Chapter 2

1. Materials science and engineering include (s) the study of:
   (a) metals
   (b) polymers
   (c) ceramics
   (d) composites
   (e) nanomaterials
   (f) all of the above

   Ans: f

2. Which one of the following engineering materials is defined as a compound containing metallic and non-metallic elements:
   (a) metals
   (b) ceramics
   (c) polymers
   (d) nanomaterials
   (e) composites

   Ans: b

3. Does the microstructure of an engineering material influence the properties of the material? Give examples.
   Ans: Yes, the microstructure of an engineering materials influence the chemical and mechanical properties of the material. For example, increase in the grain size increases the strength of the material.

4. Why are metals good conductors of electricity?
   Ans: Metals are good conductors of electricity due to the presence of nonlocalized valence electrons (cloud of electrons).

5. Nanomaterials is a class of materials based on:
   (a) chemical structure
   (b) mechanical properties
   (c) density
   (d) colour
   (e) size

   Ans: e (<100nm size materials are called nanomaterials)

6. How are atoms arranged in crystalline and amorphous materials? Comment on the density of these materials.
   Ans: In crystalline materials, the atoms are orderly arranged in a long range, whereas in the amorphous materials, there is no orderly arrangement of the atoms. Hence, crystalline materials have higher density than amorphous materials.

7. What is an alloy? Give examples.
   Ans: An alloy is basically made of solute and solvent atoms. It can be a mixture of two or more metals, or metals and non-metallic elements such as carbon, nitrogen or oxygen. Examples of alloys, brass (copper and zinc) and steel (iron and carbon).

8. Explain why ceramics have higher melting points than polymers?
   Ans: Ceramics have higher melting points than polymers since the bonding in ceramics is predominantly ionic bonding (high binding energy). In the case of polymers, the bonding is generally covalent bonding.

9. Define valence electron. What is the significance of valence electron(s)?
   Ans: The electron occupying the outermost shell in the electron configuration is called valence electron. Many physical and chemical properties of materials are related to valence electron(s).

10. All crystalline solids contain vacancies. (True/False)
    Ans: True

11. Self-interstitials are highly probable in solids. (True/False)
    Ans: False

12. What is the difference between solid solution and second phase particles in an alloy?
    Ans: Solid solution is a homogeneous microstructure in an alloy (e.g. Brass Cu-Zn). Secondary phase particles in an alloy forms a heterogeneous microstructure (e.g. iron carbide (Fe_3C) in steel)

13. Calculate the theoretical density of aluminium (FCC) and chromium (BCC).
Ans:

Theoretical density (ρ)

$$\rho = \frac{nA}{V_C N_A}$$

Aluminium:
FCC, n = 4 atoms/unit cell; $V_C = 16R^3\sqrt{2}$

Atomic weight of aluminium = 26.9 g/mol

Radius of an aluminium atom = 0.143nm

$$\rho = \frac{nA_{Al}}{V_C N_A}$$

$$\rho = \frac{(4)(26.9)}{16(0.143\ x10^{-7})^3\sqrt{2})6.023x10^{23}}$$

$$\rho = 2.7\ \text{g/cm}3$$

Chromium:
BCC, n = 2 atoms/unit cell;

$$V_c = \left(\frac{4\text{R}}{\sqrt{3}}\right)^3$$

Atomic weight of chromium = 51.9 g/mol;

Radius of a chromium atom (R) = 0.128nm

$$\rho = \frac{2 \times 51.9}{\left(\frac{4 \text{ x } 0.128 \text{ x } 10^{-7}}{\sqrt{3}}\right)^3 \times 6.023 \times 10^{23}}$$

$$\rho = 7.1\ \text{g/cm}3$$

14. Gold has an atomic radius of 0.1442 nm and a density of 19.3 g/cm^3. Determine whether it has a BCC or FCC crystal structure.

Ans:

$$\rho = \frac{nA}{V_C N_A}$$

Atomic weight of gold = 196.9 g/mol

First, assume that gold has a BCC crystal structure:

For BCC, *n* = 2 atoms/unit cell;

$$V_c = \left(\frac{4\text{R}}{\sqrt{3}}\right)^3$$

$$\rho = \frac{nA_{Au}}{V_C N_A}$$

$$\rho = \frac{2 \times 196.9}{\left(\frac{4 \text{ x } 0.1442 \text{ x } 10^{-7}}{\sqrt{3}}\right)^3 \times 6.023 \times 10^{23}}$$

Density, $\rho = 17.7\ \text{g/cm}3$ *(not correct)*

Now, assume gold has an FCC crystal structure:

For FCC, *n* = 4 atoms/unit cell

$V_C = 16R^3\sqrt{2}$

$$\rho = \frac{nA_{Au}}{V_C N_A}$$

$$\rho = \frac{(4)(196.9)}{16(0.1442\ x10^{-7})^3\sqrt{2})6.023x10^{23}}$$

Density, $\rho = 19.3\ \text{g/cm}3$ *(correct)*

Gold has an FCC crystal structure.

15. Suggest a suitable microscope for fracture-surface analysis.

Ans: Scanning electron microscope (SEM) is a suitable microscope for fracture-surface analysis since the depth of focus in SEM is high.

16. Explain how imperfections in materials alter their properties.

Ans: Imperfections such as point defects (vacancies), line defects (dislocations) and surface defects (grain boundaries) alter the properties of materials. For example, the internal energy of the crystal will increase when there are vacancies; plastic deformation of a material is influenced by dislocations; and orientation of the gain boundaries affect the mechanical properties.

17. Comment on the influence of dislocations in metals on their ductility.
    Ans: Dislocation is a line defect and is caused by localized lattice distortion. Dislocations play a major role in the plastic deformation (irreversible change in shape when force or stress is applied) of materials, especially in metallic materials. In low concentrations, dislocations enhance ductility through slipping, whereas in high concentrations the material will become brittle.

18. Suggest two methods to decrease the grain size of a material for improved mechanical properties.
    Ans: The grain size of materials can be controlled by altering the cooling rate during the casting (liquid to solid) process or by heat treatments. In general, fast cooling produces smaller grains, and larger grains are formed under slow cooling. Fine grains can be also produced by alloying and/or thermomechanical treatments.

19. List the advantages of AFM as compared to TEM.
    Ans: AFM and TEM can be used to analyse a material at nanoscale. However, AFM has some advantages over TEM. AFM does not require vacuum. It can be operated in ambient air or even in a liquid environment, and also there is no need for any special sample preparation.

20. Suggest a method to identify crystallinity in materials.
    Ans: XRD is a nondestructive analytical technique used for phase identification and quantification of a crystalline material. Using this technique, a wide range of materials can be tested, including metals; fine-grained minerals such as clays, composites, inorganic and organic compounds; and polymers.