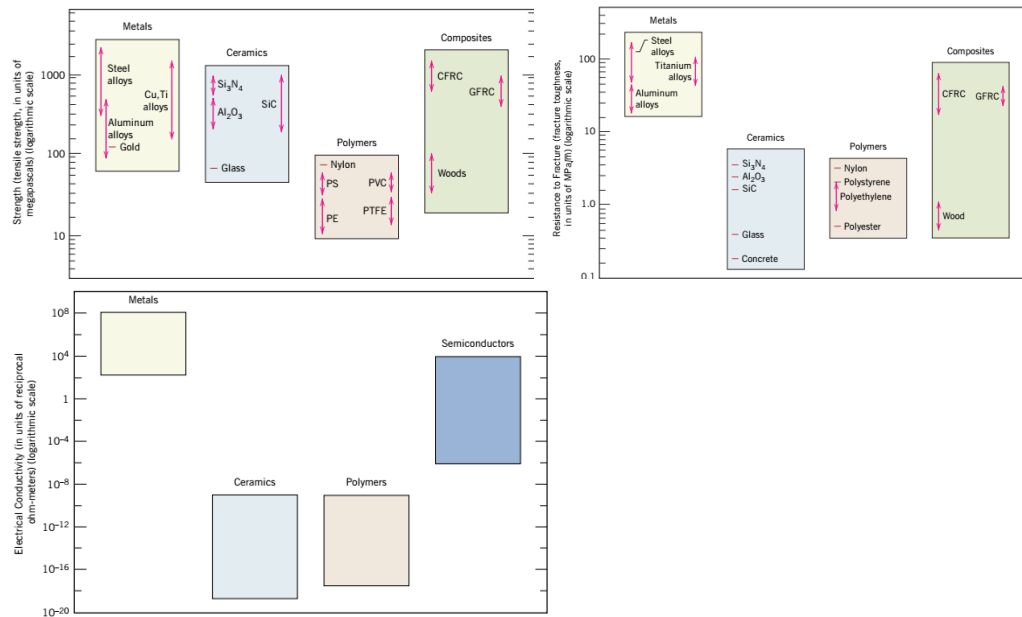
structure, properties, processing and performance; the structure of a material will depend on how it is processed. Furthermore, a material's performance will be a function of its properties.

**1-5 What are the five categories that solid materials have been grouped into?**

metallic materials, ceramic materials, polymeric materials, advanced materials, composites

**1-6 How are metals, ceramics, polymers, composites different in density, stiffness, strength, resistance to fracture, and electrical conductivity?**





**1-7 List two items in your daily life (in addition to those shown in Figure 1.9) made from metals or their alloys. For each item, note the specific metal or alloy used and at least one characteristic that makes it the material of choice.**

举例题，言之有理即可

**1-8 List two items in your daily life (in addition to those shown in Figure 1.10) made from ceramic materials. For each item, note the specific ceramic used and at least one characteristic that makes it the material of choice.**

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**1-9 List two items in your daily life (in addition to those shown in Figure 1.11) made from polymeric materials. For each item, note the specific polymer used and at least one characteristic that makes it the material of choice.**

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**1-10 Classify each of the following materials as to whether it is a metal, ceramic, or polymer. Justify each choice: (a) brass; (b) magnesium oxide ( $\text{MgO}$ ); (c) Plexiglas®; (d) polychloroprene; (e) boron carbide ( $\text{B}_4\text{C}$ ); and (f) cast iron.**

- (a) brass; *metal*
- (b) magnesium oxide ( $\text{MgO}$ ); *metal*
- (c) Plexiglas®; *polymer*
- (d) polychloroprene; *polymer*
- (e) boron carbide ( $\text{B}_4\text{C}$ ); *ceramic*
- (f) cast iron: *metal*

**1-11 What are semiconductors, biomaterials, smart materials/systems, and nanomaterials, respectively? What are their representative characteristics? Why do we need these materials?**

Semiconductors have electrical properties that are intermediate between those of electrical conductors (i.e., metals and metal alloys) and insulators (i.e., ceramics and polymers). Semiconductors have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries, not to mention our lives over the past three decades; Biomaterials are employed in components implanted into the human body to replace diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissues. They must not cause adverse biological reactions; Smart Materials The adjective *smart* implies that these materials are able to sense changes in their environment and then respond to these changes in predetermined manners—traits that are also found in living organisms; Nanomaterials they are not distinguished on the basis of their chemistry but rather their size; the *nano* prefix denotes that the dimensions of these structural entities are on the order of a nanometer (10<sup>-9</sup> m)—as a rule, less than 100 nanometers. Because of these unique and unusual properties, nanomaterials are finding niches in electronic, biomedical, sporting, energy production, and other industrial applications.

**1-12 List three modern materials' needs and give at least one characteristic that makes it the material of choice for each need.**

Nuclear energy holds some promise, but the solutions to the many problems that remain necessarily involve materials, such as fuels, containment structures, and facilities for the disposal of radioactive waste. Significant quantities of energy are involved in transportation. Reducing the weight of transportation vehicles (automobiles, aircraft, trains, etc.), as well as increasing engine operating temperatures, will enhance fuel

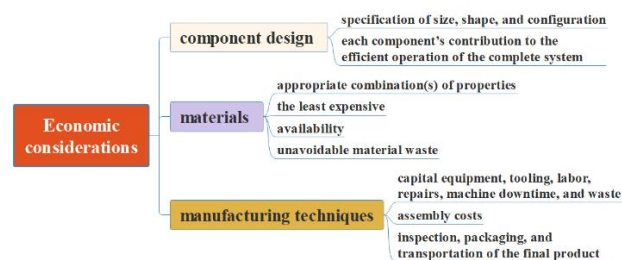
efficiency. Few high-strength, low-density structural materials remain to be developed, as well as materials that have higher-temperature capabilities, for use in engine components. Furthermore, there is a recognized need to find new and economical sources of energy and to use present resources more efficiently. Materials will undoubtedly play a significant role in these developments. For example, the direct conversion of solar power into electrical energy has been demonstrated. Solar cells employ some rather complex and expensive materials. To ensure a viable technology, materials that are highly efficient in this conversion process yet less costly must be developed.

### 1-13 What are the key issues that must be taken into consideration in materials selection process?

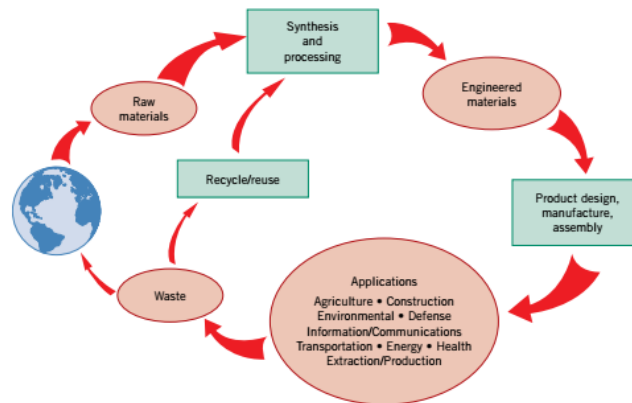
Three important criteria in materials selection are in-service conditions to which the material will be subjected, any deterioration of material properties during operation, and economics or cost of the fabricated piece.

### 1-14 What are the factors that influence product price? How do these factors affect the cost of a product?

component design, the materials used, and manufacturing processes



### 1-15 Draw a schematic diagram of the materials cycle.



**1-16 What are the inputs and outputs involved in the inventory for the life-cycle analysis (LCA) /assessment of a product?**

| No. | Phase                                 | Issues to be considered  |
|-----|---------------------------------------|--|
| 1   | Extraction of raw materials           | Does any ecological damage and landscape spoilage result?  |
| 2   | Synthesis & processing                | Are polluting gases being released into the environment, or are toxic metals and chemicals being flushed into our rivers and streams?    |
| 3   | Manufacturing engineered materials    | Does the waste contains heavy metals or toxic chemicals that would be dangerous to the animals food chain?                               |
| 4   | Product design, manufacture, assembly | What are the results of the processing methods? Can raw materials be transformed into a finished product by using low-energy processing? |
| 5   | Application                           | During use, does the product safeguard our health?   |
| 6   | Recycle/reuse/Disposal                | At the end of the product's useful life, how can it be disposed of safely? Can the product be recycled?                                  |

**1-17 How is “design for disassembly” important to minimize any impact on the environment?**

It emphasis easy product assembly by robots and other automated equipment. Important stages in the materials cycle where materials science and engineering plays a significant role are recycling and disposal. The issues of recyclability and disposability are important when new materials are being designed and synthesized

**1-18 How can the stage of recycling/disposal become the first stage in the materials cycle?**

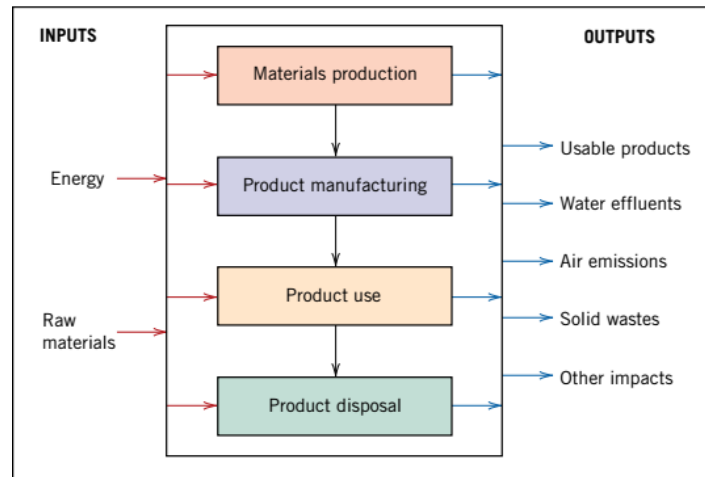
Through the resurrection of material when recycling is employed

**1-19 Beverages are generally marketed in aluminum (metal) cans, glass (ceramic) bottles, and plastic (polymer) bottles. Make a list of the advantages and disadvantages of using each of these three material types; include such factors as cost, recyclability, and energy consumption for container production.**

|         | Cost   | Recyclability | energy consumption |
|---------|--------|---------------|--------------------|
| Metal   | High   | Easy          | High               |
| Ceramic | Medium | Difficult     | Medium             |
| Polymer | Low    | Difficult     | Low                |

**1-20 Discuss why the materials cycle is really a system that involves interactions and exchanges**

among materials energy, and the environment by using any stage in the materials cycle.



**1-21 Discuss why it is important to consider the entire life cycle rather than just the first stage.**

Many materials that we use are derived from resources that are nonrenewable—that is, not capable of being regenerated. These include most polymers, for which the prime raw material is oil, and some metals. These nonrenewable resources are gradually becoming depleted. Furthermore, energy must be supplied at each cycle stage; It has been estimated that approximately one-half of the energy consumed by manufacturing industries goes to produce and fabricate materials.

**1-22 Discuss how materials engineering can play a role in “green design.”**

One approach being implemented by industry to improve the environmental performance of products is termed *life cycle analysis/assessment*. With this approach to product design, consideration is given to the cradle-to-grave environmental assessment of the product, from material extraction to product manufacture to product use and, finally, to recycling and disposal; sometimes this approach is also labeled *green design*. One important phase of this approach is to quantify the various inputs (i.e., materials and energy) and outputs (i.e., wastes) for each phase of the life cycle; this is represented schematically in Figure 22.2. In addition, an assessment is conducted relative to the impact on both global and local environments in terms of the effects on ecology, human health, and resource reserves.

**1-23 Suggest other consumer actions for minimal environmental impact than just recycling.**

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## Self-review Questions for Module 2

1. What is the Chemical Bonding? What are the groups and subgroups of the chemical bonding?  
Chemical bonding is an interaction between atoms or ions that results in a reduction in the potential energy of the system which hence becomes more stable. Chemical bonds are formed by the electrons in the atom's outermost energy levels.  
Ionic, covalent and metallic bonding.
2. Understand the terms: (a) covalent bonding; (b) ionic bonding; (c) metallic bonding; (d) hydrogen bond. What key word can be used to describe covalent bonding, ionic bonding, and metallic bonding?  
(a) Covalent bonding is a description of chemical bonding that is characterized by the sharing of one or more electrons between two atoms.  
(b) Ionic bonding is formed by the transferring of electrons to other elements. The positive and negative ions are strongly attracted to each other. This electrostatic attraction is called ionic bonding.  
(c) Metallic bonding is found in metals and their alloys. Bonding is formed by electron swarming, i.e. valence electrons are detached from atoms, and spread in an 'electron sea' that 'glues' the ions together.  
(d) Hydrogen bond is the strongest type of secondary bond. It is a very strong dipole-dipole attraction formed between an electropositive atom (typically hydrogen) and a strongly electronegative atom, such as oxygen or nitrogen.
3. What types of bonding would be expected for Iron, diamond, salt, brass, polyethylene, and glass respectively?  
(a) covalent bonding; (b) ionic bonding; (c) metallic bonding; (d) van der Waals bonding  
Iron (c) metallic bonding; diamond (a) covalent bonding;  
salt (b) ionic bonding; brass (c) metallic bonding;  
polyethylene (a) covalent bonding and (d) van der Waals bonding;  
glass (a) covalent bonding and (b) ionic bonding.
4. Which bond is the strongest among the secondary bonds?  
Hydrogen bond
5. How is the hydrogen bond formed? Exemplify the contributions of hydrogen bond to the properties and behavior of polymeric materials.  
Hydrogen bond occurs between molecules in which hydrogen is covalently bonded to fluorine, oxygen, or nitrogen. For H-F, H-O, or H-N bond, the single hydrogen electron is shared with the other atom.  
For polymer materials, the bonding along the polymer chains is strong covalent bonding, whereas bonding between chains is secondary bonding. The presence of hydrogen bonding among polymer chains will enhance the crystallinity and strength of the polymers. For example, because of the hydrogen bonding in Kevlar fiber, its transverse tensile, compressive and shear moduli and strength are enhanced significantly.
6. List the two forms of microstructure of solid. What is the difference between them in terms of



atomic arrangement?

Crystalline and noncrystalline (or amorphous) solids

Crystalline material is one in which the atoms are situated in a repeating or periodic array over large atomic distances—that is, long-range order exists, such that upon solidification, the atoms will position themselves in a repetitive three-dimensional pattern, in which each atom is bonded to its nearest neighbor atoms.

Noncrystalline solids lack a systematic and regular arrangement of atoms over relatively large atomic distances. Sometimes such materials are also called amorphous.

7. How many parameters are used to describe a unit cell? What are they?  
Six, they are the length  $a$ ,  $b$ ,  $c$  and the angle  $\alpha$ ,  $\beta$ ,  $\gamma$ .
8. Understand the terms: unit cells, space lattices, coordination number (CN), atomic packing factor (APF), void fraction, polymorphism, allotropy, crystalline, noncrystalline, isotropy, anisotropy.

**Unit cells:** in describing crystal structures, it is often convenient to subdivide the structure into small repeat entities called unit cells. It is the smallest component of the crystal, describing the basic geometric arrangement of atoms in a crystal

**Space lattices:** a three-dimensional array of points coinciding with atom positions.

**Coordination number (CN):** for metals, each atom has the same number of nearest-neighbor or touching atoms, which is called the coordination number.

**Atomic packing factor (APF):** APF is the sum of the sphere volumes of all atoms within a unit cell divided by the unit cell volume.

**Void fraction:** the proportion of void volume in bulk volume of the material.

**Polymorphism:** The ability of a material to exist in more than one crystalline structure.

**Allotropy:** The existence of two or more crystalline structural forms of an element. And the change is reversible.

**Crystalline** means the atoms are situated in a repeating or periodic array over large atomic distance—that is long-range order exists, each atom is bonded to its nearest-neighbor atoms.

**Noncrystalline** means the lack of a systematic and regular arrangement of atoms over relatively large atomic distances.

**Isotropic:** substances in which measured properties are dependent of the direction of measurement are isotropic.

**Anisotropy:** The directionality of properties is termed anisotropy.

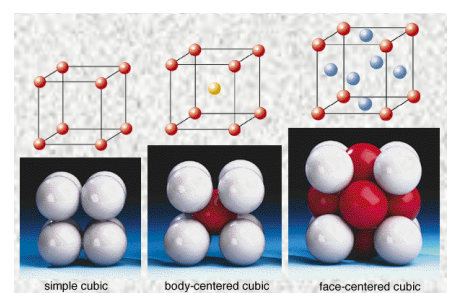
9. Describe the lattice parameters of cubic, tetragonal, and hexagonal crystal systems.

Cubic:  $a=b=c$ ;  $\alpha=\beta=\gamma=90^\circ$

Tetragonal:  $a=b \neq c$ ;  $\alpha=\beta=\gamma=90^\circ$

Hexagonal:  $a=b \neq c$ ;  $\alpha=\beta=90^\circ$ ,  $\gamma=120^\circ$

10. What are the three basic cubic crystal systems, and draw their unit cells? What are their abbreviations?



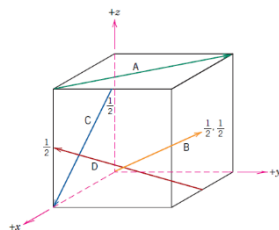
Face-centered cubic (FCC)  
 Body-centered cubic (BCC)  
 Simple cubic (SC)

11. Calculate the Atomic Packing Factor (APF) for BCC.

解：(1) 体心立方  
 $4R = \sqrt{3}a$   
 按致密度APF定义

$$APF = \frac{2 \times \frac{4}{3} \pi R^3}{a^3} = \frac{2 \times \frac{4}{3} \pi}{\frac{64}{3\sqrt{3}}} = \frac{\sqrt{3}\pi}{8} \approx 0.68$$

12. Determine the indices for the directions shown in the following cubic unit cell.



A  $[\bar{1}10]$     B  $[121]$     C  $[0\bar{1}2]$     D  $[1\bar{2}1]$

A

$$(0,1,1) - (1,0,1) = [\bar{1}\bar{0}]$$

B

$$(1/2, 1/2, 1/2) - (0,0,0) = [121]$$

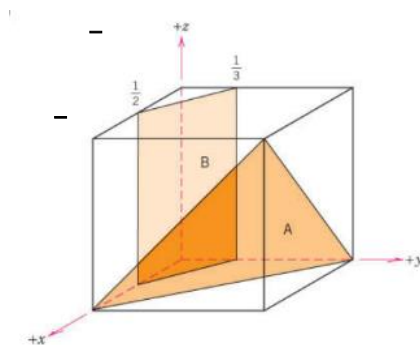
C

$$(1,0,0) - (1,1/2,1) = 0, -1/2, -1 = [0\bar{1}\bar{2}]$$

D

$$(1,0,1/2) - (1/2,1,0) = 1/2, -1, 1/2 = [1\bar{2}\bar{1}]$$

13. Determine the Miller indices for the planes shown in the following unit cell.



A: (1 1 1)

x 1, y 1, z -1

(1 1 1)

B: (2 3 0)

x 1/2, y 1/3, z ∞

Take reciprocals: 2, 3, 0

(2 3 0)

14. Give expressions of Miller indices for planes, equivalent planes (a family of planes), directions and equivalent directions (a family of directions).

Planes:  $(h\ k\ l)$ ,      Equivalent planes:  $\{h\ k\ l\}$   
 Directions:  $[uvw]$ ,      Equivalent directions:  $\langle uvw \rangle$

15. What is the difference in the crystal structures of polymorphic and allotropic materials? Exemplify the properties of polymorphic and allotropic materials.

An allotropic material can, after changing to one structure, reverse the phenomenon and return to its previous structure; a polymorphic material does not possess this reverse phenomenon.

Example: Over one-fourth of the elements are allotropic. Steel owes its extensive use to this property. When iron is heated to above  $910^{\circ}\text{C}$ , its structure changes from bcc to fcc, allowing for a much greater absorption of carbon atoms (2% maximum).

One example of polymorphic materials is carbon: graphite is the stable polymorph at ambient conditions, whereas diamond is formed at extremely high pressures.

16. Is the atomic packing factor (APF) dependent on the radius of the spheres being packed if all the atoms are of the same size?

APF is independent of the radius of the spheres being packed if all the atoms are of the same size

17. Understand the terms: point defect, linear defects or dislocation, and area defect.

**Point defect:** A Point Defect involves a single atom change to the normal crystal array.

**Linear defect:** linear defect is known as a dislocation, which is a linear array of atoms along which there is some imperfection in the bonding of the atoms.

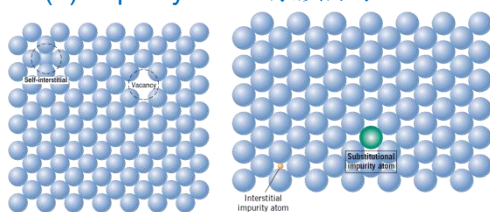
**Area defect:** Interfacial defects are boundaries that have two dimensions and normally separate regions of the materials that have different crystal structures and/or crystallographic orientations. These imperfections include external surfaces, grain boundaries, phase boundaries, twin boundaries, and stacking faults.

18. Draw a schematic sketch of the three types of point defects, and give a brief written description.

(1) Vacancy: the absence of an atom at a lattice site

(2) Self-Interstitialcy: the presence of an extra atom in a void, the space between normal lattice positions.

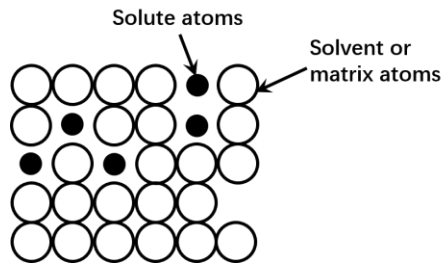
(3) Impurity atoms 杂质原子: Interstitial impurity atom; Substitutional impurity atom



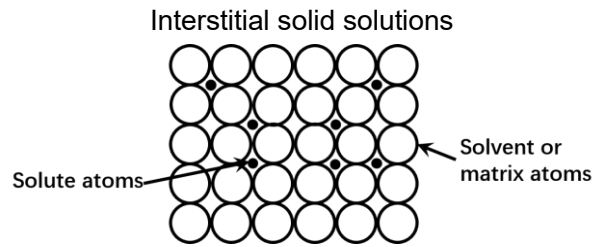
19. Name the two types of solid solutions, provide a brief written definition and schematic sketch of each, and describe their forming conditions.

**Substitutional solid solutions:** in a substitutional solid solution, the solute atoms replace some of solvent atoms in a crystal structure of the solvent.

**Interstitial solid solutions:** this kind of solid solution formed by impurity atoms is the interstitial. If the impurity atoms take up sites in the lattice structure that are normally unfilled or unoccupied by the pure (solvent) atoms, they form an interstitial solid solution.



Substitutional solid solutions



Interstitial solid solutions

The forming conditions for substitutional solid solutions

Solvent atoms and Solute atoms have

- ① Similar atomic sizes (less than  $\pm 15\%$ )
- ② Same crystal lattice structures
- ③ Similar electron configurations
- ④ Valences: more tendency to dissolve another metal of higher valency than to dissolve one of a lower valency

The forming condition for interstitial solid solution: solute atom must be very small relative to solvent atom.

20. Why a relatively little force is able to deform a crystal structure with strongly bonded atoms or ions?

The dislocation plane in the crystal structure is a region of higher energy; which means weak bonding forces along the dislocation plane. Only a small shear force is needed to break the bonds.

21. What are the effects of line defect (dislocation) on the strength and ductility of a crystalline solid?

Dislocations have a great deal to do with the strength and ductility of a solid. The presence of a few dislocations increases the ductility of a crystalline solid. An abundance of them will cause a mutual interference in their movement through a crystal, preventing the planes of atoms from slipping, thereby strengthening the material and reducing the ductility.

22. Describe the characteristics possessed by atoms making up the grain boundary.

The atoms are less efficiently packed together.

The atoms making up the grain boundary possess greater disorder, and hence greater energy, than their counterparts within the crystals themselves.

23. Explain how grain boundaries impede dislocation motion and why a metal having small grains is stronger than one having large grains.

Grain boundary can hinder the dislocation movement. When the motion of a dislocation encounters a grain boundary, the boundary acts as a barrier to continued slip. Slip planes are discontinuous and change directions across the boundary.

By changing grain size, the dislocation movement and yield strength should be influenced. Smaller size grains have more grain boundary than large ones, so a fine-grained material is harder and stronger than coarse-grained one.

24. A copper-nickel alloy contains 47 wt% Cu and 53 wt% Ni and is at 1300°C. Use Fig. 9.3 to answer the following questions:

a) What is the weight percent of copper in the liquid and solid phases at this temperature? b) What weight percent of this alloy is liquid and what weight percent is solid?

A: (a) Cu 55% in liquid and 48% in solid

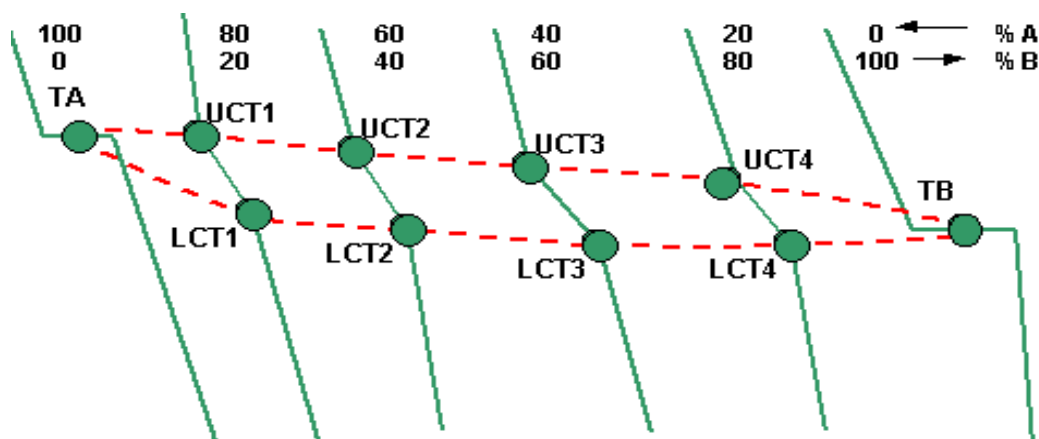
(b) liquid% =  $(58-53)/(58-45) \times 100\% = 38.5\%$ ; solid % =  $(53-45)/(58-45) \times 100\% = 61.5\%$

25. Explain how the liquidus and solidus of a binary isomorphous phase diagram can be determined experimentally.

A: As for pure components, the solid-to-liquid transformation takes place at the melting temperature, and no further heating is possible until this transformation has been completed.

For any composition other than pure components, this melting phenomenon occurs over the range of temperatures.

Series of cooling curves for alloys with different compositions in a completely soluble system are recorded. A temperature that the melting of the solid solution starts at is lower critical temperature (LCT), and a temperature that the melting of the solid solution completes at is upper critical temperature (UCT). All upper critical temperatures are joined to form liquidus line above which only liquid is present. All lower critical temperatures are joined to form solidus line below which only solid is present.



26. At 100°C, what is the maximum solubility (a) Pb in Sn? (b) Sn in Pb? (Figure 9.8) (9.2)

A: (a) From Figure 9.8, the maximum solubility of Pb in Sn at 100°C corresponds to the position of the  $\beta-(\alpha+\beta)$  phase boundary at this temperature, or to about 2 wt% Pb.

(b) From this same figure, the maximum solubility of Sn in Pb corresponds to the position of the  $\alpha-(\alpha+\beta)$  phase boundary at this temperature, or about 5 wt% Sn.

27. Cite three variables that determine the microstructure of an alloy. (9.3)

A: Three variables that determine the microstructure of an alloy are (1) the alloying elements present, (2) the concentrations of these alloying elements, and (3) the heat treatment of the alloy.

28. Cite the phases that are present and the phase compositions for the following

**alloys: (a) 15 wt% Sn–85 wt% Pb at 100°C (212°F) (Figure 9.8) (b) 85 wt% Ag–15 wt% Cu at 800 °C(1470°F) (Figure 9.7) (c) 1.25 kg Sn and 14 kg Pb at 200 C (390 °F) (d) 4.2 mol Cu and 1.1 mol Ag at 900C (1650°F) (9.10, (a)(c)(e)(h))**

**A:** (a) For an alloy composed of 15 wt% Sn-85 wt% Pb and at 100°C, from Figure 9.8, and phases are present, and using a tie line constructed at this temperature, the compositions of these phases are determined as follows:

$$C_{\alpha} = 5 \text{ wt\% Sn-95 wt\% Pb}$$

$$C_{\beta} = 98 \text{ wt\% Sn-2 wt\% Pb}$$

(b) For an alloy composed of 85 wt% Ag-15 wt% Cu and at 800°C, from Figure 9.7, and liquid phases are present, and using a tie line constructed at this temperature the compositions of these phases are determined as follows:

$$C_{\beta} = 92 \text{ wt\% Ag-8 wt\% Cu}$$

$$C_L = 77 \text{ wt\% Ag-23 wt\% Cu}$$

(c) For an alloy composed of 1.25 kg Sn and 14 kg Pb and at 200°C, we must first determine the Sn and Pb concentrations in weight percent (using Equation 4.3a), as

$$C_{\text{Sn}} = \frac{1.25 \text{ kg}}{1.25 \text{ kg} + 14 \text{ kg}} \times 100 = 8.2 \text{ wt\%}$$

$$C_{\text{Pb}} = \frac{14 \text{ kg}}{1.25 \text{ kg} + 14 \text{ kg}} \times 100 = 91.8 \text{ wt\%}$$

From Figure 9.8, only the phase is present; its composition is 8.2 wt% Sn-91.8 wt% Pb.

(d) For an alloy composed of 4.2 mol Cu and 1.1 mol Ag and at 900°C, it is necessary to determine the Cu and Ag concentrations in weight percent. However, we must first compute the masses of Cu and Ag (in grams) using a rearranged form of Equation 4.4 (and the atomic weights of Cu and Ag—63.55 g/mol and 107.87 g/mol) as follows:

$$m_{\text{Cu}} = n_{\text{mCu}} A_{\text{Cu}} = (4.2 \text{ mol})(63.55 \text{ g/mol}) = 266.9 \text{ g}$$

$$m_{\text{Ag}} = n_{\text{mAg}} A_{\text{Ag}} = (1.1 \text{ mol})(107.87 \text{ g/mol}) = 118.7 \text{ g}$$

Now, using Equation 4.3a, concentrations of Cu and Ag are determined as follows:

$$C_{\text{Cu}} = \frac{266.9 \text{ g}}{266.9 \text{ g} + 118.7 \text{ g}} \times 100 = 69.2 \text{ wt\%}$$

$$C_{\text{Ag}} = \frac{118.7 \text{ g}}{266.9 \text{ g} + 118.7 \text{ g}} \times 100 = 30.8 \text{ wt\%}$$

From Figure 9.7,  $\alpha$  and liquid phases are present; and using a tie line constructed at this temperature, the compositions of these phases are determined as follows:

$$C_{\alpha} = 8 \text{ wt\% Ag-92 w\% Cu}$$

$$C_L = 45 \text{ wt\% Ag-55 wt\% Cu}$$

**29. Is it possible to have a copper–silver alloy that, at equilibrium, consists of a  $\beta$  phase of composition 92 wt% Ag–8 wt% Cu and also a liquid phase of composition 76 wt% Ag–24wt% Cu? If so, what will be the approximate temperature of the alloy? If this is not possible, explain why?(9.11)**

**A:** It is possible to have a Cu-Ag alloy, which at equilibrium consists of a  $\beta$  phase of composition 92 wt% Ag-8 wt% Cu and a liquid phase of composition 77 wt% Ag-23 wt% Cu. From Figure 9.7 a horizontal tie line can be constructed across the  $\beta$ +L phase region at about 800°C which intersects the L-( $\beta$ +L) phase boundary at 76 wt% Ag, and also the ( $\beta$ +L)- $\beta$  phase boundary at 92 wt% Ag

**30. A lead–tin alloy of composition 30 wt% Sn–70 wt% Pb is slowly heated from a temperature of 150°C (300 °F).**

**(a) At what temperature does the first liquid phase form?**

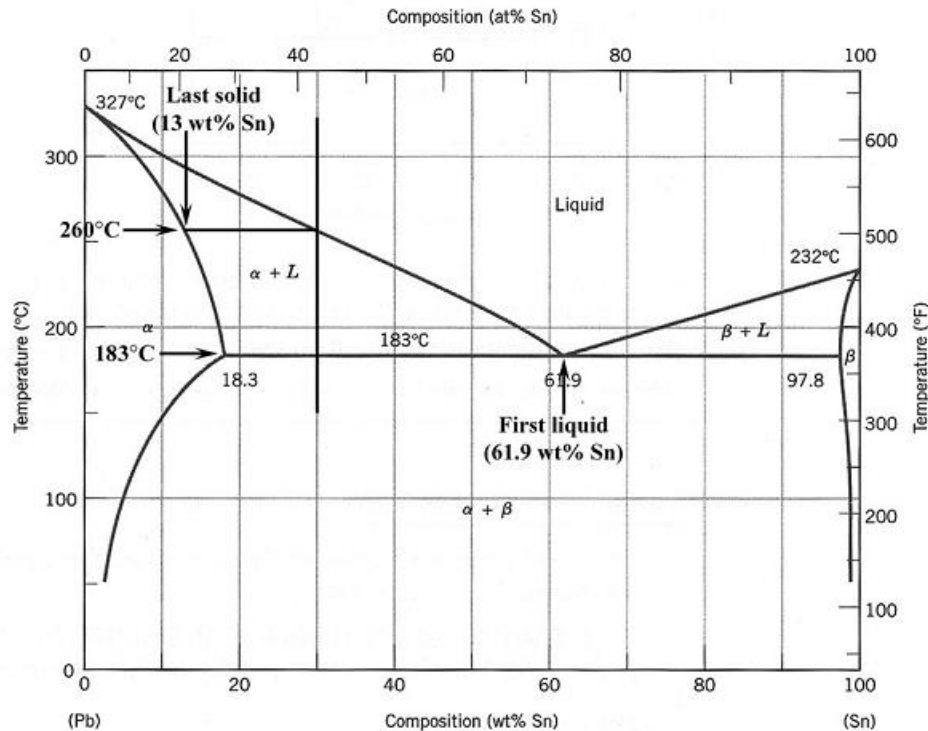
(b) What is the composition of this liquid phase?

(c) At what temperature does complete melting of the alloy occur?

(d) What is the composition of the last solid remaining prior to complete melting?

(9.13)

A: Upon heating a lead-tin alloy of composition 30 wt% Sn-70 wt% Pb from 150°C and utilizing Figure 10.8 as shown below:



(a) The first liquid forms at the temperature at which a vertical line at this composition intersects the eutectic isotherm--i.e., at 183°C.

(b) The composition of this liquid phase corresponds to the intersection with the  $(\alpha+L)$ -L phase boundary, of a tie line constructed across the  $\alpha+L$  phase region just above this eutectic isotherm--i.e., CL= 61.9 wt% Sn.

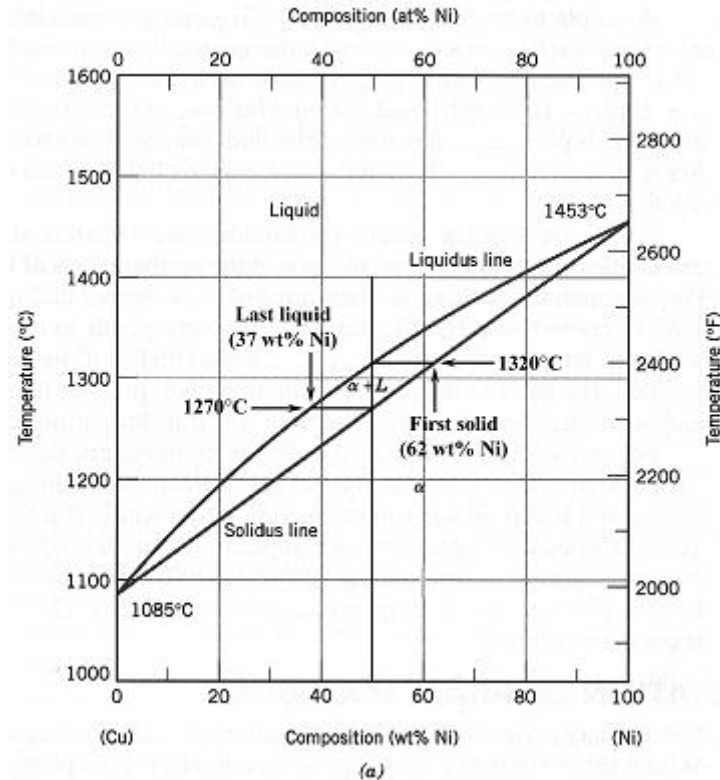
(c) Complete melting of the alloy occurs at the intersection of this same vertical line at 30 wt% Sn with the  $(\alpha+L)$ -L phase boundary--i.e., at about 260°C.

(d) The composition of the last solid remaining prior to complete melting corresponds to the intersection with  $\alpha$ - $(\alpha+L)$  phase boundary, of the tie line constructed across the  $\alpha+L$  phase region at 260°C--i.e.,  $C_\alpha$  is about 13 wt% Sn.

31. A 50 wt% Ni-50 wt% Cu alloy is slowly cooled from 1400 °C (2550°F) to 1200°C (2190°F). (a) At what temperature does the first solid phase form? (b) What is the composition of this solid phase? (c) At what temperature does the liquid solidify? (d) What is the composition of this last remaining liquid phase? (9.14)

A: Shown below is the Cu-Ni phase diagram (Figure 10.3a) and a vertical line constructed at a composition of 50 wt% Ni-50 wt% Cu.





(a) The first solid phase forms at the temperature at which a vertical line at this composition intersects the L-(α+L) phase boundary--i.e., at about 1320°C.

(b) The composition of this solid phase corresponds to the intersection with the L-(α+L) phase boundary, of a tie line constructed across the α+L phase region at 1320°C--i.e.,  $C_{\alpha} = 62 \text{ wt\% Ni}$ -38 wt% Cu.

(c) Complete solidification of the alloy occurs at the intersection of this same vertical line at 50 wt% Ni with the (α+L)-α phase boundary--i.e., at about 1270°C.

(d) The composition of the last liquid phase remaining prior to complete solidification corresponds to the intersection with the L-(α+L) boundary, of the tie line constructed across the α+L phase region at 1270°C--i.e.,  $C_L$  is about 37 wt% Ni-63 wt% Cu

**32. Determine the relative amounts (in terms of mass fractions) of the phases for the alloys and temperatures given in Problem 28. (9.17)**

**A:** (a) For an alloy composed of 15 wt% Sn-85 wt% Pb and at 100°C, compositions of the α and β phases are:  $C_{\alpha} = 5 \text{ wt\% Sn}$ -95 wt% Pb;  $C_{\beta} = 98 \text{ wt\% Sn}$ -2 wt% Pb

And, since the composition of the alloy,  $C_0 = 15 \text{ wt\% Sn}$ -85 wt% Pb, then, using the appropriate lever rule expressions and taking compositions in weight percent tin

$$W_{\alpha} = \frac{C_{\beta} - C_0}{C_{\beta} - C_{\alpha}} = \frac{98 - 15}{98 - 5} = 0.89$$

$$W_{\beta} = \frac{C_0 - C_{\alpha}}{C_{\beta} - C_{\alpha}} = \frac{15 - 5}{98 - 5} = 0.11$$

(b) For an alloy composed of 85 wt% Ag-15 wt% Cu and at 800°C, compositions of the β and liquid phases are

$$C_{\beta} = 92 \text{ wt\% Ag}$$
-8 wt% Cu

$$C_L = 77 \text{ wt\% Ag}$$
-23 wt% Cu

And, since the composition of the alloy,  $C_0 = 85 \text{ wt\% Ag}$ -15 wt% Cu, then, using the



appropriate lever rule expressions and taking compositions in weight percent silver

$$W_{\beta} = (C_0 - C_L) / (C_{\beta} - C_L) = (85 - 77) / (92 - 77) = 0.53$$

$$W_L = (C_{\beta} - C_0) / (C_{\beta} - C_L) = (92 - 85) / (92 - 77) = 0.47$$

(c) For an alloy composed of 1.25 kg Sn and 14 kg Pb (8.2 wt% Sn-91.8 wt% Pb) and at 200°C, only the  $\alpha$  phase is present; therefore  $W_{\alpha} = 1.0$ .

(d) For an alloy composed of 4.2 mol Cu and 1.1 mol Ag (30.8 wt% Ag-69.2 wt% Cu) and at 900°C, compositions of the  $\alpha$  and liquid phases are

$$C_{\alpha} = 8 \text{ wt\% Ag-92 wt\% Cu}$$

$$C_L = 45 \text{ wt\% Ag-55 wt\% Cu}$$

And, since the composition of the alloy,  $C_0 = 30.8 \text{ wt\% Ag-69.2 wt\% Cu}$ , then, using the appropriate lever rule expressions and taking compositions in weight percent silver

$$W_{\alpha} = (C_L - C_0) / (C_L - C_{\alpha}) = (45 - 30.8) / (45 - 8) = 0.38$$

$$W_L = (C_0 - C_{\alpha}) / (C_L - C_{\alpha}) = (30.8 - 8) / (45 - 8) = 0.62$$

**33. A 2.0-kg specimen of an 85 wt% Pb–15 wt% Sn alloy is heated to 200 °C (390 °F); at this temperature it is entirely an  $\alpha$ -phase solid solution (Figure 9.8). The alloy is to be melted to the extent that 50% of the specimen is liquid, the remainder being the  $\alpha$  phase. This may be accomplished by heating the alloy or changing its composition while holding the temperature constant. To what temperature must the specimen be heated? (9.18)**

**A:** This part of the problem calls for us to cite the temperature to which a 85 wt% Pb-15 wt% Sn alloy must be heated in order to have 50% liquid. Probably the easiest way to solve this problem is by trial and error—that is, on the Pb-Sn phase diagram (Figure 9.8), moving vertically at the given composition, through the  $\alpha + L$  region until the tie-line lengths on both sides of the given composition are the same. This occurs at approximately 280°C (535°F).

**34. A 65 wt% Ni–35 wt% Cu alloy is heated to a temperature within the  $\alpha + \text{liquid}$ -phase region. If the composition of the  $\alpha$  phase is 70 wt% Ni, determine (a) the temperature of the alloy (b) the composition of the liquid phase (c) the mass fractions of both phases. (9.21)**

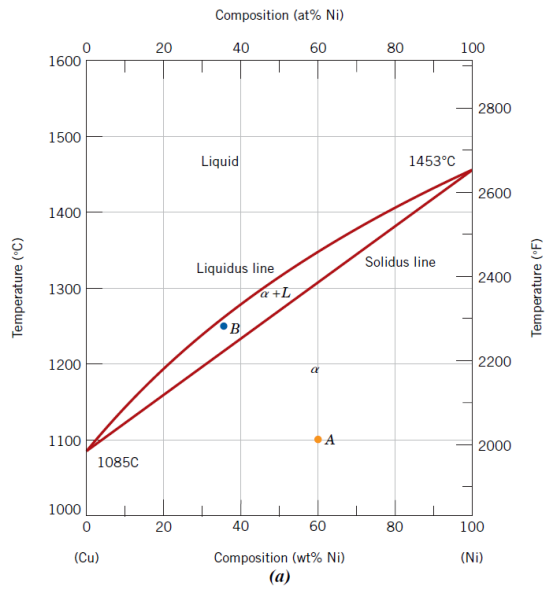
**A:** (a) In order to determine the temperature of a 65 wt% Ni-35 wt% Cu alloy for which  $\alpha$  and liquid phases are present with the  $\alpha$  phase of composition 70 wt% Ni, we need to construct a tie line across the  $\alpha + L$  phase region of Figure 10.3a that intersects the solidus line at 70 wt% Ni; this is possible at about 1345°C.

(b) The composition of the liquid phase at this temperature is determined from the intersection of this same tie line with liquidus line, which corresponds to about 59 wt% Ni.

(c) The mass fractions of the two phases are determined using the lever rule, Equations 9.1 and 9.2 with  $C_0 = 65 \text{ wt\% Ni}$ ,  $C_L = 59 \text{ wt\% Ni}$ , and  $C_{\alpha} = 70 \text{ wt\% Ni}$ , as

$$W_{\alpha} = (C_0 - C_L) / (C_{\alpha} - C_L) = (65 - 59) / (70 - 59) = 0.55$$

$$W_L = (C_{\alpha} - C_0) / (C_{\alpha} - C_L) = (70 - 65) / (70 - 59) = 0.45$$



## Self-review Questions for Module 3

1. Understand the terms: (a) stress; (b) strain; What is the engineering stress and engineering strain? why we say 'engineering stress and engineering strain' instead of 'true stress and true strain'?

**Stress:** as a resistance offered by a material. A reaction of a material to external force.

**Strain** is change in size or shape of material which subjects to external force.

Engineering stress is the quotient of average uniaxial tensile force to the original cross-sectional area.

Engineering strain is calculated by the change in sample length divided by the original length of the sample.

Because in reality the cross-section of the material tends to shrink during the pulling process or expand during the compression.

2. Understand the terms: (a) shear stress; (b) shear strain; How are the shear stress and shear strain calculated?

When the load or force imposed parallel to the surface of a material, it is called shear stress.

shear stress  $\tau = F/A_0$

Shear strain  $\gamma = \text{Amount of shear displacement 'a' / Distance 'h' over which shear acts or } \tan(\theta)$ .

3. What is the elastic modulus or young's modulus ?

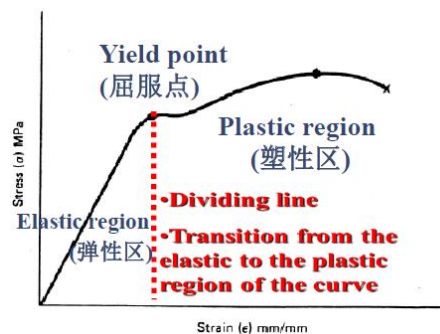
Elastic modulus=Stiffness, a material's resistance to elastic deformation. A measure of the inter atomic bonding force and elastic deformation is recoverable

We can obtain the elastic modulus by formula  $E = \Delta\sigma / \Delta\epsilon$

E-elastic modulus;  $\Delta\sigma$ -stress;  $\Delta\epsilon$ -strain.

4. What is the yield strength and yield point strain?

The dividing line or transition from elastic to the plastic region is call the yield point. Yield strength is the strength corresponding to the material's elastic limit in the yield point ; Yield strain is the strain corresponding to the elastic limit. It equals to the lowest strain at which plastic deformation occurs.



5. What is the 0.2 % offset yield strength and please give detail description that how the 0.2 % offset yield strength is obtained in the stain-stress curve.

The 0.2% offset yield strength is that strength at which 0.2% plastic deformation takes place and the 0.2 % offset yield strength can be obtained following three steps in the stain-stress curve

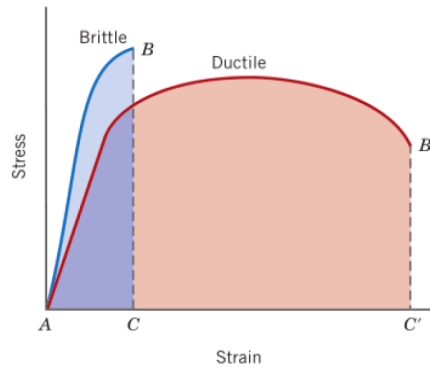
- 1) find a starting point at stain axis;
- 2) draw a offset line paralleled to the elastic region of the stress-stain curve;
- 3) find the intersection of the offset line and stress-strain curve.

6. Describe the definition of ductility and please list two methods to distinguish a ductile material from a brittle material by the stress-strain curve.

Ductility is a measure of the degree of plastic deformation that has been sustained at fracture.

Ductile materials and brittle materials have different performances in the stress-strain curve

- 1) The difference between yield strength and tensile strength;
- 2) The difference in the amount of plastic deformation shown by each curve prior to fracture.



7. Understand the methods of evaluate ductility using the data from the test. What is the percentage elongation?

Percentage elongation , written as capital letter %EL, is the percentage of the elastic strain at fracture;

$$\%EL = \left( \frac{l_f - l_0}{l_0} \right) \times 100$$

8. What is the differences in necking behaviour between ductile and brittle materials?

The more ductile a metal is, the more the specimen will neck before fracture.

9. Write the measure the toughness of materials and try to make a comparison what is the difference of the impact and tensile test?

Toughness can be expressed in terms of:

- 1) Fracture toughness: the ease or difficulty in propagating a crack.

K<sub>c</sub>-the fracture toughness A property that is a measure of a material's resistance to brittle fracture when a crack is present.

$$Kc = Y\sigma_c \sqrt{\pi a}$$

Y- a dimensionless parameter or function that depends on both crack and specimen sizes and geometries as well as the manner of load application;  $\sigma$ -Yield strength;  $a$ -one-half the length of an internal crack

- 2) Impact toughness: the amount of energy absorbed by a material in creating an unit area of crack.
- 3) Static toughness: the energy per unit volume of a material required to produce fracture under static conditions.

Impact toughness test is performed to measure the response (i.e.: impact energy) of a material to dynamic loading; Stress-strain tensile test is a Static testing

10. Understand the terms of ductile-brittle transition. List three Morphologies or types of structures of brittle fracture.

As temperature increase, toughness of material may be brittle at low temperature;

Cleavage, intergranular path and chevron pattern.

11. How to quantitatively measure fatigue property?

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft, and machine components). Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling.

Cyclic loading: A transverse loading is applied and removed in some cyclic fashion. We can observe Fatigue S–N probability of failure curves and Both the stress & the number of cycles are needed in describing the life of the material.

12. Understand the concept of fatigue limit and fatigue strength. What is the difference of the fatigue limit and fatigue strength?

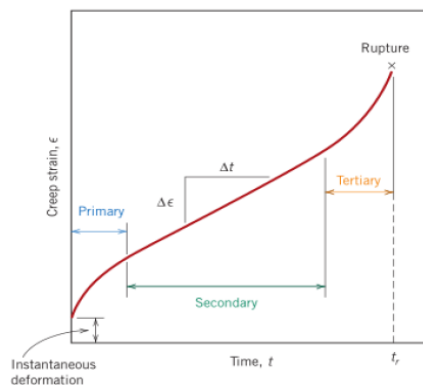
Fatigue limit or endurance limit: the maximum stress that can be sustained for an infinite number of stress cycles;

Fatigue strength: the maximum stress that can be sustained for a specified number of cycles.

13. Please describe the four different stage of creep.

Definition: Creep is defined as the time-dependent and permanent deformation of materials when subjected to a constant load or stress. Creep deformation subjected primary, secondary, tertiary and rupture stages in the creep strain versus time curve as the following picture.

Possibly the most important parameter from a creep test is the slope of the secondary portion of the creep curve ( $\Delta\epsilon/\Delta t$ ); this is often called the minimum or steady-state creep rate. It is the engineering design parameter that is considered for long-life applications.



14. How does engineer apply the creep forming property to make a product?

This process is called creep forming so what happens in creep forming is like that you put a work piece load again a die or tool for a specific time. You apply vacuum or pressure to this work piece, and also heat it at temperature around 160°C. Deformation happens, and you get the product with desired shape.

15. Understand the terms of hardness and List four different measurements of hardness.

Hardness is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch).

Measuring hardness based on the degree of penetration:

1) Brinell hardness (HB);

- 2) Vickers hardness (HV);
- 3) Rockwell hardness (HR);
- 4) Knoop Hardness (HK)

16. What factors will affect heat capacity?

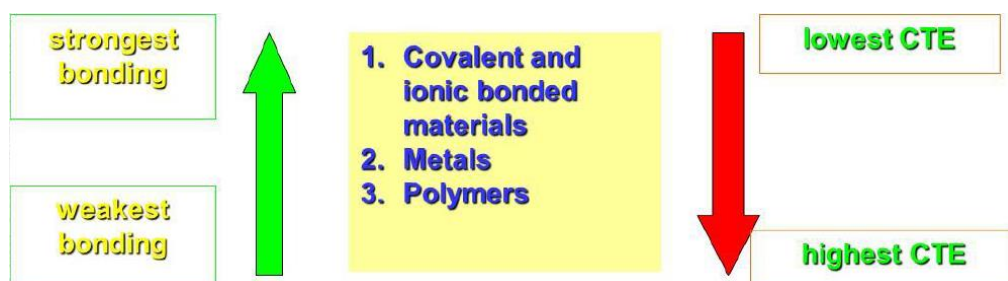
Heat Capacity: The ratio of energy change (energy gained or lost) and the resulting temperature change. Heat capacity is a property that is indicative of a material's ability to absorb heat from the external surroundings; it represents the amount of energy required to produce a unit temperature rise. In mathematical terms, the heat capacity  $C$  is expressed as follows:

$$C = \frac{dQ}{dT}$$

Temperature and heating conditions, generally speaking, Heat Capacity will increase with the heating temperature and constant pressure heat capacity is bigger than constant volume heating value. In addition, the number of atoms, material property would affect heat capacity to some extent.

17. Different materials have different coefficient linear thermal expansion (CTE), if you compare three different materials containing metal, ceramic and polymers, you can find there exist different bonding energy. What is the relationship of the CTE and bonding energy of material?

For each class of materials (metals, ceramics, and polymers), the greater the atomic bonding energy, the deeper and more narrow this potential energy trough. As a result, the increase in inter-atomic separation with a given rise in temperature will be lower, yielding a smaller value of coefficient of thermal expansion (CTE).



18. Thermal conduction is the phenomenon by which heat is transported from high- to low-temperature regions of a substance. What is the mechanism of thermal conduction?

Heat is transported in solid materials by both lattice vibration waves (phonons) and free electrons. A thermal conductivity is associated with each of these mechanisms, and the total conductivity is the sum of the two contributions.

$$k = k_l + k_e$$

$k_e$ , electron thermal conductivity, i.e. the movement of free electrons

$k_l$ , the movement of phonons (声子) (lattice vibrations)

Free electrons participate in electronic thermal conduction.

A gain in kinetic energy is imparted to the free electrons in a hot region of the specimen. They then migrate to colder areas, where some of this kinetic energy is transferred to the atoms themselves (as vibrational energy) as a consequence of collisions with phonons or other imperfections in the crystal. The relative contribution of  $k_e$  to the total thermal conductivity increases with increasing free electron concentrations, because more

electrons are available to participate in this heat transference process.

19. The structure determines materials performance. Metal, ceramics and polymers have diverse thermal conductivity. Try to explain why polymer can be used as good insulator material compared with metal and ceramics materials.

Nonmetallic materials are thermal insulators in as much as they lack large numbers of free electrons. Thus the phonons are primarily responsible for thermal conduction:  $k_e$  is much smaller than  $k_l$ . Again, the phonons are not as effective as free electrons in the transport of heat energy as a result of the very efficient phonon scattering by lattice imperfections. Thermal conductivity range between approximately 2 and 50 W/m K.

In high-purity metals, the electron mechanism of heat transport is much more efficient than the phonons contribution because electrons are not as easily scattered as phonons and have higher velocities. Furthermore, metals are extremely good conductors of heat because relatively large numbers of free electrons exist that participate in thermal conduction.

Thermal conductivity for most polymers are on the order of 0.3 W/m•K. For these materials, energy transfer is accomplished by the vibration and rotation of the chain molecules. Polymers lacking free electrons and having a less crystalline structure. Polymers usually have poor thermal conductivity and can be used as good thermal insulators

## Self-review Questions for Module 4

4-1 Why are metals used so often as engineering materials, based on the common properties of metallic materials?

As compared with ceramics and polymers, metals are relatively dense, and stiff and strong, yet ductile and are resistant to fracture.

4-2 Please compare the properties of metallic materials with those of ceramics and polymers in density, stiffness, tensile strength, Fracture toughness, and electrical conductivity.

Metals are relatively dense in comparison to the ceramics and polymers (Figure 1.4).

Metals are relatively stiff (Figure 1.5) and strong (Figure 1.6), yet are ductile and are resistant to fracture (Figure 1.7). Metals are extremely good conductors of electricity (Figure 1.8) and heat.

4-3 Name the types of steels based on the carbon content or total alloying elements, respectively, and describe the difference between the steels (which are based on the carbon content) from composition, microstructure, and property.



|                     | composition                   | microstructure       | property  |
|---------------------|-------------------------------|----------------------|---|
| Low-carbon steel    | Carbon content: <0.25 wt%     | ferrite and pearlite | Relatively soft and weak; outstanding ductility and toughness |
| Medium-carbon steel | Carbon content: 0.25-0.60 wt% | Tempered martensite  | Low hardenability; stronger than low-carbon steel             |
| High-carbon steel   | Carbon content: 0.60-1.4 wt%  | ----                 | The hardest, strongest, and yet least ductile, wear resistant |

4-4 Name the five types of cast iron, and describe the difference between them based on composition, microstructure, and property.

Five types of cast iron: gray cast iron, nodular cast iron, white cast iron, malleable cast iron, compacted graphite iron.

|                   | composition                   | Graphitic structure   | property   |
|-------------------|-------------------------------|---|--|
| gray cast iron    | 2.5-4.0 wt% C, 1.0-3.0 wt% Si | Graphite flakes surrounded by an $\alpha$ -ferrite or pearlite matrix | Machinability, lubricity, damping ability, wear resistance |
| nodular cast iron | Contain Mg and/or Ce          | Graphite forms as nodules spherulike                                  | Ductility and machinability                                |



|                         |                                      |  |   |
|-------------------------|--------------------------------------|--|---|
|                         |                                      | particles  |   |
| white cast iron         | Low-silicon (< 1.0 wt%)              | Carbon exists as cementite ( $\text{Fe}_3\text{C}$ ) | Very hard but brittle, good abrasion resistant  |
| malleable cast iron     | > 2.14 wt% C                         | Graphite exists in the form of clusters or rosettes  | Relatively high strength and good ductility   |
| compacted graphite iron | 3.1–4.0 wt% C, 1.7–3.0 wt% Si, Mg/Ce | Consists of the wormlike graphite particles          | Higher thermal conductivity, better resistance to thermal shock, lower oxidation at elevated temperatures |

4-5 Describe the typical characteristics of aluminum and its alloys, based on these, understand the main applications of aluminum alloys.

Typical characteristics of aluminum and its alloys: low density, specific strength, high electrical and thermal conductivities, high ductility, corrosion resistance in atmosphere.

Common applications: aircraft structural parts, beverage cans, bus bodies, automotive parts (engine blocks, pistons, and manifolds).

4-6 Please give several reasons that why titanium is known as the most glamorous metal in the world.

Basic properties of titanium and its alloys: superior specific strength (relatively low density, extremely strong), high melting point, High ductility, high elastic modulus, high corrosion resistance.

4-7 Name two nonferrous metals which have superplasticity.

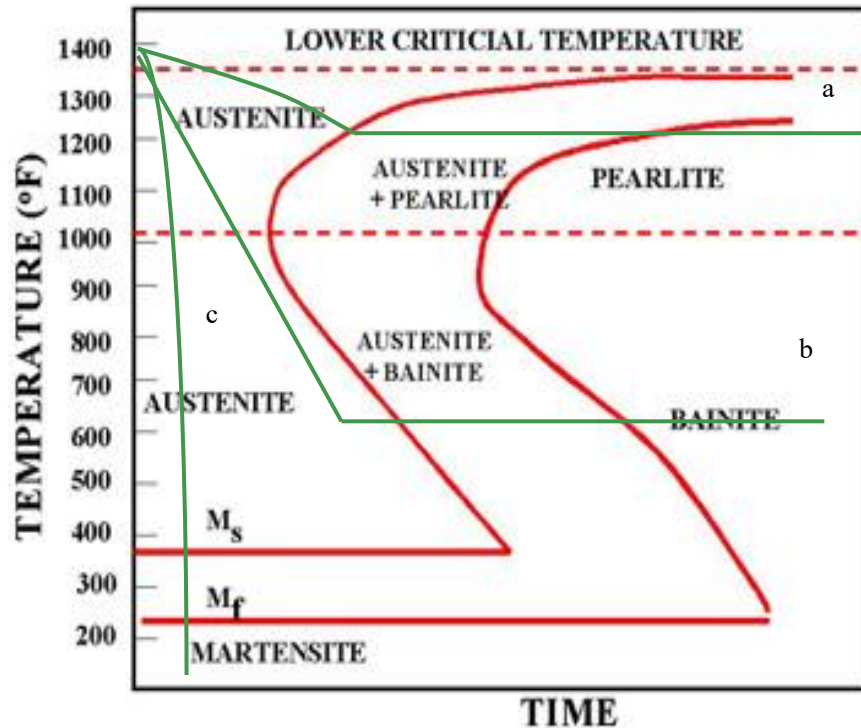
Aluminum and its alloys, Titanium and its alloys

4-8 Please describe the difference between ferrite and austenite in their composition and crystal structure.

Ferrite, also known as  $\alpha$ -iron, is an interstitial solid solution of a small amount of carbon dissolved in iron with a body centered cubic (BCC) crystal structure. C (wt%): < 0.022% (the maximum content at 727 °C)

Austenite, also known as  $\gamma$ -iron, is an interstitial solid solution of carbon dissolved in iron with a face centered cubic (FCC) crystal structure. C (wt%): 2.14% (1148 °C), 0.76% (727 °C)

4-9 List the possible transformations involved in austenite (with eutectoid composition) via three typical temperature protocol based on TTT diagram.



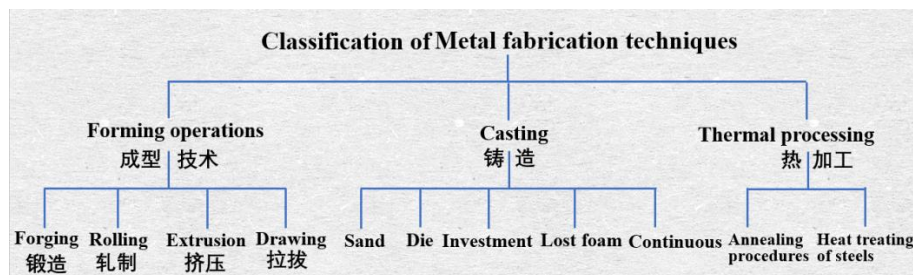
curve a: Pearlite; curve b : Bainite; curve c: Matensite

- 4-10 Considering austenite containing 0.76 wt%C, when it is cooled to below 727°C, what is the eutectoid phase? Please sketch the resulting microstructure.



The eutectoid phase: Pearlite.

- 4-11 Please list the main fabrication techniques used for metal alloys



- 4-12 Name and describe four forming operations used to shape metal alloys.

Forging, rolling, extrusion, drawing.

- 4-13 A deformation is produced when a metal is formed into a fixed shape by cold or hot working. Is it plastic deformation or elastic deformation?

Plastic deformation

- 4-14 What are the differences between hot working and cold working?

Hot working: Deformation is carried out above the recrystallization temperature.

Cold working: Deformation is carried out below the recrystallization temperature

4-15 Name and describe five casting techniques.

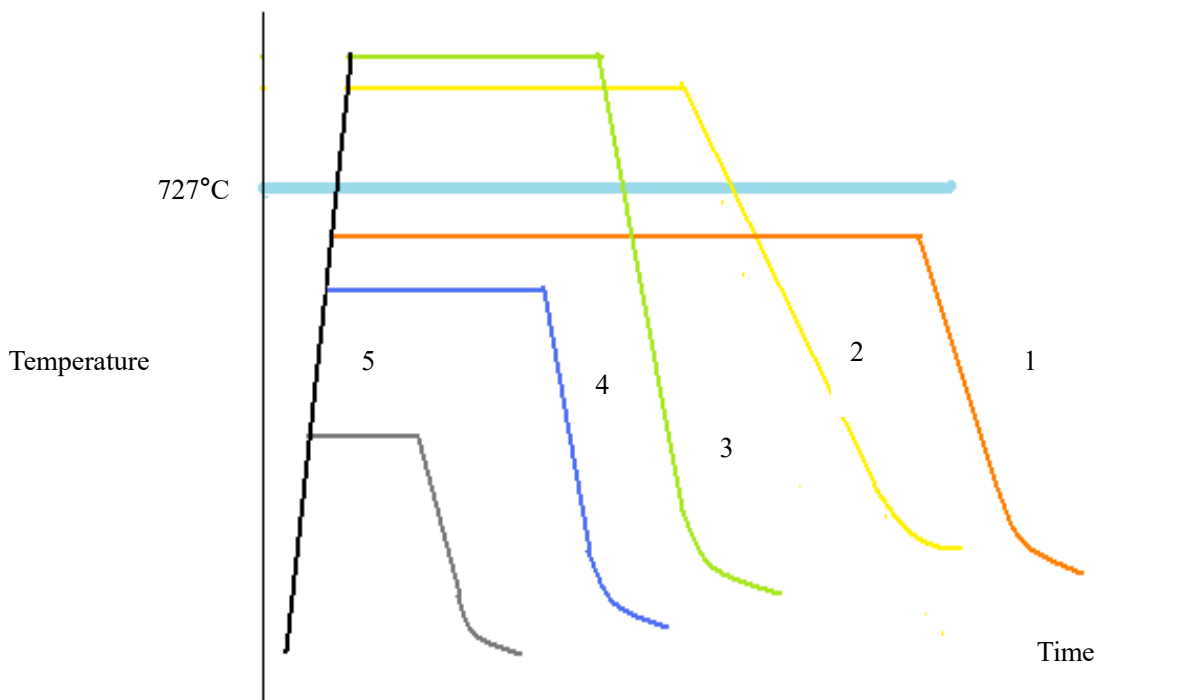
Sand casting, Die casting, Investment casting, lost foam casting, continuous casting.

4-16 What are the purposes of the annealing?

The technology of controlling thermal energy for the purpose of altering the properties of metals and metals.

4-17 Please list types of annealing treatment, and distinguish the temperature protocol.

1. Spheroidizing anneal, 2. Full annealing, 3. Normalizing,, 4. Process anneal, 5. Stress relief



4-18 Describe the following heat treatment procedures for steels and, for each, the intended final microstructure: normalizing, full annealing, quenching, and tempering.

(a) Full annealing--Heat to about  $50^{\circ}\text{C}$  above the  $A_3$  line, Figure 11.11 (if the concentration of carbon is less than the eutectoid) or above the  $A_1$  line (if the concentration of carbon is greater than the eutectoid) until the alloy comes to equilibrium; then furnace cool to room temperature. The final microstructure is coarse pearlite; the grain size is relatively small and the grain structure is uniform.

(b) Normalizing--Heat to at least  $55^{\circ}\text{C}$  above the  $A_3$  line Figure 11.11 (if the concentration of carbon is less than the eutectoid) or above the  $A_{cm}$  line (if the concentration of carbon is greater than the eutectoid) until the alloy completely transforms to austenite, then cool in air. The final microstructure is fine pearlite.

(c) Quenching--Heat to a temperature within the austenite phase region and allow the specimen to fully austenitize, then quench to room temperature in oil or water. The final microstructure is martensite.

(d) Tempering--Heat a quenched (martensitic) specimen, to a temperature between 250°C and 650°C, for the time necessary to achieve the desired hardness. The final microstructure is tempered martensite.

4-19 What is quenching and what are the purposes of the quenching?

Quenching--Heat to a temperature within the austenite phase region and allow the specimen to fully austenitize, then quench to room temperature in oil or water. The final microstructure is martensite. To obtain the steel with greater strength under the non-equilibrium condition than under the equilibrium condition

4-20 Why does the quenching have to be followed by tempering?

The purpose of the tempering: As-quenched hardened steels are so brittle that even slight impacts may cause fracture. Tempering is a heat treatment that reduces the brittleness of a steel without significantly lowering its hardness and strength. All hardened steels must be tempered before use

4-21 What is the difference between the hardenability and hardness?

Hardness is a measure of a material's resistance to localized surface deformation, whereas hardenability is a measure of the depth to which a ferrous alloy may be hardened by the formation of martensite. Hardenability is determined from hardness tests.

4-22 How is the hardenability of the metal measured?

Hardenability of metal can be measured by Jominy End Quench Test, in which readings in the Rockwell C scale along the flat surface of the Jominy specimen are taken and the hardness versus distance from quenched end is plotted.

## Self-review Questions for Module 5

5-1 Name and briefly describe the following terms and recall their meaning in Chinese:

- (1) Ceramic: are inorganic, nonmetallic materials processed or consolidated at high temperatures.
- (2) Traditional ceramic: the ceramic materials based primarily on natural materials of clay and silicates.
- (3) Advanced ceramic: ceramic materials included artificial raw materials, exhibited specialized properties, and required more sophisticated processing.
- (4) Clay: a silicate material with inexpensive ingredient, found naturally in great abundance and without any upgrading of quality
- (5) Refractories: Material that can withstand very high temperatures over 1580 °C or more without degrading or softening
- (6) Glass: are noncrystalline silicates containing other oxides, notably CaO, Na<sub>2</sub>O, K<sub>2</sub>O, and Al<sub>2</sub>O<sub>3</sub>, which influence the glass properties.
- (7) Glass-ceramic: are inorganic glasses with a fine-grained polycrystalline material by the proper high-temperature heat treatment.
- (8) Cement: The characteristic feature of these materials is that when mixed with water, they form a paste that subsequently sets and hardens.
- (9) SiO<sub>4</sub><sup>4-</sup> tetrahedral: is the basic unit of the silicates, in which each atom of silicon is bonded to four oxygen atoms which situated at the corners of the tetrahedron.
- (10) Spinel: A solid solution with the chemical formula MgAl<sub>2</sub>O<sub>4</sub> exists in MgO–Al<sub>2</sub>O<sub>3</sub> phase diagram.
- (11) Mullite: A solid solution with the chemical formula 3Al<sub>2</sub>O<sub>3</sub>–2SiO<sub>2</sub> exists in SiO<sub>2</sub>–Al<sub>2</sub>O<sub>3</sub> phase diagram.
- (12) Acid refractories: The refractories contained silica as main constituents.
- (13) Basic refractories: The refractories contained MgO or periclase as main constituents.
- (14) Portland cement: A cement formed by grinding and firing of a mixture of clay and lime minerals.
- (15) Hydration reaction: a chemical reaction when cement and water are mixed.

5-2 What are the categories that ceramic materials have been grouped into?

Glass, clay products, refractories, abrasives, cements, carbons, advanced ceramics

5-3 List the types of ceramic crystal structure and give at least one example on the basis of table 12.4.

**Table 12.4** Summary of Some Common Ceramic Crystal Structures

| Structure Name              | Structure Type                 | Anion Packing | Coordination Number |       | Examples  |
|-----------------------------|--------------------------------|---------------|---------------------|-------|---|
|                             |                                |               | Cation              | Anion |   |
| Rock salt (sodium chloride) | AX                             | FCC           | 6                   | 6     | NaCl, MgO, FeO  |
| Cesium chloride             | AX                             | Simple cubic  | 8                   | 8     | CsCl  |
| Zinc blende (sphalerite)    | AX                             | FCC           | 4                   | 4     | ZnS, SiC  |
| Fluorite                    | AX <sub>2</sub>                | Simple cubic  | 8                   | 4     | CaF <sub>2</sub> , UO <sub>2</sub> , ThO <sub>2</sub>               |
| Perovskite                  | ABX <sub>3</sub>               | FCC           | 12 (A)<br>6 (B)     | 6     | BaTiO <sub>3</sub> , SrZrO <sub>3</sub> , SrSnO <sub>3</sub>        |
| Spinel                      | AB <sub>2</sub> X <sub>4</sub> | FCC           | 4 (A)<br>6 (B)      | 4     | MgAl <sub>2</sub> O <sub>4</sub> , FeAl <sub>2</sub> O <sub>4</sub> |

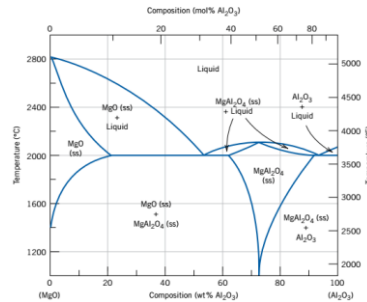
Source: W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

AX: NaCl, AX: CsCl, AX: ZnS, AX<sub>2</sub>: CaF<sub>2</sub>, ABX<sub>3</sub>: BaTiO<sub>3</sub>, AB<sub>2</sub>X<sub>4</sub>: MgAl<sub>2</sub>O<sub>4</sub>

5-4 How many structures can be formed for the SiO<sub>4</sub><sup>4-</sup> tetrahedral in the linear manner?

fibers, rings, chains, planar sheets, or framework.

5-5 From Figure 12.23, the phase diagram for the MgO–Al<sub>2</sub>O<sub>3</sub> system, it may be noted that the spinel solid solution exists. Determine the maximum MgO content of the spinel phase at about 2000°C.

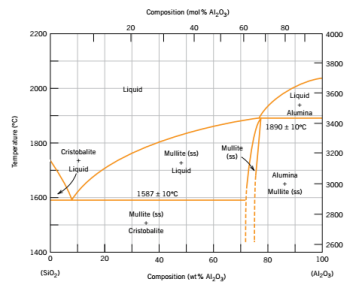


**Figure 12.23** The magnesium oxide–aluminum oxide phase diagram; ss denotes solid solution. Adapted from J. F. Ballstedt, 'Thermodynamic Assessment of the System MgO–Al<sub>2</sub>O<sub>3</sub>,' *J. Am. Ceram. Soc.*, **75**, 1199, 1992. Reprinted by permission of the American Ceramic Society.

Approximately 37.8 %

说明：读相图 12.23 中三角形的最左边，数据为大致，但不可偏差太大。注意，MgO 含量是从右到左，这是学生容易忽略而读成 62.2%。

5-6 From Figure 12.25, write the eutectic reaction at 1587°C for cooling.



**Figure 12.25** The silica–alumina phase diagram; ss denotes solid solution. Adapted from J. F. Klug, N. Prochazka, and J. F. Doremus, 'Alumina–Silica Phase Diagram in the Eulite Region,' *J. Am. Ceram. Soc.*, **70**, 1199, 1992. Reprinted by permission of the American Ceramic Society.



5-7 Explain the difference behavior of plastic deformation for crystalline ceramics and noncrystalline ceramics.

Crystalline ceramics: Plastic deformation occurs by dislocation motion because there are very few slip systems.

Noncrystalline ceramics: Plastic deformation occurs by viscous flow.

5-8 Name at least three forms of carbon.

Diamond, Graphite, Carbon Fibers, Nanocarbons

5-9 A three-point bending test is performed on a spinel (MgAl<sub>2</sub>O<sub>4</sub>) specimen having a rectangular cross section of height  $d = 3.8$  mm and width  $b = 9$  mm; the distance between support points is 25 mm. Compute the flexural strength if the load at fracture is 350 N.

The flexural strength for a rectangular cross-section is just

$$\sigma_f = \frac{3F_f L}{2bt^2} \quad \sigma_f = \frac{(3)(350 \text{ N})(25 \times 10^{-3} \text{ m})}{(2)(9.0 \times 10^{-3} \text{ m})(3.8 \times 10^{-3} \text{ m})^2} = 101 \text{ MPa}$$

5-10 Cite three important requirements that normally must be met by refractory ceramics. Cite some refractory ceramics and some applications with extremely high temperature.

- 1) withstand high temperatures without melting or decomposing;
- 2) remain unreactive and inert when exposed to severe environments;
- 3) provide thermal insulation.

Refractories are used in heat insulation of furnaces, jet and rocket engines, and parts of space vehicles such as the shuttle

5-11 Describe the brittle fracture and stress-strain behavior of ceramics

Elastic behavior: the range of elastic moduli for ceramic materials is between about 70 and 500 GPa.

Plastic deformation: crystalline ceramics occur plastic deformation by the motion of dislocations.

Noncrystalline ceramic deform by viscous flow.

5-12 (a) Explain why residual thermal stresses are introduced into a glass piece when it is cooled. (b) Are thermal stresses introduced upon heating? Why or why not?

(a) Because surface and interior regions cool at different rates, therefore, contract different amounts; if any deformation, stresses are established.

(b) Yes, thermal stresses will be introduced because of thermal expansion upon heating as for thermal contraction upon cooling.

5-13 Cite three important requirements of abrasive and list at least three common abrasive ceramics.

Hardness, wear resistance, high toughness

5-14 List the three classifications of cements on the basis of composition.

Portland cement, Slag cement, Pozzolan cement

5-15 Describe the manufacture processes of Portland cement.

First, grinding and mixing clay and lime minerals in the proper proportions and then heating the mixture to about 1400 °C in a rotary kiln; then ground into a very fine powder, to which is added a small amount of gypsum to retard the setting process. This product is Portland cement.

5-16 What is hydration reaction, write the hydration reaction formula for dicalcium silicate.

A chemical reaction when cement and water are mixed.



5-17 What are setting and hardening caused? The strength after hardening is higher than that of setting? Why?

Setting and Hardening are caused by hydration reactions as soon as water is added to the cement.

The strength after hardening is higher than that of setting.

Because in setting process, the gel coatings formed around individual grains join and Hardening results from densification of the contact areas in the gel.

5-18 Cite one reason why drying shrinkage is greater for slip cast or hydroplastic products that have smaller clay particles.

Because there is more particle surface area, and, consequently, more water will surround a given volume of particles. The drying shrinkage will thus be greater as this water is removed, and as the interparticle separation decreases.

5-19 Some ceramic materials are fabricated by hot isostatic pressing. Cite some of the limitations and difficulties associated with this technique.

The limitations and difficulties of hot-isostatic pressing is that it is costly in terms of time, because both mold and die must be heated and cooled during each cycle. In addition, the mold is usually expensive to fabricate and typically has a short lifetime.

5-20 List three common types of glass. Cite the two desirable characteristics of glasses.

Fused silica, 96% silica, borosilicate, soda-lime glass, optical flint, glass-ceramic  
Optical transparency and ease of fabrication.  
(玻璃种类可任选)

5-21 List the main technique of glass forming.

Glass blowing, Glass pressing, Glass drawing, and glass sheet and fiber forming

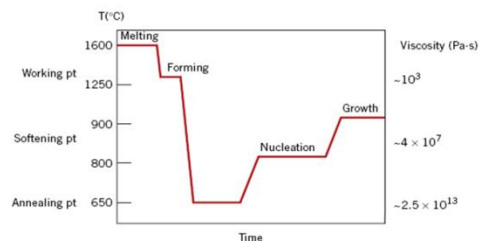
5-22 Cite the two desirable characteristics of clay minerals relative to fabrication processes.

(1) become hydroplastic when mixed with water;  
(2) clays melt over a range of temperatures during firing, which allows some fusion and bonding of the ware without complete melting and a loss of mechanical integrity and shape.

5-23 Briefly explain the fabrication processes of glass–ceramics, draw the time vs temperature processing curve for a  $\text{Li}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  glass–ceramic.

The first stage is melting and forming operation to obtain the desired shape as a glass.

Then nucleation and growth of the crystalline phase particles are carried out isothermally at two different temperatures



5-24 What is tempering glass? What are their representative characteristics on the surface or in the core of glass? Why tempering glass can be used in doors in buildings and homes?

The glassware is heated to a temperature above the glass transition region yet below the softening point.

When rapid cooling, compressive stress is presented on the surface, while tensile stresses survive in the core.

Because glass can fracture into small pieces rather than large splinters.



## Self-review Questions for Module 6

6-1 Define the term polymer. List the major groups of polymers according to their applications.

A chainlike molecule made up of smaller molecular units, called monomers.

Plastics, elastomers, and fibers.

6-2 Give the four types of polymers according to molecular structure.

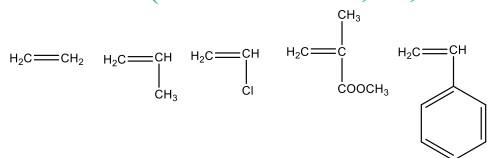
Linear polymers, branched polymers, crosslinked polymers, and polymer networks

6-3 Write out the full name for common polymers, PE, PP, PS, PC, etc.

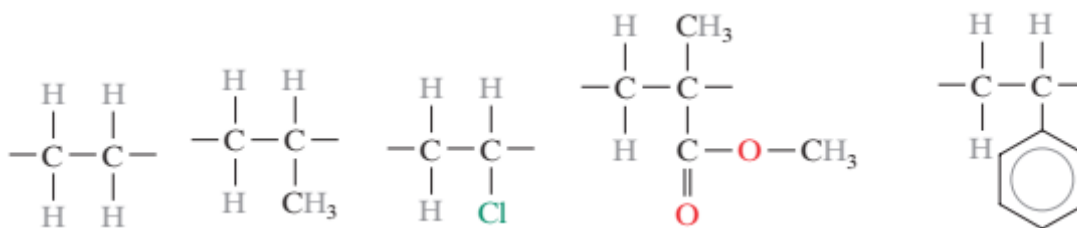
Polyethylene, polypropylene, polystyrene, polycarbonate

6-4 Draw molecules of monomers and repeating units of common polymers (PE, PP, PVC, PMMA, PS).

Molecules (in the order: PE, PP, PVC, PMMA, PS):



Repeating units (in the order: PE, PP, PVC, PMMA, PS):



6-5 List the prerequisites of monomers for polymerization.

(1) Unsaturated monomers, (2) bifunctional monomers

6-6 Define homopolymer and copolymer. List the four types of copolymers.

Homopolymer: the repeating units of the same type.

Copolymer: composed of two or more different types of repeating units.

6-7 Define the term isomer. Note the three categories of stereoisomers, taking PP as example.

Hydrocarbon compounds with the same composition have different atomic arrangement.

Atactic PP, isotactic PP, syndiotactic PP.

6-8 What are the two types of geometrical isomers?

Cis and trans

6-9 What is the difference between unsaturated hydrocarbons and saturated hydrocarbons?

Unsaturated hydrocarbons: have double and triple covalent bonds; or, each carbon atom is not bonded to the maximum (four) other atoms.

Saturated hydrocarbons: all bonds are single ones, and no new atoms may be joined

without the removal of others that are already bonded.

6-10 Define the term polymerization, list two types of polymerization based on reaction mechanism, and typical products obtained by each polymerization.

The reaction for linking monomers into a polymer chain.

Addition polymerization (chain-reaction polymerization);

Condensation polymerization (step-reaction polymerization).

For the former one: only polymers formed; for the latter one: besides polymers, some small molecular byproducts formed.

6-11 Define degree of polymerization (DP). How to determine the molecular weight of a polymer according to DP?

DP: the average number of repeat units in a polymer chain.

DP times  $m$  (the molecular weight of repeating unit).

6-12 Compare HDPE and LDPE in terms of degree of crystallinity.

HDPE > LDPE

6-13 State the main factors affecting crystallinity of polymers.

Internal factors: structural regularity, compactness, flexibility, configuration, tacticity of polymer chains.

External factors: processing (extrusion and drawing), cooling rate, annealing.

6-14 Generally speaking, what is the difference in crystallinity between polymers and metals?

For polymers: only semi-crystalline structure (crystallinity cannot be 100%); for metals, crystallinity can be 100%.

6-15 What type of polymer develops highly oriented (rod-like) molecules for increasing directional strength?

Liquid crystal polymer (LCP)

6-16 Distinguish the interactions among chains in thermoplastic polymers and thermosetting polymers? Compare toughness and impact resistance of thermoplastics with those of thermosets.

(1) The interactions among chains in thermoplastic polymers are mainly van der Waals force and hydrogen bonds, and those in thermosetting polymers are mainly covalent bonds, van der Waals force and hydrogen bonds.

(2) Toughness: thermoplastics > thermosets; impact resistance: thermoplastics > thermosets

6-17 List the common additives used for polymers. What are the functions of colorants, plasticizers, flame retardants, fillers, stabilizers, and carbon black?

(1) Colorant: it can impart a specific color and change the opacity.

(2) Plasticizer: it can improve the flexibility and toughness.

(3) Flame retardant: it can enhance the flammability resistance.

(4) Filler: it can improve the tensile and compressive strength, abrasion resistance, toughness, and dimensional and thermal stability, and reduce the cost.

(5) Carbon black: it can improve the tensile strength and abrasion resistance.

6-18 What is viscoelasticity? List the two properties incorporated in it.

- (1) Viscoelasticity is a combination of viscosity and elasticity.
- (2) Viscosity and elasticity.

6-19 Define the terms: glass-transition temperature ( $T_g$ ) and glass transition. How is the strength of a material related to  $T_g$  value?

- (1) Glass-transition temperature: For the polymers at amorphous state, it is the temperature for the transition between flexible rubbery and rigid glass state.
- (2) Glass transition: it is the transition for amorphous polymers between flexible rubbery and rigid glass state.
- (3) The strength of a material is higher at a temperature below  $T_g$  than that at a temperature above  $T_g$ .

6-20 Compare polymers with metals in terms of thermal conductivity, thermal expansion, and density.

Thermal conductivity: polymers < metals

Thermal expansion: polymers > metals

Density: polymers < metals

6-21 Compare the flammability of thermoplastics with that of thermosets.

Usually, flammability of thermoplastics is higher than that of thermosets; that is, thermoplastics are more flammable than thermosets.

6-22 How does crystallinity affect the optical properties of plastics? Give detailed examples.

- (1) For the semi-crystalline polymers with a high crystallinity, opaque property can be obtained, such as polyethylene.
- (2) For the highly amorphous polymers with low crystallinity, transparency can be higher, such as polycarbonate.

6-23 Note the typical processes for processing polymers.

- (1) Compression molding and transfer molding for both TP and TS
- (2) Injection molding for both TP and TS
- (3) Extrusion majorly for TP
- (4) Blow molding for TP
- (5) Calendering for TP

6-24 Why do the properties of natural rubber need to be improved? How are the properties changed through vulcanization? Is natural rubber a thermoplastic polymer, and vulcanized rubber a thermosetting polymer?

- (1) It is due to the poor resistance to abrasion and poor resistance to oxidation.
- (2) Tensile modulus, tensile strength, and resistance to degradation are all improved due to the formation of crosslinks among polymer chains.
- (3) Natural rubber is a thermoplastic polymer and vulcanized rubber a thermosetting

polymer.

6-25 Is it mainly physical or chemical cross-linking in the rubber network of thermoplastic elastomers?

Physical cross-linking

6-26 What are the advantages of thermoplastic elastomers? List two commercially available thermoplastic elastomers.

- (1) Polymers have both thermoplastic behavior and elastomeric behavior.
- (2) Vulcanization is eliminated.

Commercially available thermoplastic elastomers: SBS and SIS.

6-27 Which elastomer has polymer chains composed of silicon and oxygen backbone?

Silicone rubber.

6-28 Give the full name for UHMWPE, LCP, and TPE.

Ultrahigh molecular weight polyethylene; liquid crystal polymer; thermoplastic elastomer.

6-29 Write out the full name for NR, NBR, SBR, SIS, and SBS.

NBR: acrylonitrile-butadiene rubber

SBR: styrene-butadiene rubber

SIS: styrene-isoprene-styrene

SBS: styrene-butadiene-styrene

## Self-review Questions for Module 7

### 7-1 Define the following terms and give their Chinese names:

- (1) composites; (2) critical length ( $l_c$ ); (3) continuous fiber; (4) discontinuous fiber;  
(5) specific strength; (6) specific modulus (stiffness)

#### Answers:

- (1) 复合材料: Composites are artificially produced multiphase materials with desirable combinations of the best properties of the constituent phases.
- (2) 临界长度 ( $l_c$ ): Critical length refers to the length limit for a fiber to have load-carrying and reinforcing abilities. It depends on fiber diameter and its tensile strength and on the fiber-matrix bond strength.
- (3) 连续纤维: Fibers with a length  $l$  is much larger than the critical length  $l_c$ , i.e.,  $l \gg l_c$  (normally  $l > 15l_c$ ).
- (4) 非连续纤维 (或短纤维): Fibers with a length is significantly less than  $l_c$ , having little reinforcement in a composite.
- (5) 比强度: the ratio of tensile strength to specific gravity
- (6) 比模量 (刚度): the ratio of modulus of elasticity to specific gravity.

### 7-2 What are the two phases many composites composed of?

#### Answers:

One phase is the matrix, another phase is the dispersed phase or reinforcing phase (reinforcement)

### 7-3 Give the full name and the abbreviations of the types of composites based on their matrix.

#### Answers:

polymer-matrix composites (PMC)

metal-matrix composites (MMC)

ceramic-matrix composites (CMC).

### 7-4 Name the four main divisions of composite materials and cite the distinguishing feature of each.

#### Answers:

Composites are classified as particle-reinforced, fiber-reinforced, structural, and nanocomposites.

- The dispersed phase for particle-reinforced composites is equiaxed (i.e., particle dimensions are approximately the same in all directions);
- For fiber-reinforced composites, the dispersed phase has the geometry of a fiber (i.e., a large length-to-diameter ratio).
- Structural composites are multilayered and designed to have low densities and high degrees of structural integrity.
- For nanocomposites, dimensions of the dispersed phase particles are on the order of nanometers.

### 7-5 List the two sub-classifications of particles-reinforced composites. Cite three examples of particle-reinforced composite.

#### Answers:

Subclassifications: Large-particle-reinforced composites and dispersion-strengthening composites

Examples:

- 1) carbon black in rubber tires,
- 2) concrete, a type of large-particle composite, consists of an aggregate of particles bonded together with cement.
- 3) cemented carbide (cermets), which is composed of extremely hard particles of a refractory carbide ceramic such as tungsten carbide (WC) or titanium carbide (TiC) embedded in a matrix of a metal such

as cobalt or nickel.

**7-6 List the geometrical and spatial characteristics of the particles that may influence the properties of particle-reinforced composites.**

**Answer:**

(a) concentration, (b) size, (c) shape, (d) distribution, and (e) orientation.

**7-7 Carbon black reinforced rubber is a typical large-particle reinforced composite, for the carbon black to provide significant reinforcement, what requirements must the carbon black meet?**

**Answers:**

For the carbon black to provide significant reinforcement, the particle size must be extremely small (normally, 20~ 50 nm); also, the particles must be evenly distributed throughout the rubber and must form a strong adhesive bond with the rubber matrix.

**7-8 What are the design goals (or characteristics) of a fiber-reinforced composite?**

**Answers:**

Fiber-reinforced composites are designed to have high strength and/or stiffness on a weight basis. In another words, they have high specific strength/high specific modulus

**7-9 Discuss the reinforcing effect of the fibers with different lengths ( $l > l_c$ ,  $l = l_c$ ,  $l < l_c$ ).**

**Answer:**

- when a stress is applied to a fiber having just this critical length ( $l = l_c$ ), the maximum fiber load is achieved only at the axial center of the fiber.
- As fiber length  $l$  increases ( $l > l_c$ ), the fiber reinforcement becomes more effective.
- For discontinuous fibers of lengths significantly less than  $l_c$ , the matrix deforms around the fiber such that there is virtually no stress transference and little reinforcement by the fiber.

**7-10 List the three different types of fiber-reinforced composites on the basis of fiber length and orientation.**

**Answers:**

- 1) Continuous and Aligned Fiber Composites;
- 2) Discontinuous and Aligned-Fiber Composites;
- 3) Discontinuous and Randomly Oriented-fiber Composites.

**7-11 Use equations to express the rule of mixture (ROM) in terms of modulus for the isostrain situation and the inverse ROM in terms of modulus for the isostress situation. Give the assuming conditions for the two cases.**

**Answers:**

- Rule of Mixture : 
$$E_{cl} = E_m V_m + E_f V_f$$

Presumptions: isostrain situation (deformation of both matrix and fibers is the same) longitudinal loading

- Inverse ROM: 
$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

Presumptions: isostress condition (The fiber and the matrix each resist the load equally), transverse Loading

**7-12 List the three different classifications of fibers on the basis of diameter and characteristics.**

**Answers:** whiskers; fibers; wires.

**7-13 Cite three examples of whisker materials and list the structure and property characteristics of these whiskers as well as their limitations.**

**Answers:**

**Examples:** to choose from **Table 16.4 (page 652)**, such as graphite, silicon nitride; aluminum oxide, silicon carbide

**Structure characteristics:** Whiskers are very thin single crystals that have extremely large length-to-diameter ratios, and they have a high degree of crystalline perfection and are virtually flaw-free.

**Property characteristics:** exceptionally high strengths.

**Limitations:** Whiskers are not used extensively as a reinforcement medium because they are extremely expensive. Moreover, it is difficult and often impractical to incorporate whiskers into a matrix.

**7-14 List the three common fiber reinforcements used in polymer-matrix composites.**

**Answers:**

glass fiber (GF); carbon fiber (CF); aramid (Kevlar) fiber.

**7-15 What are the functions of the matrix (ductile matrices such as metals and polymers) in a composite?**

**Answer:**

1) binds the fibers; 2) transmit stress to the fibers; 3) provide ductility; 4) protect the individual fibers from surface damage; 5) serves as a barrier to crack propagation

**7-16 Give the full names of GFRP and CFRP and list the typical advantages and disadvantages of GFRP.**

**Answer:**

GFRP: glass fiber reinforced plastics. CFRP: Carbon fiber reinforced plastics

**Advantages:** GFRP is produced in the largest quantities and have a very high specific strength. The composite are useful in a variety of corrosive environments.

**Disadvantages:** GFRP are not very stiff and do not display the rigidity that is necessary for some applications (e.g., as structural members for airplanes and bridges).

Most GFRP materials are limited to service temperatures below 200 °C.

**7-17 List the typical property characteristics (advantages and disadvantages) of carbon fibers.**

**Answer:**

**Advantages:**

- 1) Carbon fibers have high specific moduli and specific strengths.
- 2) They retain their high tensile modulus and high strength at elevated temperatures;
- 3) At room temperature, carbon fibers are not affected by moisture or a wide variety of solvents, acids, and bases. (i.e., have good corrosion resistance at room temperature)

**Disadvantages:** high-temperature oxidation

**7-18 What are the structure and property characteristics of aramid fibers? Give the trade names for the most two common aramid fibers.**

**Answer:**

**Structure:** Rigid molecules are aligned in the direction of the fiber axis.

**Property:** high specific strength and modulus;  
exceptional toughness; impact resistance;  
resistance to creep and fatigue failure;  
resistant to combustion and stable to relatively high temperatures -200°C and 200°C;

Chemically, they are susceptible to degradation by strong acids and bases, but they are relatively inert in other solvents and chemicals.

**Trade names:** Kevlar and Nomex.

**7-19 What are carbon-carbon composites? List the typical advantages and disadvantages of carbon-carbon composites?**

**Answer:**

**Definition:** carbon fiber-reinforced carbon matrix composites.

**Advantages:**

- High-tensile moduli and tensile strengths that are retained to temperatures in excess of 2000°C.
- Resistance to creep
- Relatively large fracture toughness values.
- Low coefficients of thermal expansion and relatively high thermal conductivities.
- Low susceptibility to thermal shock

**Disadvantages:** high-temperature oxidation; expensive

**7-20 What is a hybrid composite? Discuss the reasons why both carbon and glass fibers are incorporated into a polymeric resin to fabricate the hybrid composites.**

**Answer:**

**Definition:** The hybrid composites contain at least two different fiber types and they have a better all-around combination of properties than composites containing only a single fiber type.

**Reasons:** The carbon fibers are strong and relatively stiff and provide a low-density reinforcement; however, they are expensive. Glass fibers are inexpensive and lack the stiffness of carbon. The glass-carbon hybrid is stronger and tougher, has a higher impact resistance, and may be produced at a lower cost than either of the comparable all-carbon or all-glass reinforced plastics.

**7-21 What is the pultrusion process for fiber-reinforced composites?**

**Answer:**

Pultrusion is a composite fabrication method by which a bundle of extremely long fibers are pulled through a resin system for impregnation and then through a heated curing die to obtain the components having continuous lengths and a constant cross-sectional shape (rods, tubes, beams, etc.)

**7-22 What is the filament winding process for fiber-reinforced composites?**

**Answer:** Filament winding is a process by which continuous reinforcing fibers are accurately positioned in a predetermined pattern to form a hollow (usually cylindrical) shape.

**7-23 What is the prepreg? Why is the prepreg stored at 0°C or lower?**

**Answer:**

**Definition:** Prepreg is the composite industry's term for continuous-fiber reinforcement preimpregnated with a polymer resin that is only partially cured.

**Reason:** At room temperature, the thermoset matrix undergoes curing reactions; therefore, the prepreg is stored at 0 °C (32 °F) or lower.

**7-24 What are the two most common structural composites? Cite one example of each.**

**Answer:**

Laminar composites (plywood, laminate); sandwich panels (honeycomb panel).

**7-25 What are laminar composites? List the four lay-ups for laminar composites.**

**Answer:**

**Definition:** Laminar composites are composed of a set of two-dimensional sheets that are bonded to one another; each sheet has a high-strength direction.



**Four lay-ups for laminar composites:** unidirectional, cross-ply, angle-ply and multidirectional.

**7-26 What is a sandwich panel? Draw the schematic diagram showing its cross section.**

**Answer:**

A panel consists of two outer sheets (faces, or skins) that are separated by and adhesively bonded to a thicker core. It is lightweight and has relatively high stiffness and strength.



**7-27 Cite the three categories of core materials for sandwich panels and list the typical characteristics of core materials.**

**Answer:**

- **Core materials** are typically fall within three categories:  
**rigid polymeric foams**, **wood**, and **honeycombs**.
- **Characteristic:** The core material is **lightweight** and normally has a low modulus of elasticity.

**7-28 What is a nanocomposite? List one example showing the size effect of nanoparticles.**

**Answer:**

**Definition:** Nanocomposites are composed of nanosized particles (or nanoparticles) that are embedded in a matrix material.

**Example:** the permanent magnetic behavior of some materials [e.g., iron, cobalt, and iron oxide ( $\text{Fe}_3\text{O}_4$ )] disappears for particles having diameters smaller than about 50 nm.

## Self-review Questions for Module 8

1. **Define the following terms: (a) biomaterial; (b) biocompatibility; (c) *in vitro* testing; (d) *ex vivo* testing (e) *in vivo* testing.**

**Biomaterial:** Any substance (other than a drug) or combination of substances synthetic or natural origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ, or function of the body.

**Biocompatibility:** the ability of a material to perform with an appropriate host response in a specific application. “appropriate host response” implies that the biomaterial displays good or harmonious behavior in contact with tissue and body fluid.

***In vitro* testing:** a Latin-based word means “(with) in the glass”. *In vitro* testing of biomaterials refers to that biomaterials are evaluated for biofunctionality and biocompatibility in a test tube or in a controlled artificial environment, i.e.: a controlled environment outside a living organism.

***Ex vivo* testing:** Latin word means “out of the living”. *Ex vivo* testing of biomaterials refers to that experimentation or measurements done in or on tissue from an organism in an external environment with minimal alteration of natural conditions.

***In vivo* testing:** Latin word means “in life” or “(with) in the living”. *In vivo* testing of biomaterials refers to that the biofunctional and biocompatible experimentation of biomaterials is done in or on the living tissue of a whole living organism.

2. **List the major groups of biomaterials.**

(1) Based on the common characteristics of materials: metallic biomaterials, ceramic biomaterials, polymeric biomaterials

3. **What are the features of three generations of biomaterials ?**

The first-generation biomaterials are off-the-shelf materials with a common feature of “bioinertness” (生物惰性).

The second-generation biomaterials exhibit the feature of “bioactivity” (生物活性), which can be breakdown and/or resorption in the physiological environment.

The third-generation biomaterials are designed with the goal to regenerate functional tissues(再生功能组织). They are designed to simulate specific cellular responses at molecular level.

4. **What are the two aspects of biocompatibility?**

Hemocompatibility and tissue compatibility

5. **What factors should be considered to evaluate biomaterials?**

Biological, physical, mechanical, and chemical properties,

6. **What mechanical and chemical properties are of primary consideration when selecting metallic biomaterials for medical devices?**

**Mechanical properties:** strength, toughness, elasticity, stiffness, wear resistance and impact resistance.

**Chemical properties:** corrosion resistance.

**7. What are the pros and cons of metallic biomaterials to be used in medical devices?**

Pros:

Excellent mechanical properties

Fair biocompatibility

Cons:

Corrosion : release corrosion products into the surrounding tissues thus cause inflammation and allergic reactions.

Stress shielding: If the elastic modulus of the metal is greater than that of bone, then the load experienced by the bone is reduced. This can cause the bone to remodel to adjust to the lower load and eventually result in the loss of bone quality.

**8. Why porous stainless steel is favorable as biomaterials?**

The main advantage of porous materials is their ability to provide biological anchorage for the surrounding bony tissue via the ingrowth of mineralized tissue into the pore space.

**9. Why Co-Cr alloys is favorable as biomaterials?**

Good corrosion resistant, good biocompatibility, good mechanical properties

**10. Why Co-Cr alloys are well known for their biocompatibility?**

Co-Cr alloys show high resistance to corrosion due to the spontaneous formation of a protective passive film composed of mostly  $\text{Cr}_2\text{O}_3$ , and minor amounts of cobalt and other metal oxides on the surface.

Co-Cr alloys are well known for their biocompatibility. Biocompatibility also depends on the film and how this oxidized surface interacts with physiological environment.

**11. What is bioactive? What are common bioactive ceramics?**

Bioactive: having an effect on a living organism

Common bioactive materials available commercially for clinical use include dense synthetic Hydroxyapatite (HA) , bioactive glass, bioactive glass ceramic, and bioactive composites such as a polyethylene–HA mixture

**12. What is chemical composition of hydroxyapatite? Why hydroxyapatite has been widely used as bioactive ceramic?**

$\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$  , Hydroxyapatite (HA) has a similar properties with mineral phase of bone and teeth.

**13. What is the main ceramic material found in bones and teeth?**

Human bone and teeth enamel are made primarily from hydroxyapatite (HA)

**14. How are polymer biomaterials classified? What are the characteristics of each group of polymeric biomaterials in the classification?**

In broad terms, polymeric biomaterials may be classified as either biodegradable or nonbiodegradable.

Non-Biodegradable Polymers consist of long chains of carbon and hydrogen atoms. These molecules form an interatomic type of bonding and is adamant meaning it is tough for microbes to break the bonds and digest them. Thus a long period is required to decompose them.

Biodegradable polymers are a special class of polymer that breaks down after its

intended purpose by bacterial decomposition process to result in natural byproducts such as gases (CO<sub>2</sub>, N<sub>2</sub>), water, biomass, and inorganic salts. These polymers are found both naturally and synthetically made, and largely consist of ester, amide, and ether functional groups.

**15. What is the difference between degradation and erosion?**

“Degradation” specifically refers to bond cleavage a chemical process. Biodegradation is the destruction and assimilation of organic polymers by living organisms and their enzymes, particularly fungi and bacteria.

“Erosion” refers to depletion of material. A physical phenomenon depending on dissolution and diffusion processes. Surface eroding polymers undergo erosion at constant velocity at any time during erosion. Bulk eroding polymers have no constant erosion velocity

**16. What are the advantages and disadvantages of using naturally occurring polymers as biomaterials?**

The naturally occurring polymers can be degraded by enzymes and therefore they are biodegradable, which provides an additional advantage over the use of non-biodegradable synthetic polymers. Naturally occurring polymers, which are also known as biopolymers or biological polymers, are being investigated as biomaterials due to their excellent properties such as biodegradability, biocompatibility with tissues and blood, non-toxicity, biological activity, availability, and low cost, etc. The principal disadvantages of naturally occurring polymers are the structural complexity and significant batch-to-batch variations of the polymers, which cause difficulties in purification and modification of biopolymers.

**17. What are the commonly used naturally occurring polymers?**

The most commonly used naturally occurring polymers include polysaccharides such as cellulose, starch, chitin and chitosan, alginate, hyaluronic acid and pectin, and protein such as collagen.

**18. Explain the aqueous insolubility of cellulose and chitosan.**

The water-insolubility is due to the stiffness of the homopolysaccharide chains and hydrogen bonding between-OH groups on adjacent chains.

**19. Define the following terms: (a) amylase; (b) amylopectin; (c) chitin; (d) chitosan; (e) degradable polymers; (f) non-degradable polymers; (g) biodegradation; (h) surface erosion; (i) bulk erosion.**

(a) the straight-chain starch fraction have been termed amylose

(b) the more highly branched starch fractions have been called amylopectin

(c) chitin is a homopolymer of  $\beta$ -(1→4)-linked 2-acetamido-2-deoxy -D-glucopyranose.

(d) chitosan is a copolymer of  $\beta$ -(1→4)-linked 2-acetamido-2-deoxy -D-glucopyranose and 2-amino-2-deoxy -D- glucopyranose.

(e) degradable polymers, however, normally possess labile functional group accessible to biological or nonbiological mechanisms of degradation

(f) non-degradable polymers, normally do not possess labile functional group accessible to biological or nonbiological mechanisms of degradation

(g) biodegradation: refers to polymers that can degrade upon implantation in the host and is subsequently replaced by endogenous tissue

(h) surface erosion: In surface erosion controlled release systems, the rate of bond cleavage is remarkably higher than the rate of water penetration. As a consequence, only the polymer at /near the surface .

(i) bulk erosion: In bulk erosion controlled release systems, the rate of bond cleavage is remarkably lower than the rate of water penetration. Backbone cleavage of the polymer occurs uniformly throughout the interior of the device.

**20. Why does chitosan dissolve readily in dilute organic acids solutions and inorganic acids? Which acids are commonly used to dissolve chitosan? How does the average molecular weight of chitosan change in acidic aqueous solution?**

The pH-dependent solubility of chitosan is due to the protonation of amino groups on the polymer chains at pH below 5.

Chitosan dissolves readily in dilute organic acids solutions and inorganic acids except phosphoric and sulfuric acids.

Chitosan undergo readily hydrolysis in acidic solution, leading to the breakdown of the polymers and thus lowering the average molecular weight.

**21. What two factors determine the characteristics of chitosan?**

The main parameters influencing the characteristics of chitosan are its molecular weight (MW) and DD

**22. Why chitosan was widely used in hemostasis wound dressings?**

Chitosan has recognized as the only positively charged polysaccharides. Chitosan based dressings could accumulate negatively charged red blood cell and blood platelet by electrostatic interactions and thus causing fast Hemostasis.

**23. What are the advantages of using chitosan and their derivatives as biomaterials in various medical and pharmaceutical applications?**

Chitosan derivatives have excellent properties such as film-or gel-forming ability, biocompatibility, biodegradability, non-toxicity, adsorption properties, antimicrobial and antifungal activities, they have found wide uses in various medical and pharmaceutical applications

**24. What properties may limit the applications of non-degradable polymers as biomaterials?**

The poor biocompatibility may limit the applications of non-degradable polymers as biomaterials

**25. What are the basic components of tissue engineering?**

Cells, scaffolds and signals.