Chapter 1

1.1 Materials Science and Engineering is an interdisciplinary field concerned with inventing new materials and improving previously known materials by developing a deeper understanding of the microstructure-composition-synthesis-processing relationships.

1.2 Compostion, is the chemical make-up of a material

Structure, is a description of arrangements of atoms or ions in material.

Synthesis, is the process by which materials are made from naturally occurring or other chemicals.

Processing means different ways of shaping materials into useful components or changing their properties.

Microstructure, is the structural feature of a material such as grain boundaries, grain size and structure, subject to observation under a microscope.

1.3 Materials Science- emphasis on relationships between synthesis and processing, structure and properties.

Materials Engineering- emphasis on transforming materials into useful devices or structures.

Chapter 2

2.1 Chemical make-up of a material

2.2 The term structure means a description of arrangements of atoms, as seen at different levels of detail.

2.5 Microstructure is in the length scale of 10 to 1000 nm whereas macrostructure is ~⟩ 100,000 nm or 100 μm.

2–7 (a) Using data in Appendix A, calculate the number of iron atoms in one ton (2000 pounds).

Solution: $\dfrac{(2000\text{ lb})(454\text{ g/lb})(6.02 \times 10^{23}\text{ atoms/mol})}{55.847\text{ g/mol}} = 9.79 \times 10^{27}\text{ atoms/ton}$

(b) Using data in Appendix A, calculate the volume in cubic centimeters occupied by one mole of boron.

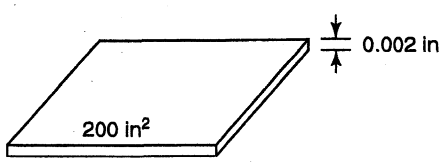
Solution: $\dfrac{(1\text{ mol})(10.81\text{ g/mol})}{2.3\text{ g/cm}^3} = 4.7\text{ cm}^3$

2–8 In order to plate a steel part having a surface area of 200 in.^{2} with a 0.002 in. thick layer of nickel, (a) how many atoms of nickel are required and (b) how many moles of nickel are required?

Solution: Volume = $(200\text{ in.}^2)(0.002\text{ in.})(2.54\text{ cm/in.})^3 = 6.555\text{ cm}^3$

(a) $\dfrac{(6.555\text{ cm}^3)(8.902\text{ g/cm}^3)(6.02 \times 10^{23}\text{ atoms/mol})}{58.71\text{ g/mol}} = 5.98 \times 10^{23}\text{ atoms}$

(b) $\dfrac{(6.555\text{ cm}^3)(8.902\text{ g/cm}^3)}{58.71\text{ g/mol}} = 0.994\text{ mol Ni required}$



2–9 Suppose an element has a valence of 2 and an atomic number of 27. Based only on the quantum numbers, how many electrons must be present in the $3d$ energy level?

Solution: We can let x be the number of electrons in the $3d$ energy level. Then:

$1s^2\, 2s^2 2p^6 3s^2 3p^6 3d^x 4s^2$ (must be 2 electrons in $4s$ for valence = 2)

Since $27-(2+2+6+2+6+2) = 7 = x$ there must be *7 electrons* in the $3d$ level.

2–11 Bonding in the intermetallic compound Ni_3Al is predominantly metallic. Explain why there will be little, if any, ionic bonding component. The electronegativity of nickel is about 1.8.

Solution: The electronegativity of Al is 1.5, while that of Ni is 1.8. These values are relatively close, so we wouldn't expect much ionic bonding. Also, both are metals and prefer to give up their electrons rather than share or donate them.

2–14 Calculate the fraction of bonding of MgO that is ionic.

Solution: $E_{Mg} = 1.2 \qquad E_O = 3.5$

$f_{covalent} = \exp[(-0.25)(3.5 - 1.2)^2] = \exp(-1.3225) = 0.266$

$f_{ionic} = 1 - 0.266 = 0.734 \therefore$ bonding is mostly ionic

2–19 Would you expect MgO or magnesium to have the higher modulus of elasticity? Explain.

Solution: MgO has ionic bonds, which are strong compared to the metallic bonds in Mg. A higher force will be required to cause the same separation between the ions in MgO compared to the atoms in Mg. Therefore, MgO should have the higher modulus of elasticity. In Mg, $E \approx 6 \times 10^6$ psi; in MgO, $E = 30 \times 10^6$ psi.

2.17 The Van Der Walls forces make PVC rigid or stiffer, as a result of which its glass transition temperature (at which all translational, vibrational and rotational motion ceases) is relatively high.

2.22 Design parameters to be considered

-Thermal coefficient of expansion (should be comparable with steel)

-Young's Modulus and Yield Strength (should be high)

Problems that might occur:

-The composite may develop crack due to differing thermal coefficients of steel and ceramic subjected to temperature variation.

Chapter3

3.1 Materials, in which the atoms or ions form a repetitive, grid like pattern, in three dimensions.

3.2 Crystalline material consisting of only one large crystal.

3.4 Polycrystalline- a material comprised of many crystals (as opposed to a single-crystal material that has only one crystal).

3-6 Amorphous Material:

Any Material that exhibits only short range order of atoms or ions.

3-11 A lattice is a collection of points called lattice points, which are arranged in a periodic pattern so that the surrounding of each point in the lattice are identical. A Lattice may be 1,2 or 3 dimensional.

The unit cell is the subdivision of a lattice that still retains the overall characteristics of entire lattice.

A group of one or more atoms located in a particular way with respect to each other and associated with each lattice point, is known as the motif or basis.

We obtain a crystal structure by adding the lattice and bases.

3-36 Recording media applications involves writing and reading of magnetic domains or "bits" by use of a polarized focused laser beam and a magnetic thin film, or "medium," on a disk. Focused laser light is used in both the writing and reading processes, and the bit size is determined by the size of the laser spot. The magnetic medium must have an easy magnetization direction, because the magnetization directions of the bits are read by using normal incidence geometry of the laser light.

It is much easier to magnetize certain magnetic materials in one particular crystallographic direction compared to the other. So the knowledge of this direction will make the processing easier.

3–14 Determine the crystal structure for the following: (a) a metal with $a_0 = 4.9489$ Å, $r = 1.75$ Å and one atom per lattice point; and (b) a metal with $a_0 = 0.42906$ nm, $r = 0.1858$ nm and one atom per lattice point.

Solution: We want to determine if "x" in the calculations below equals $\sqrt{2}$ (for FCC) or $\sqrt{3}$ (for BCC):

(a) $(x)(4.9489 \text{ Å}) = (4)(1.75 \text{ Å})$

$x = \sqrt{2}$, therefore FCC

(b) $(x)(0.42906 \text{ nm}) = (4)(0.1858 \text{ nm})$

$x = \sqrt{3}$, therefore BCC

3–18 A metal having a cubic structure has a density of 1.892 g/cm^3, an atomic weight of 132.91 g/mol, and a lattice parameter of 6.13 Å. One atom is associated with each lattice point. Determine the crystal structure of the metal.

Solution:
$$1.892 \text{ g/cm}^3 = \frac{(x \text{ atoms/cell})(132.91 \text{ g/mol})}{(6.13 \times 10^{-8} \text{ cm})^3(6.02 \times 10^{23} \text{ atoms/mol})}$$

$x = 2$, therefore BCC

3–20 Bismuth has a hexagonal structure, with $a_0 = 0.4546$ nm and $c_0 = 1.186$ nm. The density is 9.808 g/cm^3 and the atomic weight is 208.98 g/mol. Determine (a) the volume of the unit cell and (b) the number of atoms in each unit cell.

Solution: (a) The volume of the unit cell is $V = a_0^2 c_0 \cos 30$.

$V = (0.4546 \text{ nm})^2(1.186 \text{ nm})(\cos 30) = 0.21226 \text{ nm}^3$
$= 2.1226 \times 10^{-22} \text{ cm}^3$

(b) If "x" is the number of atoms per unit cell, then:

$$9.808 \text{ g/cm}^3 = \frac{(x \text{ atoms/cell})(208.98 \text{ g/mol})}{(2.1226 \times 10^{-22} \text{ cm}^3)(6.02 \times 10^{23} \text{ atoms/mol})}$$

$x = 6$ atoms/cell

3–24 Aluminum foil used to package food is approximately 0.001 inch thick. Assume that all of the unit cells of the aluminum are arranged so that a_0 is perpendicular to the foil surface. For a 4 in. × 4 in. square of the foil, determine (a) the total number of unit cells in the foil and (b) the thickness of the foil in number of unit cells. (See Appendix A.)

Solution: The lattice parameter for aluminum is 4.04958×10^{-8} cm. Therefore:

$V_{\text{unit cell}} = (4.04958 \times 10^{-8})^3 = 6.6409 \times 10^{-23} \text{ cm}^3$

The volume of the foil is:

$V_{\text{foil}} = (4 \text{ in.})(4 \text{ in.})(0.001 \text{ in.}) = 0.016 \text{ in.}^3 = 0.262 \text{ cm}^3$

(a) The number of unit cells in the foil is:

$$\text{number} = \frac{0.262 \text{ cm}^3}{6.6409 \times 10^{-23} \text{ cm}^3/\text{cell}} = 3.945 \times 10^{21} \text{ cells}$$

(b) The thickness of the foil, in number of unit cells, is:

$$\text{number} = \frac{(0.001 \text{ in.})(2.54 \text{ cm/in.})}{4.04958 \times 10^{-8} \text{ cm}} = 6.27 \times 10^4 \text{ cells}$$

3–40 Determine the indices for the planes in the cubic unit cell shown in Figure 3–38.

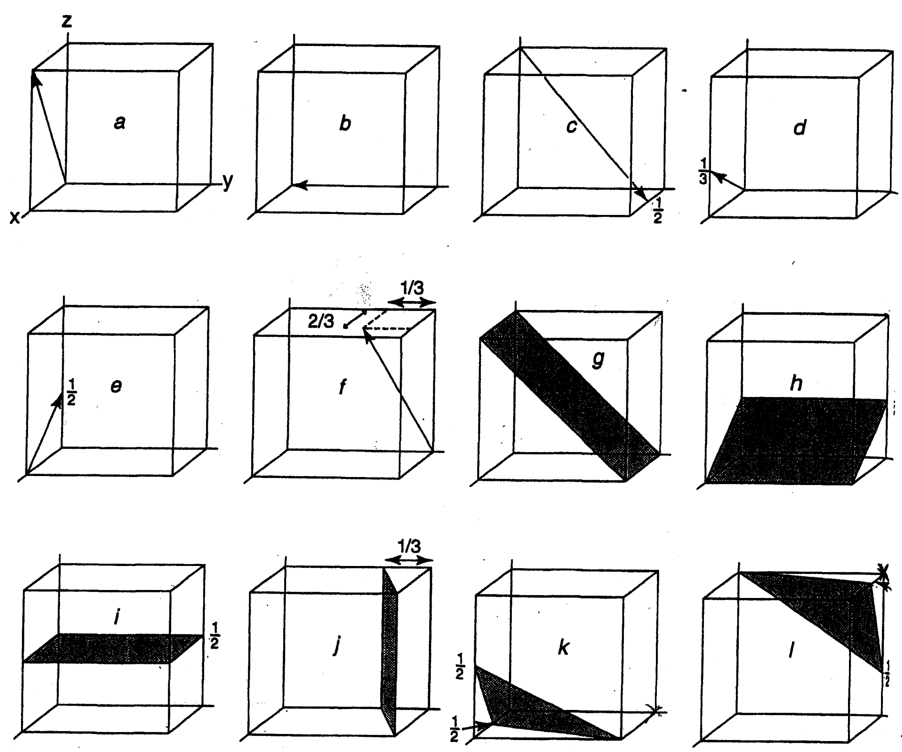
Solution:

A:	$x = -1$	$1/x = -1 \times 3 = -3$		
	$y = \frac{1}{2}$	$1/y = 2 \times 3 = 6$	$(\bar{3}64)$	(origin at 1,0,0)
	$z = \frac{3}{4}$	$1/z = \frac{4}{3} \times 3 = 4$		
B:	$x = 1$	$1/x = 1 \times 3 = 3$		
	$y = -\frac{3}{4}$	$1/y = -\frac{4}{3} \times 3 = -4$	$(3\bar{4}0)$	(origin at 0,1,0)
	$z = \infty$	$1/z = 0 \times 3 = 0$		
C:	$x = 2$	$1/x = \frac{1}{2} \times 6 = 3$		
	$y = \frac{3}{2}$	$1/y = \frac{2}{3} \times 6 = 4$	(346)	
	$z = 1$	$1/z = 1 \times 6 = 6$		

3–45 Sketch the following planes and directions within a cubic unit cell.

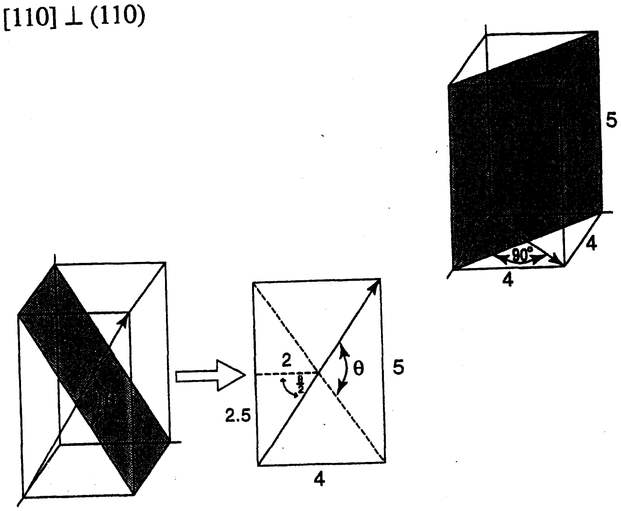
(a) $[101]$ (b) $[0\bar{1}0]$ (c) $[12\bar{2}]$ (d) $[301]$ (e) $[\bar{2}01]$ (f) $[2\bar{1}3]$
(g) $(0\bar{1}\bar{1})$ (h) (102) (i) (002) (j) $(1\bar{3}0)$ (k) $(\bar{2}12)$ (l) $(3\bar{1}\bar{2})$

Solution:



3–52 Determine the angle between the [110] direction and the (110) plane in a tetrago unit cell; then determine the angle between the [011] direction and the (011) pla in a tetragonal cell. The lattice parameters are $a_0 = 4$ Å and $c_0 = 5$ Å. What is responsible for the difference?

Solution: [110] ⊥ (110)



$$\tan(\theta/2) = 2.5 / 2 = 1.25$$
$$\theta/2 = 51.34°$$
$$\theta = 102.68°$$

The lattice parameters in the x and y directions are the same; this allows the angle between [110] and (110) to be 90°. But the lattice parameters in the y and z directions are different!

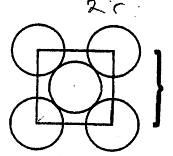
3–54 Determine the repeat distance, linear density, and packing fraction for FCC nickel, which has a lattice parameter of 0.35167 nm, in the [100], [110], and [111] directions. Which of these directions is close packed?

Solution: $r = (\sqrt{2})(0.35167)/4 = 0.1243$ nm

For [100]: repeat distance = $a_0 = 0.35167$ nm

linear density = $1/a_0 = 2.84$ points/nm

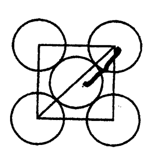
linear packing fraction = $(2)(0.1243)(2.84) = 0.707$



For [110]: repeat distance = $\sqrt{2}\,a_0/2 = 0.2487$ nm

linear density = $2/\sqrt{2}\,a_0 = 4.02$ points/nm

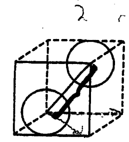
linear packing fraction = $(2)(0.1243)(4.02) = 1.0$



For [111]: repeat distance = $\sqrt{3}\,a_0 = 0.6091$ nm

linear density = $1/\sqrt{3}\,a_0 = 1.642$ points/nm

linear packing fraction = $(2)(0.1243)(1.642) = 0.408$



Only the [110] is close packed; it has a linear packing fraction of 1

3–66 Would you expect NiO to have the cesium chloride, sodium chloride, or zinc ble structure? Based on your answer, determine (a) the lattice parameter, (b) the den and (c) the packing factor.

Solution: $r_{Ni^{+2}} = 0.69$ Å $\quad r_{O^{-2}} = 1.32$ Å $\quad \dfrac{r_{Ni^{+2}}}{r_{O^{-2}}} = 0.52 \quad CN = 6$

A coordination number of 8 is expected for the CsCl structure, and a coordination number of 4 is expected for ZnS. But a coordination nu ber of 6 is consistent with the *NaCl structure*.

(a) $a_o = 2(0.69) + 2(1.32) = 4.02$ Å

(b) $\rho = \dfrac{(4 \text{ of each ion/cell})(58.71 + 16 \text{ g/mol})}{(4.02 \times 10^{-8} \text{ cm})^3(6.02 \times 10^{23} \text{ atoms/mol})} = 7.64 \text{ g/cm}^3$

(c) $\text{PF} = \dfrac{(4\pi/3)(4 \text{ ions/cell})[(0.69)^3 + (1.32)^3]}{(4.02)^3} = 0.678$