The SCIENCE *and* ENGINEERING *of* MATERIALS

Second SI edition

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Solutions manual

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7. The nose of the space shuttle is composed of graphite (carbon). Based on this information, what type of material would graphite be?

   The nose of the shuttle will experience extremely high temperatures upon re-entering the atmosphere from orbit. Protection therefore requires a very high melting point material, such as a ceramic. Graphite is sometimes considered to be a ceramic, although it is not a combination of metallic and non-metallic elements.

8. Suppose we would like to make a porous metal filter to keep the oil in our automobile engine clean. Which one of the metal processing techniques listed in Table 1-3 might be used to produce these filters?

   Powder metallurgy might be an excellent choice. We can compact spherical metal powder particles to a small degree and sinter just long enough so the powder particles are joined together. This will leave interconnected voids between the particles that will allow liquid oil to penetrate but will trap small solid impurities.

9. Sintering is listed in Table 1-3 as a ceramic processing technique. In which one of the metal processing techniques would you expect sintering also to be used?

   Sintering is an integral portion of the powder metallurgy process, joining the powder particles together, reducing void space, increasing density, and providing good mechanical properties after the powder metallurgy part has been initially formed by compaction.

10. Which of the three ceramic processing methods mentioned in Table 1-3 do you think is used to produce glass bottles?

    The bottles are normally produced by a "compaction" process, in which the glob of hot, viscous glass is introduced into a die and then formed, often using gas pressure.

11. By which one of the four methods of producing composite materials listed in Table 1-3 would you expect plywood to be made?

    Plywood is produced by "joining"; the individual plies are joined by adhesive bonding, or glueing.

12. Injection molding to produce plastic parts most closely resembles which one of the metals processing methods?

    Injection molding is very similar to die <u>casting</u>, in which pressure is used to force a molten material into a metal die to give the desired shape.

13. The <u>Voyager</u> is an experimental aircraft that flew around the world non-stop on a single tank of fuel. What type of material do you think made up most of the aircraft? Explain why this type of material was selected.

    The Voyager was produced primarily from composite materials, including carbon fiber-epoxy and fiberglass materials. These materials provided both the exceptionally light weight and the high strength and stiffness required.

14. United Stages coinage, such as the quarter, appear silvery on the face, but close inspection reveals a reddish color at the edges. Based on your observations, to which one of the five categories of materials should a quarter belong? Explain.

    The coinage is a composite material composed of high nickel sheets on the two flat surfaces surrounding a core sheet of high copper. the high nickel provides good corrosion resistance and the appropriate silvery appearance, while the high copper in the core minimizes cost. The edge appears reddish because when the coins are stamped from the original sheet, the copper core is partly revealed.

15. Relays in electrical circuits open and close frequently, causing the electrical contacts to wear. MgO is a very hard, wear resistant material. Why would this material not be suitable for use as the contacts in a relay?

    The MgO is a ceramic material and consequently acts as an electrical insulator rather than as a conductor. Although it may not wear, it also will never allow current to flow through the relay. Also, if the relay closes very rapidly, the brittle MgO could fracture; however this latter point is not very important compared to the electrical properties.

16. What mechanical properties would you consider most important when selecting a material to serve as a spring for an automobile suspension? Explain.

    The spring must have a high strength in order to support the automobile; it must have a high modulus of elasticity so little elastic deformation occurs; it must have sufficient ductility so that it can be formed in the first place; it should have reasonably good resistance to corrosion, particularly to salt that might be picked up from the highway during the winter.

17. The devices used for memory in personal computers typically contain an integrated circuit, electrical leads, a strong, non-conducting base, and an insulating coating. From what material should each of these four basic components be made? Explain your selections.

    The heart of the integrated circuit should be a semiconducting material such as silicon or GaAs so that electrical signals can be properly processed and information can be stored. The electrical leads must have a high electrical conductivity and might be made of aluminum or gold. Because the base must be both strong and non-conducting, it should be made from a ceramic material. Finally, the insulating coating could be made from either ceramic or polymer material. Polymers are most often used.

18. Automobile bumpers might be made from a polymer material. Would you recommend a thermoplastic of a thermosetting polymer for this application? Explain.

    A thermosetting polymer, due to its network structure, is expected to be very brittle; even slight impacts of the bumper against another car, the end of the garage, or flying rock or gravel could cause it to break. The thermoplastic polymer has better ductility and impact resistance and consequently would be the better choice.

19. Sometimes a nearly finished part is coined. During coining, a force is applied to deform the part into its final shape. For which of the following could this be done without danger of breaking the part - brass, Al_2O_3, thermoplastic polymers, thermosetting polymers, silicon?

    In order to be coined, the material must possess at least some ductility. Of the materials mentioned, Al_2O_3 is a ceramic and is very brittle, thermosetting polymers are brittle, and silicon is brittle; none of these could easily be coined without a danger of introducing cracks or even fracture. Both brass and thermoplastic polymers have good ductility and can be deformed.

20. A scrap metal processor would like to be able to identify different materials quickly, without resorting to chemical analysis or lengthy testing. Describe some possible testing techniques based on the physical properties of materials.

    He could separate copper-base alloys from other metals by color - copper, brass, and bronze are yellow or red. A magnet could be used to identify most iron and steel alloys - with only a few exceptions these are magnetic while most other common alloys that a scrap yard might encounter are not. Austenitic stainless steels could be separated from other stainless steels by the same method. The weight or density might also be used; aluminum and magnesium are lightweight compared to iron, copper, or nickel. Chapter 21 will also describe a variety of non-destructive tests, some of which might be easily adapted by a scrap metal processor.

Chapter 2

ATOMIC STRUCTURE

1. Silicon, which has an atomic number of 14, is composed of three isotopes: 92.21% of the Si atoms contain 14 neutrons, 4.7% contain 15 neutrons and 3.09% contain 16 neutrons. Estimate the atomic mass of silicon.

$$M_{Si} = (0.9221)(14 + 14) + (0.047)(15 + 14) + (0.0309)(16 + 14)$$
$$= 28.1099 \text{ g/mol}$$

2. Titanium, which has an atomic number of 22, is composed of five isotopes: 7.93% of the Ti atoms contain 24 neutrons, 7.28% contain 25 neutrons, 73.94% contain 26 neutrons, 5.51% contain 27 neutrons and 5.34% contain 28 neutrons. Estimate the atomic mass of titanium.

$$M_{Ti} = (0.0793)(24 + 22) + (0.0728)(25 + 22) + (0.7394)(26 + 22) +$$
$$(0.0551)(27 + 22) + (0.0534)(28 + 22) = 47.9305 \text{ g/mol}$$

3. Bromine, which has an atomic number of 35 and an atomic mass of 79.909 g/mol, contains two isotopes - Br^{79} and Br^{81}. Determine the percentage of each isotope of bromine.

Let "x" represent the fraction of the Br^{79} isotopes and "x-1" represent the fraction of the Br^{81} isotopes. Then

$$79.909 = (x)(79) + (1 - x)(81) = 79x + 81 - 81x$$
$$x = (81 - 79.909)/(81 - 79) = 0.5455$$

Therefore Br contains 54.55% Br^{79} and 45.45% Br^{81}.

4. Silver, which has an atomic number of 47 and an atomic mass of 107.87 g/mol, contains two isotopes - Ag^{107} and Ag^{109}. Determine the percentage of each isotope of silver.

Let "x" represent the fraction of Ag^{107} isotopes and "x-1" represent the fraction of Ag^{109} isotopes. Then

$$107.87 = (x)(107) + (1 - x)(109) = 107x + 109 - 109x$$
$$x = (109 - 107.87)/(109 - 107) = 0.565$$

Therefore Ag contains 56.5% Ag^{107} and 43.5% Ag^{109}.

5. Tin, with an atomic number of 50, has all of its inner energy levels filled except the 4f level, which is empty. From its electronic structure, determine the expected valence of tin.

First let's sum the electrons in the first four energy shells:

$$1s^2 = 2 \text{ electrons}$$
$$2s^2 2p^6 = 8 \text{ electrons}$$
$$3s^2 3p^6 3d^{10} = 18 \text{ electrons}$$
$$4s^2 4p^6 4d^{10} 4f^0 = \underline{18 \text{ electrons}}$$
$$46 \text{ electrons}$$

There must be 50 - 46 = 4 electrons in the outer energy shell:

$$5s^2 5p^2 = 4 \text{ electrons} = \text{valence of tin}$$

6. Mercury, with an atomic number of 80, has all of its inner energy levels filled except the 5f and 5g levels, which are empty. From its electronic structure, determine the expected valence of mercury.

First let's sum the electrons in the first five energy shells:

$$1s^2 = 2 \text{ electrons}$$
$$2s^2 2p^6 = 8 \text{ electrons}$$
$$3s^2 3p^6 3d^{10} = 18 \text{ electrons}$$
$$4s^2 4p^6 4d^{10} 4f^{14} = 32 \text{ electrons}$$
$$5s^2 5p^6 5d^{10} 5f^0 5g^0 = \underline{18 \text{ electrons}}$$
$$78 \text{ electrons}$$

There must be 80 - 78 = 2 electrons in the outer energy shell:

$$6s^2 = 2 \text{ electrons} = \text{valence of mercury}$$

7. Calculate the number of atoms in 100 grams of silver. Assuming that all of the valence electrons can carry an electrical current, calculate the number of these charge carriers per 100 grams.

(a) The number of atoms in 100 grams of Ag can be calculated from the molecular weight 107.87 g/mol and Avogadro's number:

$$\text{number of atoms} = \frac{(100 \text{ g})(6.02 \times 10^{23} \text{ atoms/mol})}{107.87 \text{ g/mol}} = 5.58 \times 10^{23} \text{atoms}$$

(b) From Table 2-2, we expect silver to have a valence of 1. Therefore is all of the valence electrons can carry a current, the number of valence electrons equals the number of atoms in the 100 gram sample, or

$$\text{number of charge carriers} = 5.58 \times 10^{23} \text{ electrons}$$

8. Suppose there are 8×10^{13} electrons in 100 grams of germanium that are free to move and carry an electrical current. (a) What fraction of the total valence electrons are free to move? (b) What fraction of the covalent bonds must be broken? (On average, there is one covalent bond per germanium atom and two electrons in each covalent bond.)

(a) First let's calculate the total number of valence electrons, using the molecular weight of 72.59 g/mole and the valence of germanium, which is 4.

$$\text{number of atoms} = \frac{(100\ \text{g})(6.02 \times 10^{23}\ \text{atoms/mol})}{72.59\ \text{g/mol}} = 8.293 \times 10^{23}$$

$$\text{number of valence electrons} = (4\ \text{electrons/atom})(8.293 \times 10^{23}\ \text{atoms}) = 3.7317 \times 10^{24}\ \text{electrons}$$

$$\text{fraction that move} = \frac{8 \times 10^{13}}{3.317 \times 10^{24}} = 2.41 \times 10^{-11}$$

(b) Because on the average there is one covalent bond per Ge atom, the number of covalent bonds in 100 g is 8.293×10^{23}. Since each broken covalent bond frees two electrons, the number of broken bonds is half the number of free electrons, or 4×10^{13} bonds. The fraction of broken bonds is therefore

$$\text{fraction} = \frac{4 \times 10^{13}}{8.293 \times 10^{23}} = 4.82 \times 10^{-11}$$

9. Compare the number of atoms in one gram of uranium with the number of atoms in one gram of boron. Then, using the densities of each (See Appendix A), calculate the number of atoms per cubic centimeter in uranium and boron.

(a) The molecular weights of uranium and boron are 238.03 g/mol and 10.81 g/mol. In 1 gram of metal,

$$\text{U atoms} = \frac{(1\ \text{g})(6.02 \times 10^{23}\ \text{atoms/mol})}{238.03\ \text{g/mol}} = 2.53 \times 10^{21}$$

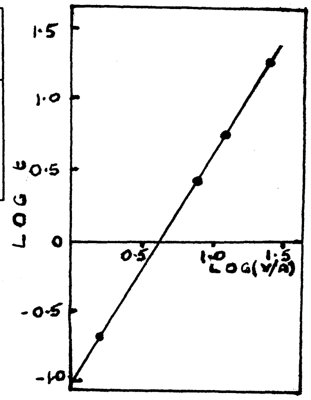
$$\text{B atoms} = \frac{(1\ \text{g})(6.02 \times 10^{23}\ \text{atoms/mol})}{10.81\ \text{g/mol}} = 5.57 \times 10^{22}$$

(b) The densities of uranium and boron are 19.05 Mg/m^3 and 2.3 Mg/m^3. The volumes of one gram of U and B are

$$\text{volume of U} = 1\ \text{g} / 19.05\ \text{Mg/m}^3 = 5.25 \times 10^{-8}\ \text{m}^3$$
$$\text{volume of B} = 1\ \text{g} / 2.3\ \text{Mg/m}^3 = 4.35 \times 10^{-8}\ \text{m}^3$$

$$\text{U atoms/cm}^3 = (2.53 \times 10^{21}\ \text{atoms}) / 0.0525\ \text{cm}^3) = 4.82 \times 10^{22}$$
$$\text{B atoms/cm}^3 = (5.57 \times 10^{22}\ \text{atoms}) / 0.435\ \text{cm}^3) = 1.28 \times 10^{23}$$

Volume mm^3	Area mm^2	V/A mm	log t	log V/A
5859.4	3828	1.53	-0.69897	0.1847
125000	16250	7.6923	0.43136	0.8861
220593	17671	12.5	0.77085	1.0969
3375000	135000	25	1.25527	1.3979



$$n = \text{gradient} = \frac{1.25527 - 0.43136}{1.3979 - 0.8861} = 1.61$$

log t = log B when log V/A = 0

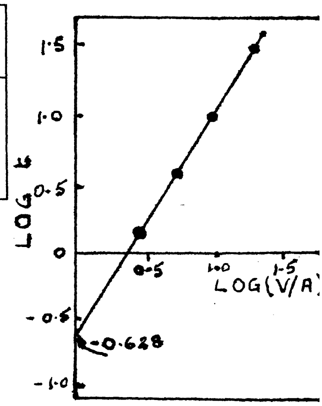
∴ log B = -1.0

∴ B = 0.10 min/mm^2

17. During conventional casting of an aluminum alloy, Chvorinov's rule is given by $t_s = 0.26(V/A)^{1.6}$, using units of mm and minutes. Using the evaporative pattern casting process (see Chapter 1), a series of aluminum castings solidifies according to the following data. Determine the constants B and n in Chvorinov's rule and determine the effect of the Styrofoam pattern on solidification time.

Size (mm))mm	Solidification Time (min)
6.25 x 150 x 150	1.3
12.5 x 150 x 150	3.5
25 x 150 x 150	8.5
75 x 150 x 150	25.9

Volume mm^3	Area mm^2	V/A mm	log t	log V/A
140625	48750	2.88	0.1149	0.4594
281250	52500	5.357	0.5441	0.7289
562500	60000	9.375	0.9294	0.9719
1687500	90000	18.75	1.4133	1.273



$$n = \text{gradient} = \frac{1.4133 - 0.5441}{1.273 - 0.7289} = 1.6$$

log t = log B when log v/a = 0

∴ log B = -0.628

∴ B = 0.236 = 0.24 min/mm^2

The effect of the styrofoam is to decrease the cooling time because B = 0.24 < 0.26 for conventional process and 'n' remains the same, because heat is used to melt and vaporise the foam.

$E_{parallel} = (0.575)(539) + (0.425)(45.5)$
$= 329.3$ GPa

$1/E_{perpendicular} = (0.575/539) + (0.425/45.5) = 0.0010667 + 0.009341$
$= 0.01041$

$\therefore E_{perpendicular} = 96$ GPa

17. An aluminum panel for an airplane measures 2 m x 2.65 m x 6.25 mm. (a) Determine the weight of the aluminum panel. (b) Determine the weight giving the same modulus of elasticity if the panel is made of polyethylene fiber-reinforced epoxy of the same thickness. The density of the epoxy is 1.3 Mg/m^3 and its modulus is 3.156 GPa.

(a) weight = 2 x 2.65 x $(6.25 \times 10^{-3})(2.7\ Mg/m^3) = 0.08944$ Mg

(b) The modulus of elasticity of Al = 70 GPa

$70 = f_{PE}(119) + (1 - f_{PE})(4.55)$

$65.45 = 114.45\ f_{PE}$

$0.572 = f_{PE}$

$\rho = (0.572)(0.97) + (0.428)(1.3) = 1.1111\ Mg/m^3$

weight = 2 x 2.65 x $(6.25 \times 10^{-3}) \times (1.1111) = 0.03681$ Mg

18. Calculate (a) the vol% fibers and (b) the specific modulus of a unidirectionally aligned fiberglass boat hull having a density of 1.6 Mg/m^3. The matrix is polyester (density 1.28 Mg/m^3, modulus of elasticity = 4.55 GPa) and S glass fibers are employed.

(a) $\rho = f_f(2.5) + (1 - f_f)(1.28) = 1.6\ Mg/m^3$

$\therefore f_f = 0.262$

(b) $E = (0.262)(88.2) + (0.738)(4.55) = 26.47$ GPa

specific modulus = $\dfrac{26.47}{1.6} = 16.5\ (m^2\ s^{-2} \times 10^6)$

19. Nickel-base superalloys can be reinforced with tungsten fibers. (a) Determine the volume fraction of tungsten fibers needed to obtain a modulus of elasticity of 280 GPa perpendicular to the fibers. (b) Calculate the modulus of elasticity parallel to the fibers for this composite. The density of the superalloy is about 8.5 Mg/m^3 and the modulus of elasticity is 196 GPa.

(a) $1/E_{perpendicular} = 1/280 = f_W/409.5 + (1 - f_W)/196$

$f_W = 0.575$

(b) $E_{parallel} = (0.575)(409.5) + (0.425)(196) = 318.8$ GPa

20. A hybrid composite is produced in which polyester is reinforced with HS carbon and kevlar fibers. The volume percent of the carbon fibers is twice that of the Kevlar fibers. If the density of the composite is 1.4 Mg/m^3, estimate (a) the vol% of carbon, Kevlar, and polyester and (b) the wt% of carbon, Kevlar, and polyester. The density of the polyester is 1.28 Mg/m^3.