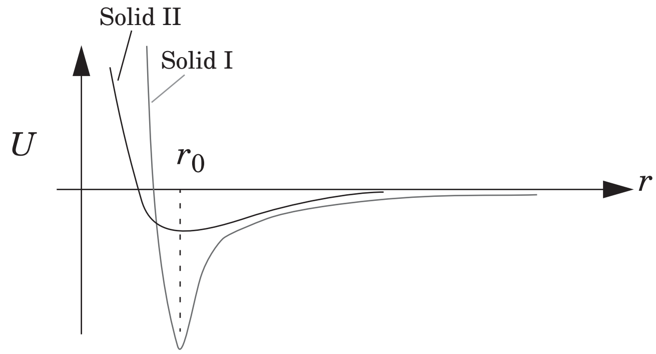
Supplementary Homework Problems

1. The potential energy curves for two solids are shown below:



Rank the two solids in terms of their expected melting temperatures, strength, modulus of elasticity, and thermal expansion coefficient. Explain your reasoning.

2. The potential energy, E_N, between an ion pair, a distance r apart is

$$E_N = \frac{-A}{r} + \frac{B}{r^9}.$$

What is the theoretical strain at which the bond will break?

3. For an ionically bonded $Al^{3+} - O^{2-}$ pair, $n = 10$.
   a) Calculate the interionic separation, r_0, by any reasonable means for this pair of ions.
   b) Calculate the contribution from coulombic interaction to the potential energy of this pair of ions at a separation of r_0.
   c) What is the repulsive contribution to the net force at a separation of r_0 for this pair of ions?

4. Calculate a theoretical value for Young's modulus for KCl based on the data in Table 3.4 of Callister and a potential energy equation of the form in Problem 2 above.

5. The net energy between a Na^+ ion and a Cl^- ion is given by

$$E_B = -\frac{1.440}{r} + \frac{6.583\times10^{-6}}{r^9}$$

with E_B in eV and r in nm. The second term is due to the energetics of electron-orbital overlap. If the energetics of electron-orbital overlap are the same for Na^+-Na^+ interactions and $Cl^- - Cl^-$ interactions, as for Na^+-Cl^- interactions:

   a. Calculate the force between nearest Na^+-Na^+ pairs in NaCl.
   b. Calculate the force between nearest $Cl^- - Cl^-$ pairs in NaCl.

Please make sure that you include your chosen force units in your answer.

6. Calculate a theoretical value for Young's modulus for KCl when the bond energetics are of the form $E_B = -\frac{C}{r} + D\exp\left(-\frac{r}{\rho}\right)$, and $C = 1.440$, $D = 9698$, $\rho = 0.03157$ nm, with E_B in eV and r in nm ($r_0 = 0.314$ nm).

7. An ionic compound has bond energetics of the form $E_B = -\frac{C}{a} + D\exp\left(-\frac{a}{\rho}\right)$ with $a_0 = 0.106$ nm, $C = 2.45$ eV nm, and $\rho = 0.051$ nm. The theoretical value of Young's modulus is $E = 1522$ eV/nm^3. Find the value of D. Be sure to include units.

8. Liquid water at room temperature exhibits hydrogen bonding. Calculate whether or not the hydrogen bond in water can be explained as simply dipole-dipole interaction. The density of water is approximately 1000 kg/m^3. The molecular weight of water is approximately 18. The dipole moment of a water molecule is approximately 1.84 Debye.

9. Calculate the ratio of the densities of chromium and aluminum from atomic weights and microstructures and compare it with the literature value of 2.653 at 20°C.

10. In what crystallographic direction is the line of intersection between the $(1\bar{1}0)$ and the $(1\bar{1}\bar{2})$ planes:
a. in a cubic structure?
b. in a tetragonal structure?

11. Oxygen, O_2, is adsorbed on the surface of tungsten in the ratio of one oxygen molecule to each exposed tungsten atom. How many moles of O_2 are adsorbed on a 1 m^2 surface of an exposed (021) tungsten plane?

12. Byzantium (an old but fictitious element) changes from FCC to BCT (body centered tetragonal) upon heating to 666°C. The lattice parameters for BCT are $a = 0.2471$ nm and $c = 0.9959$ nm. The lattice parameter of the FCC structure is 0.5132 nm. Calculate the volume change associated with this change in crystal structure.

13. Wüstite (FeO) is a high-temperature phase of iron oxide with the NaCl struc-

ture. The density is $\rho = 5.70(g/cm^3)$. Determine the interionic distance (the distance from the center of an Fe^{2+} ion to its nearest O^{2-} neighbor) in wüstite.

14. Suppose that the compounds BeO, MgO, and CaO could be constructed by placing the oxygen ions in an FCC array and by putting the cations into the octahedral sites. (The ionic radii for the ions in question are found on the inside front cover)
    a. If the oxygen ions are arranged in a close-packed array (FCC), which of the cations, Be, Mg, or Ca, would most nearly fit into the octahedral hole provided by the oxygen ions?
    b. Which of the cations would cause the most distortion in the oxygen lattice?
    c. Calculate the radius of a cation that would fit exactly into the octahedral hole.

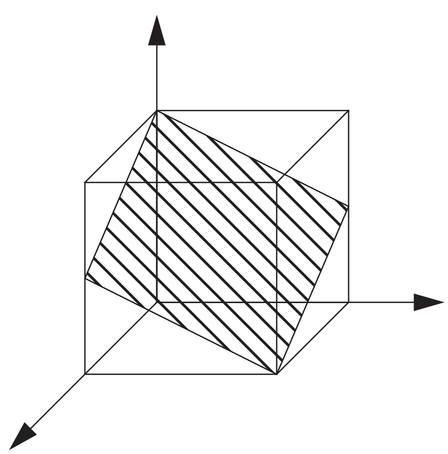
15. The structure of CaO is O^{2-} ions in an f.c.c. lattice with all of the 6-fold sites occupied by Ca^{2+} ions (The NaCl structure. See Fig. 3.5 on p. 43). Calculate the planar ionic densities of Ca^{2+} ions and O^{2-} ions on the (110) plane.

Data: Ca^{2+} Ionic radius = 0.100 nm
O^{2-} Ionic radius = 0.140 nm

16. The structure of CaO is O^{2-} ions in an f.c.c. lattice with all of the 6-fold sites occupied by Ca^{2+} ions (The NaCl structure. See Fig. 3.5 on p. 43).
    a. Sketch a (100) plane showing the ion locations and where the ions would touch.
    b. Calculate the theoretical density of CaO in units of g/cm^3.

Data: Ca^{2+} Ionic radius = 0.100 nm
O^{2-} Ionic radius = 0.140 nm

17.
    a. Identify the following plane.



b. Calculate the planar packing density (in atom/nm^2, of this plane in chromium (properties in Appendix B of Callister and Table 3.1, p. 35).

18. Calculate the planar packing density for the (210) plane in BCC tungsten in units of atoms/cm^2.

19. Calculate the linear packing density on the $[01\bar{5}]$ direction in tantalum in atoms/cm.

20. Calculate the planar packing density on the $(10\bar{1})$ in aluminum (data in Table 3.1 on page 35 of Callister).

21. Calculate the linear packing density in the $[03\bar{1}]$ in copper (data in Table 3.1 on page 35 of Callister).

22. Unobtanium oxide, UoO_2, has a theoretical density of $10.599\ \mathrm{g/cm^3}$ and packs in the Fluorite crystal structure. $r_{\mathrm{Uo^{4+}}} = 0.1070\ \mathrm{nm}$, $r_{\mathrm{O^{2-}}} = 0.1320\ \mathrm{nm}$, the atomic weight of oxygen is $15.9994\ \mathrm{g/g\text{-}atom}$. What is the atomic weight of unobtanium?

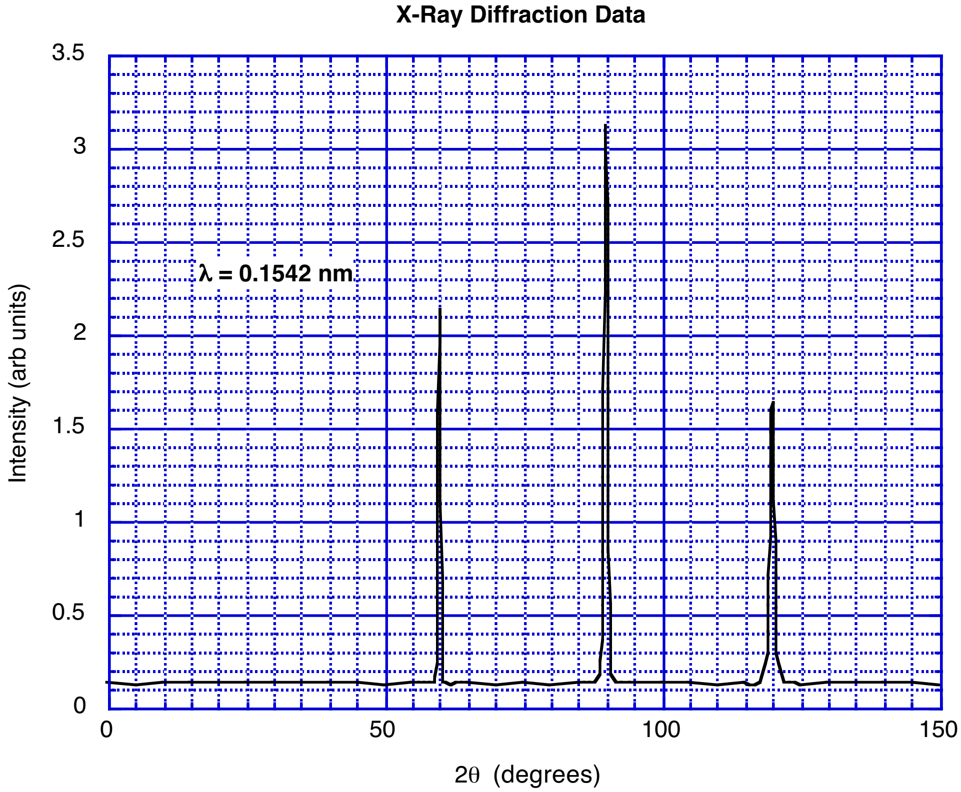
23. An iridium sample is irradiated with Cu Kα radiation (λ=1.541Å).
   a) What is the angle of the first diffraction peak?
   b) What family of planes is responsible for that peak?

24. One can distinguish an FCC crystal structure from a BCC crystal structure by looking at the first two diffraction peaks. It has been stated that if Simple Cubic (SC) materials existed, one would have to examine the seventh diffraction peak to distinguish an SC crystal structure from a BCC crystal structure. Is the statement true? Why or why not?
Additional information: In simple cubic all planes cause diffraction peaks.

25. A Cu-Ni alloy (data in Table 3.1 of Callister, assume ideal solution) is examined with x-ray diffraction. The monochromatic x-rays have a wavelength of 0.1542 nm. The first three diffraction peaks are at 2θ values of 44.14°, 51.42°, and 75.69°. What is the composition of the alloy in atomic fraction?

26. Nonamium is a metal that packs in one of the cubic array structures. The experimental x-ray diffraction data for nonamium in Cu_{K_α}-radiation is given

below. Determine if nonamium is fcc or bcc and calculate the lattice constant, a .



27. A Cu-Ni alloy (data in Table 3.1 of Callister, assume ideal solution) with an average lattice spacing a of 0.3547 nm is desired.
    a. How many moles of Cu would need to be added to 1 mole of Ni to make the desired alloy?
    b. What would the theoretical density of the alloy be in $\mathrm{kg/m^3}$?
    c. How many kilograms of Cu would need to be added to 1 kilogram of Ni to make the desired alloy?

28. Calculate the fraction of lattice sites that are vacant in Iron at 1123 K. The energy for vacancy formation is 1.08 eV/atom.

29. Calculate the fraction of lattice sites that are vacant in a material with an energy of vacancy formation of 1.25 eV at 1453 K.

30. Phosphorus is diffused into a thick slice of silicon with no previous phosphorus in it at a temperature of 1100°C. If the surface concentration of the phosphorus is 1.0×10^{18} $\mathrm{atoms/cm^3}$ and its concentration at 1 μm is 1.0×10^{15} $\mathrm{atoms/cm^3}$, how long must the diffusion time be? $D = 3.0\times10^{-13}\,\mathrm{cm^2/s}$ for P diffusing in Si at 1100°C. If the temperature is dropped to 1050°C, what is the diffusion time? If the temperature remains 1100°C but the depth is increased to 2 μm, what is the

diffusion time?

31. A cubical vessel ($V = 1\,\mathrm{m}^3$) of steel walls 2 mm thick contains hydrogen. The pressure in the vessel is maintained at 189 psia and a temperature of 300°C. The internal surface will be at the saturation concentration of hydrogen. The outer surface will be maintained at zero hydrogen content. The solubility is proportional to $p^{1/2}$ where p is the hydrogen pressure; and at 1 std atm, 300°C, the solubility is 1 ppm (parts per million) by weight. At 300°C, the diffusivity of hydrogen in the steel $= 5\times10^{-10}$ m²/s. The steel density is 7500 kg/m³. Calculate the rate (in kg/h) at which hydrogen must be supplied to the tank to maintain the pressure in the tank.

32. For the conditions in the homework problem 4.7.6, find the flux of boron atoms [atoms/cm²/s] at a depth of 1.98×10^{-4} cm in the silicon at a time of 5 hours.

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-\eta^2}d\eta\ , \qquad \frac{d}{dx}[f(u)] = \frac{d}{du}[f(u)]\cdot\frac{du}{dx}$$

33. Determine the carburizing time necessary to achieve a carbon concentration of 0.45 wt% at a position 2 mm into an iron–carbon alloy that initially contains 0.20 wt% C. The surface concentration is to be maintained at 1.30 wt% C, and the treatment is to be conducted at $1000°\mathrm{C}$. Use the diffusion data for C in fcc-Fe in Table 6.2.

34. A sample of silicon initially had 1.00×10^{24} atom/m³ of P in it. The sample was heated and the surface was held at 1.000×10^{25} atom/m³ of P for 11 minutes. The sample was cooled and sectioned. The amount of phosphorus at a depth of 20 µm was found to be 5.00×10^{24} atom/m³. What is the diffusivity of P in Si at the operating temperature?

35. Parts made out of 1040 steel (data in Table 13.2a on p.536 and Table 6.2 on p.164) must be carburized until the carbon concentration at depth of 2 mm is 0.5573 wt% C. For the given process, the surface concentration can be maintained at 1.40 wt% C. The operating cost of the furnace is given by $\$/\mathrm{hr} = 0.001T^2 - T + 400$. The boss wants to know, should you process the parts at $1000°\mathrm{C}$ or $1050°\mathrm{C}$?

36. A 200 cm long copper wire (with an elastic modulus of 110 GPa) is loaded in tension with a 250 MPa stress to produce a strain of 0.01. What is the length of the wire when the load is removed?

37. Determine the applied longitudinal stress which will reduce the cross-sectional area of a cylindrical titanium rod by 0.01% (Table 7.1 on p184 may be helpful).

38. Consider the brass alloy whose stress-strain behavior is shown in Figure 7.12 (p. 193) of the text. A cylindrical specimen of this alloy 20 mm in diameter and 200 mm long is to be pulled in tension.
   a) Compute the minimum force necessary to cause a permanent strain of 0.002 in the rod.
   b) What is the reduction in diameter of the rod if a force equal to 1/2 of the force in part (a) is applied to the rod? Assume a value of 0.34 for Poisson's ratio.

39. Evaluate all of the coefficients in the compliance matrix and the stiffness matrix for an isotropic solid in terms of E, ν, and G.

40. Regarding Poisson's Ratio:
   a. Prove or disprove the book's claim that volume is conserved in uniaxial stress for a Poisson's Ratio of 0.5. Assume all strains are small compared to 1.
   b. Calculate the fractional volume change in a circular cylinder of tungsten (commercially pure) when a tensile stress of 80% of the yield strength is applied along the z-axis.

41. A $1\text{ cm} \times 1\text{ cm} \times 1\text{ cm}$ cube has a tensile force of 800 N applied along the x-direction, a tensile force of 300 N applied along the y-direction and a compressive force of 500 N applied along the z-direction. Determine the stress vector for this cube.

42. A 1.000 cm cube of 7075-T6 aluminum (properties in Appendix B of Callister) has an equally distributed tensile force, F, applied to its x-faces, and an equally-distributed compressive force of magnitude $2F$ applied to its z-faces. The y-faces are unstressed. Calculate the magnitude of F at which the cube begins to plastically deform.

43. A 1.000 cm cube of 7075-T6 aluminum (properties in Appendix B of Callister) has an equally distributed tensile force, F, applied to its x-faces, and an equally-distributed compressive force of magnitude $2F$ applied to its z-faces. The y-faces are unstressed. Calculate the dimensions of the cube when $F = 600\text{ N}$.

44. Two test specimens are to undergo stress deformation. They are identical in size in the unstressed condition. They are both long rods with square cross sections. The longitudinal axis is the z-axis. The first specimen (Rod 1) is to undergo tensile stress along the z-axis. The second (Rod 2) is to undergo compressive stresses along the x- and y-axes. The stress in the x-axis will be twice that in the y-axis. At one point in the tests the longitudinal strains, ε_{1z}, and ε_{2z}, are equal. At this point:

a. Calculate the relative values of stress in the two samples, $\sigma_{2x} / \sigma_{1z}$, and $\sigma_{2y} / \sigma_{1z}$.

b. Calculate the relative values of the strains in the two samples, $\varepsilon_{2x} / \varepsilon_{1x}$, and $\varepsilon_{2y} / \varepsilon_{1y}$.

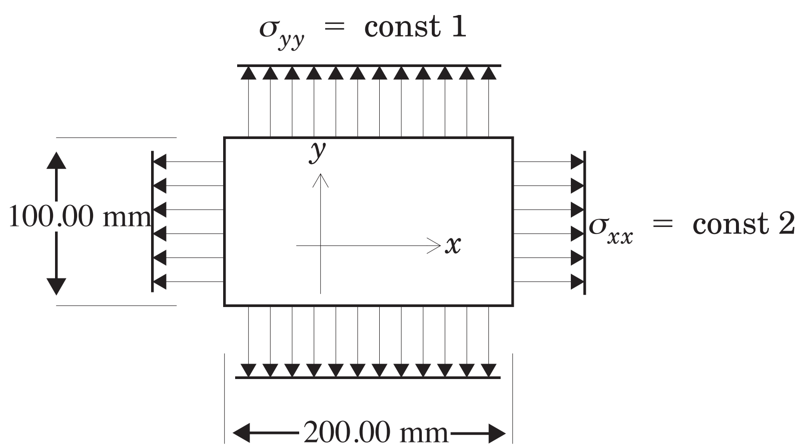
State all assumptions.

45. A flat plate of initial thickness $h = 20$ mm is acted upon by (calculated) stresses σ_{xx}, σ_{yy} in the plane of the plate so that the new lateral dimensions are 199.99 mm × 99.99 mm. Assuming that the plate is free to expand in the thickness direction ($\sigma_{zz} = 0$), compute:

a) σ_{xx}, σ_{yy}

b) The change in thickness.

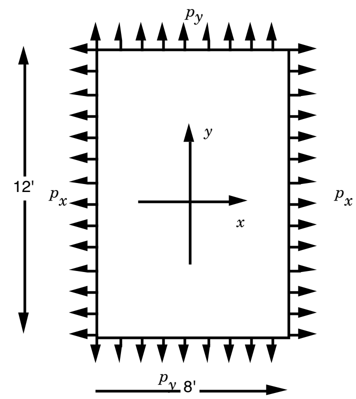
Data: $E = 200$ GPa, $G = 77$ GPa



46. A standard circular tensile specimen (Fig. 7.2 on p. 180) of titanium (properties listed in Table 7.1 on p. 184 and Table 7.2 on p. 195) is stretched to its yield point. What is the change in diameter of the center section?

47. An 8ft×12ft, 1/4" thick steel panel is subjected to a uniformly distributed force/length p_x in the x-direction, and p_y in the y-direction. If the resulting total change in length from the unstressed condition in the x-direction is 0.0768", and in the y-direction is 0.0864", what are the numerical values for p_x and p_y? Take

$E = 30\times10^6\text{psi}$ and $G = 12\times10^6\text{psi}$.



48. A cube that is three centimeters in each dimension has a distributed force of 900 N applied on the front (x) face in the positive y-direction, a distributed force of 450 N applied on the top (z) face in the negative y-direction, a distributed compressive force of 1800 N applied on the side (y) face in the y-direction, and sufficient distributed forces on the other faces to keep the cube from accelerating. Calculate the stress tensor for the cube.

49. The strains in an elastically-deformed material are measured. The x-direction strain is 0.0001, the y-direction strain is –0.0002, and the engineering shear-strain for the xy-direction is –0.0003. The stiffness matrix is:

$$\mathbf{Q} = \begin{bmatrix} 175\text{GPa} & 90\text{GPa} & 90\text{GPa} & 0 & 0 & 0 \\ 90\text{GPa} & 175\text{GPa} & 90\text{GPa} & 0 & 0 & 0 \\ 90\text{GPa} & 90\text{GPa} & 175\text{GPa} & 0 & 0 & 0 \\ 0 & 0 & 0 & 43\text{GPa} & 0 & 0 \\ 0 & 0 & 0 & 0 & 43\text{GPa} & 0 \\ 0 & 0 & 0 & 0 & 0 & 43\text{GPa} \end{bmatrix}$$

Calculate the applied stresses.

50. A cube of extruded AZ31B magnesium alloy (properties in Appendix B of Callister) measures initially 1.0000 inches along each side. It is deformed by applied stresses to dimensions of $h = 0.9950\text{ in}$, $w = 1.0020\text{ in}$, and $l = 1.0020\text{ in}$. The stresses are then removed. Does the sample return to its initial perfect cubical shape? The stiffness and compliance matrices for extruded AZ31B magnesium alloy are:

$$[\mathbf{Q}] = \begin{bmatrix} 59 & 24 & 24 & 0 & 0 & 0 \\ 24 & 59 & 24 & 0 & 0 & 0 \\ 24 & 24 & 59 & 0 & 0 & 0 \\ 0 & 0 & 0 & 17 & 0 & 0 \\ 0 & 0 & 0 & 0 & 17 & 0 \\ 0 & 0 & 0 & 0 & 0 & 17 \end{bmatrix}, \quad [\mathbf{S}] = \begin{bmatrix} \frac{1}{45} & \frac{-0.29}{45} & \frac{-0.29}{45} & 0 & 0 & 0 \\ \frac{-0.29}{45} & \frac{1}{45} & \frac{-0.29}{45} & 0 & 0 & 0 \\ \frac{-0.29}{45} & \frac{-0.29}{45} & \frac{1}{45} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{17} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{17} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{17} \end{bmatrix}$$

where stresses are in GPa.

51. The experimental stiffness matrix for unobtanium is

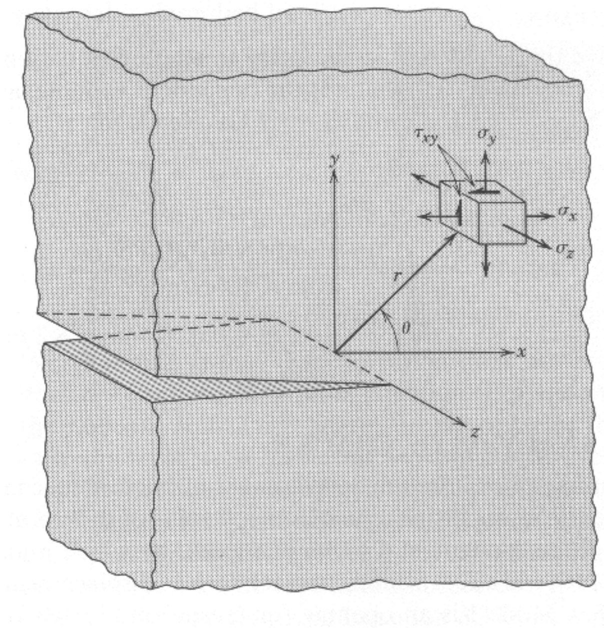
$$[\mathbf{Q}] = \begin{bmatrix} 300 & -50 & -25 & 0 & 0 & 3 \\ -50 & 250 & -10 & 0 & 2 & 0 \\ -25 & -10 & 195 & 0 & 0 & 0 \\ 0 & 0 & 0 & 37 & 0 & 0 \\ 0 & 2 & 0 & 0 & 38 & 1 \\ 3 & 0 & 0 & 0 & 1 & 39 \end{bmatrix}$$

where the entries are in GPa. An unknown set of stresses are applied to a sample of unobtanium. The following strains are measured: $\epsilon_x = -0.001$, $\epsilon_z = 0.0002$, $\gamma_{xy} = 0.00025$, $\gamma_{xz} = -0.0003$, and all others 0. Assuming elastic behavior, what was the set of applied stresses?

52. The stress state near a crack is given by the expressions below:

$$\sigma_{xx} = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right),$$
$$\sigma_{yy} = \frac{K}{\sqrt{2\pi r}} \cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right),$$
$$\sigma_{xy} = \frac{K}{\sqrt{2\pi r}} \sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{3\theta}{2},$$

where K is the stress intensity, and r and θ are the distance from the edge of the crack and angle from the plane of the crack respectively, for the geometry shown in the figure. Assuming that the system is in plane strain ($\epsilon_{zz} = 0$), calculate σ_{zz} and the strains at a point at a distance of 1 mm from the edge of a crack at an angle of 30° above the horizontal for a piece of nylon 66 of width 60 mm and a surface crack of length 3 mm with a tensile load of 25 MPa. Tables B.2 and B.3 on pages A8 and A10 may be helpful.



53. An iron oxide contains 52 atomic percent oxygen. What is the Fe^{2+}/Fe^{3+} ion ratio?

54. Determine the amount of pearlite in 100 g of a 99.5 weight percent Fe – 0.5 weight percent C alloy that is air cooled from 870°C.

55. A copper pipe creeps at a steady-state rate of 0.002 $(\text{hour})^{-1}$ when a stress of 100 MPa is applied at 600°C. Assuming the steady-state creep rate of copper is due to self diffusion of copper atoms, estimate the steady-state creep rate at 800°C. The activation energy for self-diffusion in copper is 211 kJ/mol.

56. 0.104 moles of hydrogen peroxide are added to 76.02 moles of vinyl acetate. Estimate the number-averaged degree of polymerization of the product.

57. Stoichiometric GaAs has a number density of 2.215×10^{28} Ga atoms/m^3 at room temperature. Calculate the electrical conductivity of $Ga_{1+\delta}As$ at room temperature for $\delta = 0.000001$. Table 12.2 on p.488 of Callister may help.

58. In order to test the strength of a ceramic, cylindrical specimens of length 25 mm and diameter 5 mm are tested in a three-point bending apparatus. Half of the specimens broke for applied loads of 300 N and less. The test is to be repeated using specimens of length 50 mm and diameter 10 mm. Estimate the applied load

that will give a probability of failure of 10^{-6}. Assume the Weibull modulus of the ceramic, $m = 10$. The survival probability is:

$$\phi = \exp\left\{\frac{-v}{v_0}\left(\frac{\sigma}{\sigma_0}\right)^m\right\}.$$

59. A sheet of aramid-fiber reinforced epoxy is rigidly clamped at 25°C along its edges parallel to and perpendicular to the fiber direction. To what temperature can the sheet be cooled before the thermal stress transverse to the fibers exceeds the tensile strength transverse to the fibers? Elastic moduli, tensile strengths, and coefficients of thermal expansion are given in Appendix B, Tables B.2, B.4, and B.6 of Callister. Assume a value of Poisson's ratio of $\nu_{lt} = 0.34$ for longitudinal loading.

60. Pressure vessels are sometimes protected from catastrophic failure with a rupture disc, a thin circular disk of radius r and thickness t that is designed to fail or rupture at a given pressure. Often the discs are scored with a thin groove of depth a to provide a rupture point. The maximum deflection δ, and maximum tensile stress σ, in a disk subject to pressure p, are reasonably approximated by:

$$\delta = \frac{2r^4p}{3Et^3}, \text{ and } \sigma = \frac{5r^2p}{4t^2}.$$

For a fixed radius, groove depth, and pressure, which steel, 1040, or 4340 tempered at 425°C, would make the least expensive rupture disk?

61. A spherical pressure vessel is subject to a periodic pressure of 2000 psi. The material has a yield strength of 200 ksi and a fracture toughness of 80 ksi$\sqrt{\text{in}}$. To ensure leak-before-break conditions, what is the maximum vessel radius? What is the maximum wall thickness?

62. The properties of a carbon-epoxy composite are given in Table 15.5 on page 648. The Poisson ratio for a longitudinally applied load is $\nu_{lt} = 0.4$. If a sheet of the composite has normal stresses σ_x and σ_y applied in the longitudinal and transverse directions respectively, calculate the ratio (σ_x / σ_y) for which the normal strains ϵ_x and ϵ_y are equal.

63. The modulus of rupture, MOR, of a hot-pressed silicon nitride sample is 150 ksi. The sample of SiN fails at a load of 84 lbs in a three-point bending test. The sample is (was) 3 inches long and 0.250 inches wide. What is (was) its thickness?

64. The critical resolved shear stress in andrabium is 33.2 ksi. What is the yield strength of andrabium in the $[12\bar{3}]$, if slip occurs in the $[210]$ on the $(\bar{1}2\bar{1})$?

65. Chloroprene, isobutylene, and dimethylsiloxane are mixed in a 3:2:1 *weight* ratio and polymerized to form an elastomer copolymer. The mer structures are in Appendix D on pp. A36-A37 of Callister.
   a. What is the mer molecular weight, $\overline{m}$?
   b. What weight of sulfur must be added for 33% cross-linkage of 1 kg of the copolymer (1 S atom per cross-link)?

66. A hypothetical ceramic compound has the chemical formula A_2BO_4 in which both A and B are cations. The O^{2-} ions form a hexagonal close-packed structure, and the A^{3+} and B^{2+} ions occupy tetrahedral or octahedral sites. The ionic radii of A^{3+}, B^{2+}, and O^{2-} are 0.041, 0.052, and 0.140 nm respectively.
   a. Determine the site type that the A^{3+} and B^{2+} ions occupy.
   b. What fraction of each of the site types is occupied with the A^{3+} and B^{2+} ions?

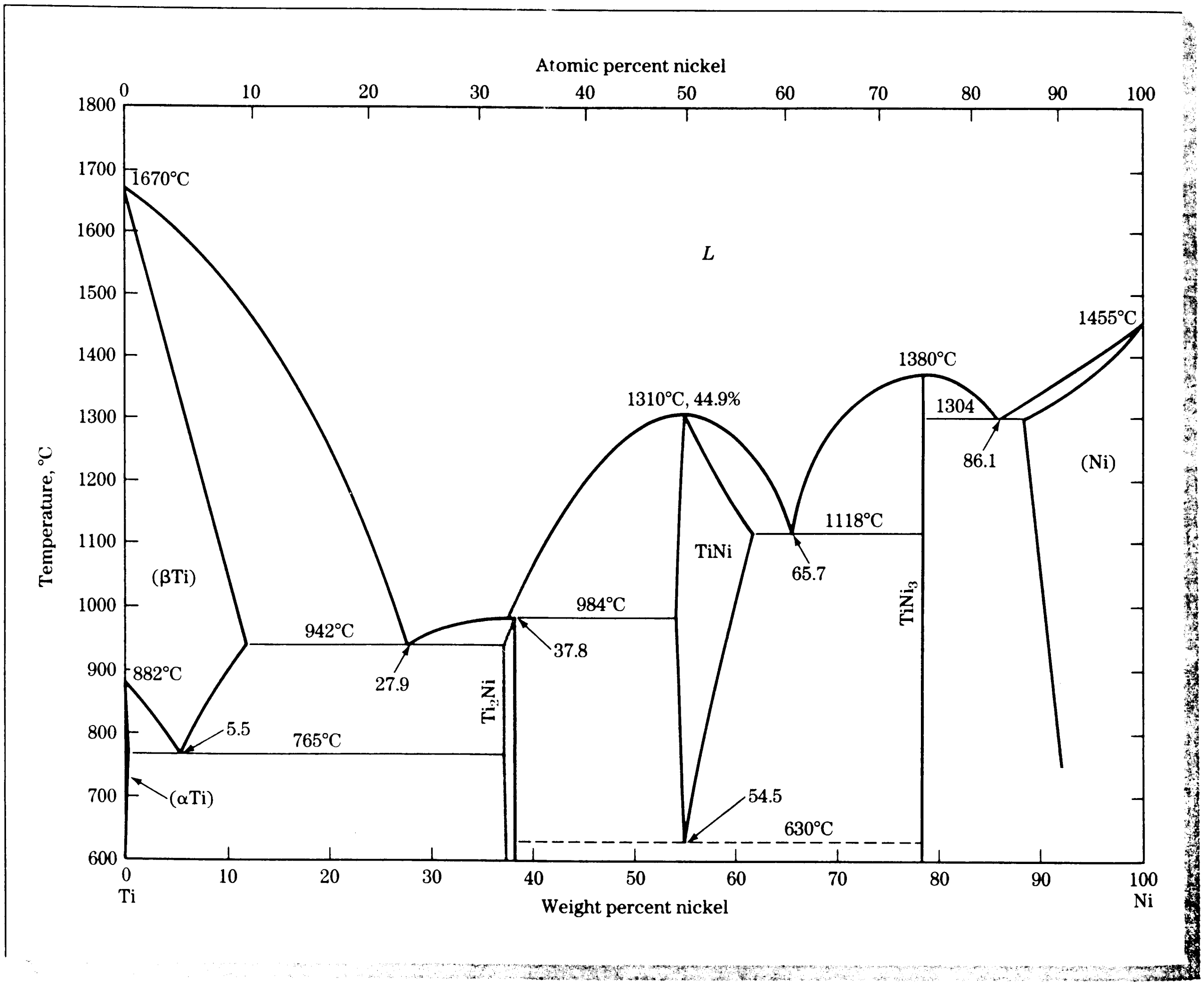
67. A thin sample of a 1080 steel is heated in an inert atmosphere to 750°C and left there for 1000 hours. It is then cooled at 150°C/s from 750°C to room temperature, whereupon it is heated quickly to 425°C, left there for 10,000 seconds and then quickly cooled to room temperature. A different sample, a 2-inch diameter bar of 4140 steel, is heated in an inert atmosphere to 750°C and left there for 1000 hours. It is then water quenched. Compare the hardness at the center of the second sample with the hardness at the surface of the first sample.

68. A steel pressure vessel is to be operated with a cyclic tensile stress between 0 and 150 MPa for a maximum of 10^6 cycles. Find the length of the largest allowable surface crack before the vessel is put into service.

   Data: The fracture toughness of the steel is 200 MPa $m^{1/2}$. The crack growth is approximated by $\frac{da}{dN} = A(\Delta K)^4$, where $A = 2\times10^{-14}(\text{MPa})^{-4}\text{m}^{-1}$.
   Assume $Y = 1$.

69. A 1020 steel (0.16 kg/m^3 C) is to be case hardened (by carburization) with a surface carbon concentration of 0.64 kg/m^3 C. How many kg of carbon will have diffused into the steel per square meter in 4 hours at 700°C?
   Data: $D = 3\times10^{-11}$ m^2/s

70. The titanium-nickel phase diagram is shown below. An enlargement of a portion of it is shown in Figure 10.20 on page 388 in Callister.



a. Write down all three-phase invariant reactions, e.g., $L \rightarrow TiNi_3 + (Ni)$, the type of reaction, e.g., monotectoid, and the temperature at which they occur.
b. A 40 wt% Ti — 60 wt% Ni sample is cooled in a hot stage microscope, starting at 1400°C. Sketch the microstructure at 1400°C, 1250°C, 1100°C, and 900°C.
c. For the sample in Part b, name the microconstituents, and calculate their relative amounts at 631°C.

71. Determine the most likely microconstituents present and their relative amounts in a 75 wt% Zn - 25 wt% Cu brass that has been slowly cooled from 800°C to 550°C. The Cu-Zn phase diagram is on p. 385 of Callister.

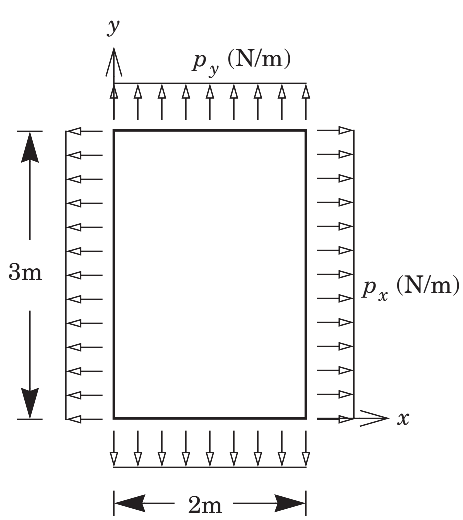
72. Consider a structural component having the general features of Figure 8-13(a), p. 198, of the text. Let the material be an aluminum alloy with a plane-strain fracture toughness of 40 MPa-m$^{1/2}$. It has been observed that this component fails at an applied stress of 200 MPa and for an edge crack of maximum length of 4.0 mm. Would this same component fail if a titanium alloy is used when the applied

stress and maximum surface crack length are 150 MPa and 10.0 mm respectively? Explain. Take the plane-strain fracture toughness for the titanium alloy to be 50 MPa-m$^{1/2}$.

73. A manufacturing process presently uses an oil-quenched 1.60 in. dia. 4140 steel rod. The boss wants to replace it with a water-quenched 5140 steel rod. The critical performance characteristic is the Rockwell C hardness at the center of the rod.
    a. What is the maximum allowable diameter for the new rod?
    b. What is the approximate tensile strength of the new rod (Section 7.16 may help)?
    c. What is the reduction in maximum tensile load (total supported weight) from the old rod to the new rod?

74. A Boron-Epoxy plate measuring $2 \text{ m} \times 3 \text{ m} \times 4 \text{ mm}$ thick is subjected to uniformly distributed loads p_x (N/m) in the x-direction and p_y (N/m) in the y-direction. If the total change in length from the unstressed condition is 2 mm in the x-direction and 3 mm in the y-direction, what are the values of the distributed loads p_x and p_y? Let the stress-strain relationship be given by:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} 2.43\times10^{5}\text{MPa} & 7.3\times10^{3}\text{MPa} & 0 \\ 7.3\times10^{3}\text{MPa} & 2.43\times10^{4}\text{MPa} & 0 \\ 0 & 0 & 2(1.034\times10^{4}\text{MPa}) \end{bmatrix} \begin{Bmatrix} \epsilon_{xx} \\ \epsilon_{yy} \\ \epsilon_{xy} \end{Bmatrix}$$



75. Consider the ceramic compound calcium fluoride, CaF_2. It is known that this

compound has the fluorite structure. Using Table 13.3,

a. Estimate the expected cation coordination number,
b. Calculate the density of the compound from its structure.

76. 1 kg of Acrylonitrile (CH_2CHCN, MW=53.06406), 1 kg of Styrene (C_8H_8, MW=104.15296), and 1 kg of Butadiene (C_4H_6, MW=54.09242) are mixed and polymerized (See Table 4.5 on page 113). For the resulting polymer $n_n = 1100$.

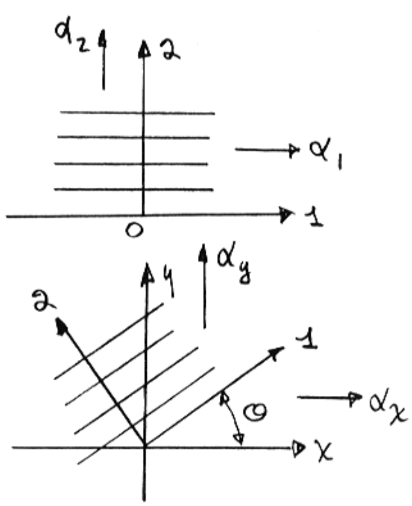
   a. What is the molecular weight, $\overline{M_n}$?
   b. What mass of Sulfur (MW=32.06) must be added to cross-link 50% of the possible sites?

77. 1.020 g of H_2O_2 (MW = 34.0147 g/g-mol) were added to an unknown quantity of a monomer. The resulting polymer had a number-averaged molecular weight of 10,038 g/g-mol. What was the initial mass of monomer?

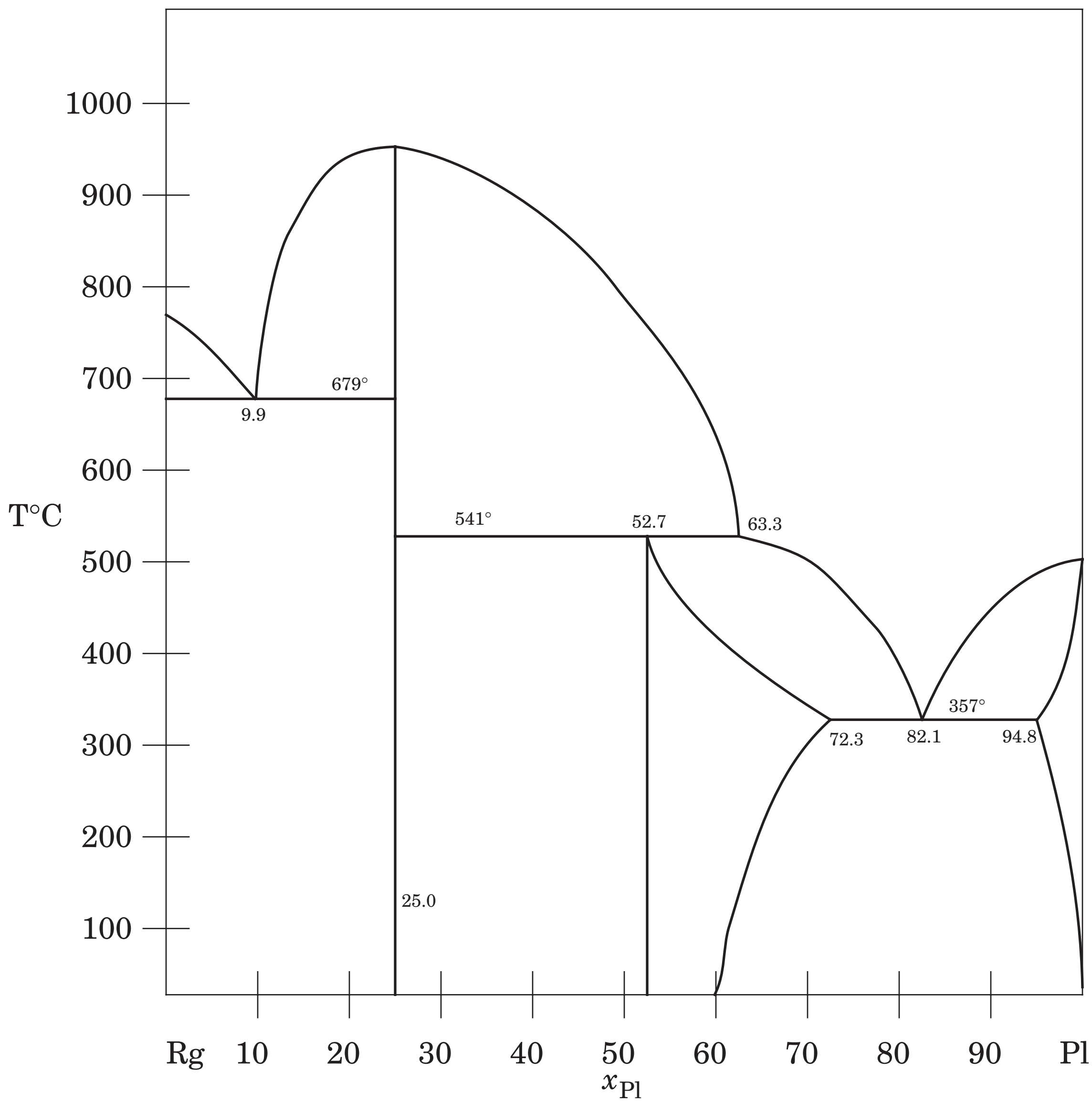
78. The strain-temperature relation for planar deformation of an orthotropic plate takes the form:

$$\begin{Bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \gamma_{12} \end{Bmatrix} = \begin{Bmatrix} \alpha_1 \\ \alpha_2 \\ 0 \end{Bmatrix} (T - T_{\text{ref}})$$

for stress-free temperature effects related to the reference axes. Consider now the rotated set of axes as shown. Find the expression for ϵ_{xx}, i.e., the normal strain associated with the rotated x-axis, in terms of the reference thermal expansion coefficients α_1, α_2, the temperature change $T - T_{\text{ref}}$, and the angle θ. In particular, find $\alpha_x(\alpha_1, \alpha_2, \theta)$ (α_x as a function of $\alpha_1, \alpha_2, \theta$), where $\epsilon_{xx} = \alpha_x \cdot (T - T_{\text{ref}})$.



79. The plattium-regurgium phase diagram is shown below. Composition is in atomic percent.



a. Label all of the one-phase regions. The Rg-rich phase is α, the Pl-rich phase is δ, the congruently-melting intermetallic is β, and the incongruently-melting phase is γ.
b. Label all of the two phase regions, *e.g.*, $l+\alpha$.
c. Write down all three-phase invariant reactions with the temperatures at which they occur.
d. For a 10 atomic-percent Rg mixture which has been cooled from 1000°C to 356 °C list the *phases* present (at 356°C) and calculate their relative amounts.
e. For a 10 atomic-percent Rg mixture which has been cooled from 1000°C to 356 °C list the *microconstituents* present (at 356°C) and calculate their relative amounts.
f. What is the chemical formula for the congruently-melting intermetallic?

80. A through-thickness center cracked plate of a medium-carbon steel alloy has dimensions $b = 40 \text{ mm}$, $t = 15 \text{ mm}$. For a safety factor of three against brittle fracture, what is the maximum permissible load on the plate if the crack half-length, a, is:

a. 10 mm and,

b. 24 mm?

For sufficiently long specimens, i.e., $h / b > 1.5$, the dimensionless factor, Y can be calculated as

$$Y = \frac{(1 - 0.5\alpha + 0.326\alpha^2)}{\sqrt{1-\alpha}}$$

where $\alpha = a / b$.

81. Suppose that fracture occurs in a single crystal of MgO when a critical tensile stress, $\sigma_f = 30{,}000 \text{ psi}$, is resolved across $\{100\}$ planes, and that yielding occurs when a critical resolved shear stress, $\tau_{\text{crss}} = 20{,}000 \text{ psi}$, is set up along the $\langle 110 \rangle$ slip directions lying in $\{110\}$ planes. Will the crystal deform plastically before fracturing when a tensile stress is applied along the $[100]$ direction?

82. Consider a leaf spring, supporting a point load, F, as shown in Figure 7.18 on page 203 of Callister. The deflection at the center, δ, is given by

$$\delta = \frac{FL^3}{4Ebd^3}.$$

The maximum stress (which occurs at the bottom surface) is given by

$$\sigma = \frac{3FL}{2bd^2}.$$

In a spring, one wants to maximize the deflection that the spring can undergo before permanent (or plastic) deformation occurs. Assuming d and L are fixed by design constraints, determine which material from the following list would make the best spring.

TF00 temper beryllium-copper
carbon fiber-epoxy composite $V_f = 0.6$
Polycarbonate (PC)

83. You have been tasked with designing a flat-plate capacitor. It must have a capacitance of $1\ \mu\text{F}$ at an operating voltage of 100 V. Your choice of materials is either soda-lime glass or polyethylene (See Table 12.4).

a. Which material will make the lightest capacitor?

b. Give the dimensions of the dielectric in the finished capacitor.

84. Will a spherical pressure vessel made of Lexan (Polycarbonate, properties in Table 9.1 p298) which is periodically pressurized to 100 kPa and then depressurized fail by leaking or by exploding?

Data: Inside Diameter = 1.00 m, Outside Diameter = 1.01 m

85. A 3-inch diameter 4340 steel bar is heated above the eutectoid and then quenched in oil.

a. What is the Rockwell hardness at the center and the surface of the bar?
b. Assuming that the cooling rates don't change as the quench proceeds (*i.e.*, the cooling rate at 700°C is the cooling rate until room temperature), what are the microconstituents at the center and the surface of the bar? (Great question, I wish I'd thought of it.)

86. A friend of yours wants to stand on her glass-topped coffee table to change a light bulb. Is it a good idea? State any assumptions.
Data: The table is 5 feet long by 2 feet wide. The top is 3/8-inch thick soda-lime glass.

87. A sample of polypropylene was measured and found to have the following molecular weight distribution:

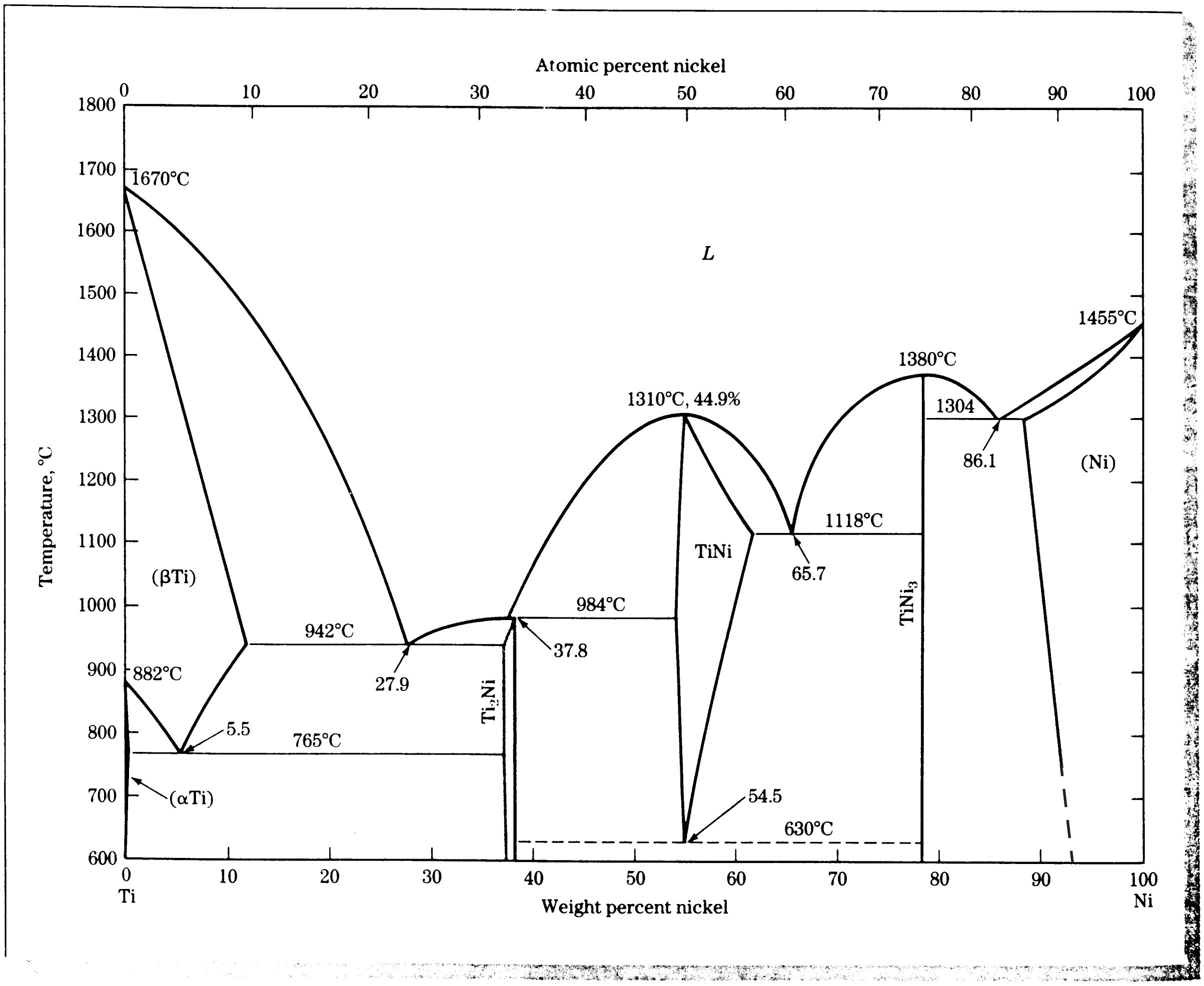
Table 1: polypropylene molecular weight distribution

MW Range	x_i	w_i
50,000–70,000	0.125	0.081
70,000–90,000	0.250	0.216
90,000–110,000	0.500	0.541
110,000–130,000	0.125	0.162

a. Calculate the number-averaged molecular weight, $\overline{M}_n$.
b. Calculate the weight-averaged molecular weight, $\overline{M}_w$.
c. How many grams of H_2O_2 were added to 1000 g of propylene to create this polymer?

88. The titanium-nickel phase diagram is shown below. All of the single-phase

regions are labeled.



a. Label all of the two phase regions.
b. Write down all six three-phase invariant reactions with the temperatures at which they occur.
c. For a 20 weight-percent Ni mixture which has been cooled from 1600°C to 940 °C list the *phases* present (at 940°C) and calculate their relative amounts.
d. For a 20 weight-percent Ni mixture which has been cooled from 1600°C to 940 °C list the *microconstituents* present (at 940°C) and calculate their relative amounts.

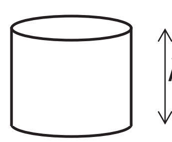
89. A carbon-fiber reinforced epoxy is desired with standard-modulus fibers (data in Table 15.6 on page 650). Parallel cylindrical fibers are to be laid in the longitudinal direction.
a. What is the maximum volume fraction possible for the fibers?
b. Estimate the longitudinal modulus for a fiber volume fraction of 80 percent of the maximum.
c. Estimate the transverse modulus for a fiber volume fraction of 80 percent of the maximum.

90. An aramid-epoxy composite (properties in table 15.5 page 648) is used to make a 1.000 m long by 1.000 cm diameter cylindrical rod. The fibers are aligned axially. The base of the rod is attached to the ceiling. A 230 kg weight is hung from the opposite end of the rod.
   a. Limiting yourself to the two-dimensional case, determine the values in the stress tensor.
   b. Write the 2-D compliance matrix inserting numerical quantities where possible. Assume $\nu_{lt} = 0.4$.
   c. Determine ν_{tl}.
   d. Determine the final dimensions of the rod.

91. Predict the tensile strength of a Kevlar-in-epoxy continuous aligned-fiber composite with 82 vol% fibers (data in Tables 15.4 on p. 644, & Table B.4 on p. A14 of Callister).

92. A slightly deranged engineer wants to design a toaster with an intrinsic silicon heating element (Si data in Table 12.2 on page 488 and in Table B.6 on page A18). The power draw at room temperature should be 115 W.
   a. What diameter should the heating element be if it has a total length of 1.000 m? (I didn't say it was a good idea).
   b. What would the approximate power draw be at the operating temperature of 500 °C?
   c. What would the heating-element length be at 500°C?
   d. What is your evaluation of the engineer's design idea?

93. It has been hypothesized that a nucleus may form as a circular cylinder instead of as a sphere. Derive the critical radius as a function of γ, T_m, ΔH_f, and ΔT for a circular cylinder where the height is equal to the diameter.



$h = 2r$

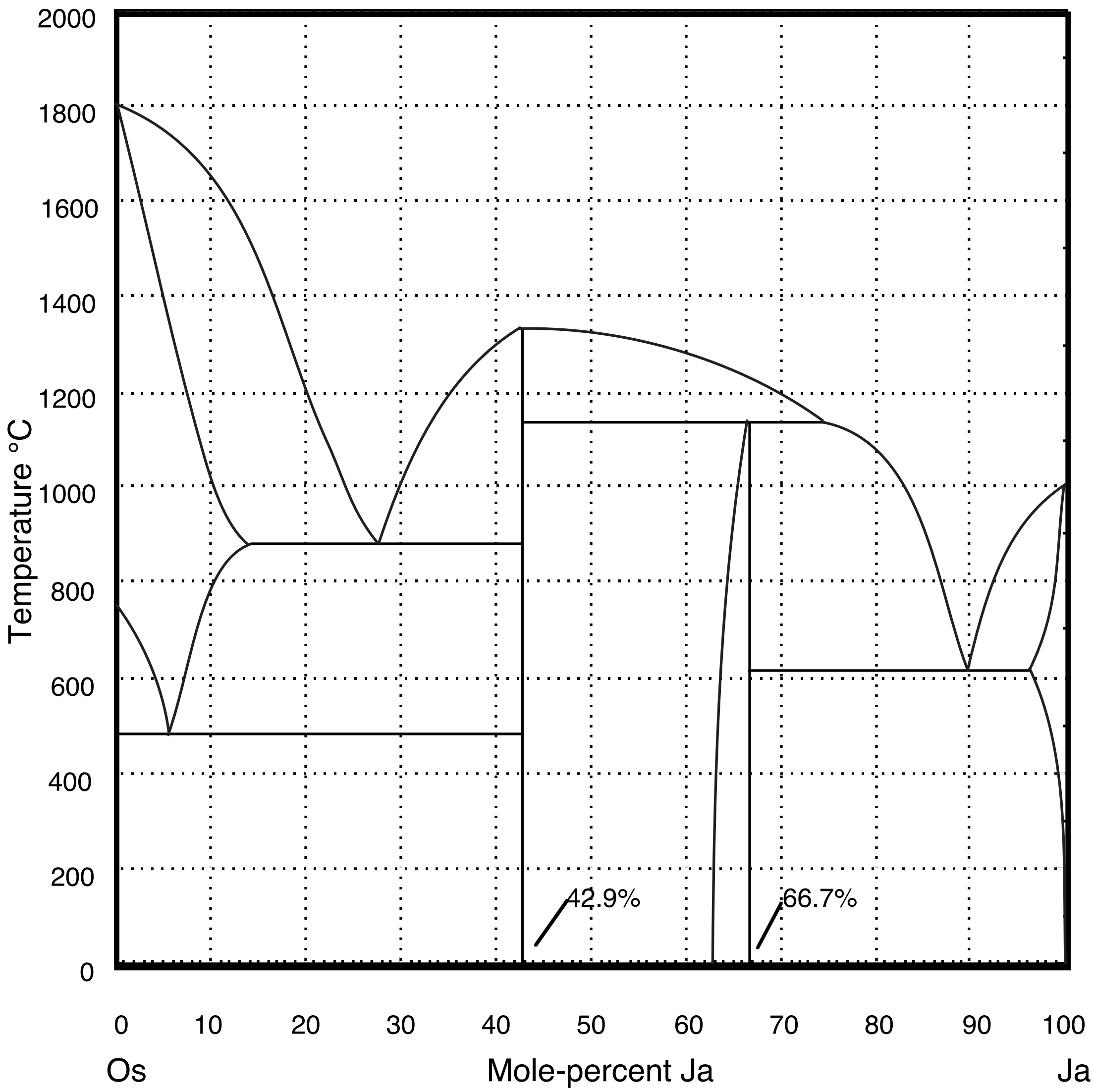
94. A polymer chemist claims to have developed a copolymer of phenol, formaldehyde, and melamine (structure on p. A35 of *Callister*). The process requires that the number of phenol molecules is the same as the number of melamine molecules. Assuming the chemist's claims are correct:
   a. Calculate the amounts (in grams) of formaldehyde and melamine that must be added to 100 g of phenol to produce a fully polymerized product.
   b. What is the percent weight change during complete polymerization?
   c. What sort of polymer do you think the final product is: thermoplastic, thermoset, or elastomer?

95. For a plate of 7150-T651 aluminum, $K_{Ic} = 26.4\text{ksi}\sqrt{\text{in}}$, $\sigma_y = 91.4\text{ksi}$, assume $Y = 1$:

a. What is the minimum plate thickness for which the fracture toughness equation applies?

b. If the sample in part a has a notch in the side which is 0.824 mm long, what is the maximum sustained stress it can support?

96. The binary phase diagram for jacsonium – osmium alloys is shown below. Jacsonium (a strongly rhythmic element) is HCP and osmium (first discovered on the Andy Williams Show) is FCC at high temperatures and BCT at lower temperatures. With respect to the below diagram do the following:



a) Label the phases present in all one- and two-phase regions on the above diagram. The high-T Os–rich phase is α, the low-T Os phase is β, the Ja–rich phase is ε, the congruently-melting intermetallic is γ and the other intermetallic is δ. Also label all invariant reactions.

b) Give the stoichiometric formulas for γ and δ, *e.g.*, Cu_3Ag.

c) For a 35%Ja – 65%Os mixture, describe what *phases* are present and approximately at what temperature they appear as the mixture is slowly cooled from 2000 °C.

d) For a 10%Ja – 90%Os mixture which is slowly cooled from 1800°C to 400°C, describe (at 400°C) what *microconstituents* are present and calculate their relative amounts.

97. Calculate the bond length (distance from atom center to atom center) for Indium Antimonide (InSb), a III-V compound semiconductor, which has the zinc blende crystal structure and a density of 5.7747 g cm^{-3}.

98. A sample of a 4340 alloy steel has been heated to 1500°F for 1000 hr, cooled at a rate of 15°F/s to 1100°F, held at 1100°F for 10 s, cooled at a rate of 500°F/s to 700°F, held at 700°F for 300 s, and then cooled rapidly to room temperature.

a) Sketch and label the microstructure, and give approximate percentages for each microconstituent.

b) Describe qualitatively the physical properties of the resultant steel.

99. Estimate the saturation magnetic moment per unit area for nickel ferrite (a = 0.834 nm) on the (110) plane.

100. A laser is being used for remote sensing. The beam exits a 5 mW HeNe laser (λ=632.8 nm), travels 250 m through Southern California air, bounces off a silver mirror, and returns toward the laser. A silica-glass collection lens sitting next to the laser focuses the beam onto a semiconductor photodiode.

a. What is the optical power impinging on the photodiode?

b. What is the minimum bandgap that the photodiode can have and still function properly?

101. A sample of a composite material (63.5 vol% fibers) was experimentally tested in the longitudinal (x)-direction and in one of the transverse (y)-directions. The experimentally determined stiffness and compliance matrices are:

$$\mathbf{Q} = \begin{bmatrix} 1.419\times10^{11} & 3.232\times10^{9} & 0 \\ 3.232\times10^{9} & 8.081\times10^{9} & 0 \\ 0 & 0 & 2.706\times10^{10} \end{bmatrix}$$

and

$$\mathbf{S} = \begin{bmatrix} 7.113\times10^{-12} & -2.845\times10^{-12} & 0 \\ -2.845\times10^{-12} & 1.249\times10^{-10} & 0 \\ 0 & 0 & 3.695\times10^{-11} \end{bmatrix}.$$

The units are SI (N/m^2 or the reciprocal).

a) Estimate the elastic moduli for the fibers by themselves and the matrix by itself.

b) Calculate the changes in length and diameter for a cylindrical sample initially 1 m long and 3 cm in diameter loaded axially with a force of 49.68 kN. The fibers run axially along the cylinder.

102. Because of a change in lattice structure at 168 K, the conductivity of V_2O_5 increases from $10^{-6}\Omega^{-1}\text{cm}^{-1}$ for lower T to $5\times10^{3}\Omega^{-1}\text{cm}^{-1}$ at higher T. Assume the dielectric constant $\kappa = 10$.

a) Calculate the complex index of refraction for 1 eV photons below and above 168 K.

b) Calculate the reflection from a V_2O_5-air interface for 1 eV photons below and above 168 K.

103. The short-circuit current of a ZnSe/GaAs solar cell (consisting of a thin film of ZnSe on a GaAs substrate) is directly proportional to the light at 700 nm that is absorbed in the GaAs after passing through the ZnSe (For this problem assume E_g for ZnSe = 2.6 eV, for GaAs = 1.4 eV). If absorption in the ZnSe can be neglected and if the index of refraction for this light is 2.44 in the ZnSe and 3.50 in the GaAs:

a) What thickness of ZnSe is needed for maximum short-circuit current?

b) What is the expected ratio of the short-circuit current for the conditions of optimum ZnSe thickness to that for the worst choice of ZnSe thickness (maximum reflection)?

104. An optical company desires to use silver in optics for a neodymium YAG laser (wavelength $\lambda = 1.064\ \mu\text{m}$). They want to use it in mirrors and attenuators (an attenuator decreases intensity by a fixed amount).

a) For the mirror application, how much energy must the mirror dissipate as heat if the incident laser beam has an intensity of 50 W (assume normal incidence)?

b) For the attenuator, neglecting reflections at the entrance and exit, how thick should a thin film of silver be to attenuate the incident light by 63.2 percent?

c) Will the actual thin film need to be thicker or thinner than calculated in part *b*?

105. The variation of electric susceptibility ($\chi_e = \kappa - 1$) with frequency of the applied field at high frequencies can be illustrated in a simple manner by considering the electronic polarization. If we let x be the displacement of a bound electron with respect to the center of positive charge of an atom, and $E_0 \sin\omega t$ is the applied field, the equation of motion of the electron is given approximately as

$$m_e \frac{d^2 x}{dt^2} + c\frac{dx}{dt} + kx = -eE_0 \sin \omega t$$

where

$$k = \frac{e^2}{4\pi\varepsilon_0 R^3}$$

and the damping, c, must be calculate using quantum mechanics. $-e$ and m_e are the electronic charge and mass respectively.

a) Express the damping factor, ζ, and the undamped natural frequency, ω_n, in terms of the other parameters in this model.

b) Derive a formula for x as a function of ω in terms of ω_n and ζ.

c) The electric susceptibility is equal to the polarization $\mathbf{P}$ divided by $\varepsilon_0 \mathbf{E}$ ($-ex$ is the dipole moment for a given electron, N is the number of electrons per unit volume). Derive an expression for χ_e as a function of ω.

d) Derive a formula for the complex index of refraction, m, in terms of ω.

e) Plot the real (n) and the imaginary (the other κ) parts of m versus $\log(\omega / \omega_n)$ from $\omega / \omega_n = 0.1$ to $\omega / \omega_n = 10$ for $\zeta = 0.1$.

106. The formula for yttrium iron garnet, ($Y_3Fe_5O_{12}$), may be written in the form $Y_3^cFe_2^aFe_3^dO_{12}$, where the superscripts *a*, *c*, and *d* represent different sites on which the Y^{3+} and Fe^{3+} ions are located. The spin magnetic moments for the Y^{3+} and Fe^{3+} ions positioned in the *a* and *c* sites are oriented parallel to one another and anti-parallel to the Fe^{3+} in *d* sites. Compute the number of Bohr magnetons associated with each Y^{3+} ion, given the following information: (1) each unit cell consists of eight formula ($Y_3Fe_5O_{12}$) units; (2) the unit cell is cubic with an edge length of 1.2376 nm; (3) the saturation magnetization for the material is 1.0×10^4 A/m; and (4) assume that there are 5 Bohr magnetons associated with each Fe^{3+} ion. (Yes, there are two possible answers.)

107. Derive a formula for the ratio of the forces in the matrix and the fiber phases for an orthotropic, continuous fiber reinforced composite loaded in the longitudinal direction. Let *F* be force, *E* be modulus, and *V* be volume fraction for the fiber (*f*) and matrix (*m*) phases.

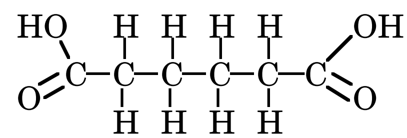
What is the most important factor in determining the extent of reinforcement in a fiber reinforced composite material?

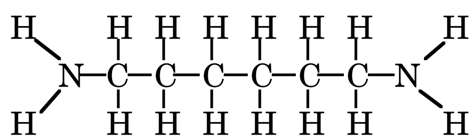
108. Calculate the bond length (distance from atom center to atom center) for Indium Arsenide, a III-V compound semiconductor, which has the zinc blende

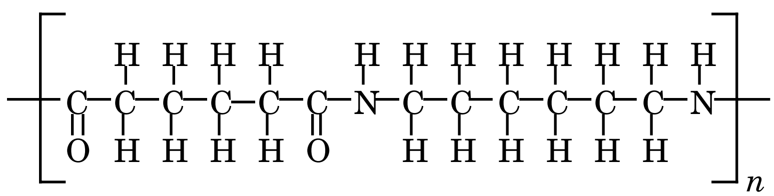
crystal structure.

109. A sample of a 4340 alloy steel has been heated to 1500°F for 1000 hr, cooled at a rate of 15°F/s to 1200°F, held at 1200°F for 1000 s, cooled at a rate of 500°F/s to 650°F, held at 650°F for 300 s, and then cooled rapidly to room temperature.
   a) Sketch and label the microstructure, and give approximate percentages for each microconstituent.
   b) Describe qualitatively the physical properties of the resultant steel.

110. Two large flasks containing copper sulfate solutions are connected by a salt bridge. The concentration of copper ions in flask one, $(C_{Cu^{2+}})$, is 2.0 M. The concentration of copper ions in flask two is 0.002 M. A copper wire is run from one flask to the other. The wire is 0.125 mm in diameter, 5 m in length, and is inserted into each flask to a depth of 0.5 cm. The flasks are large and well stirred.
   a) Which end of the wire will disappear? Why?
   b) Approximately how long will it take for the end to disappear? State all assumptions.

111. Nylon 66 is formed by reacting adipic acid,  , with

hexamethylenediamine,  , to form

 and water.

What is the percent weight change if 1 mol of adipic acid polymerizes with 1 mol of hexamethylenediamine and all of the water evaporates?

Data: $MW_{adipic\ acid} = 146.1442$
$MW_{hexamethylenediamine} = 116.20782$
$MW_{water} = 18.01534$

112. Bavarium and zaynicon are fictitious Group IV semiconductors used to dope III-V compound semiconductors. Bavarium always replaces the Group III element and zaynicon always replaces the Group V element.
   a) Determine the dopant element (bavarium or zaynicon) and quantity (in parts-per million, ppm) required to form a p-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\ m)^{-1}$ from gallium arsenide, GaAs.

b) Determine the dopant element (bavarium or zaynicon) and quantity (in parts-per million, ppm) required to form an n-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\ \mathrm{m})^{-1}$ from gallium antimonide, GaSb.

113. An optical company desires to use silver in optics for a neodymium YAG laser (wavelength $\lambda = 1.064\ \mu\mathrm{m}$). They want to use it in mirrors and attenuators (an attenuator decreases intensity by a fixed amount).
   a) For the mirror application, how much energy must the mirror dissipate as heat if the incident laser beam has an intensity of 50 W (assume normal incidence)?
   b) For the attenuator, neglecting reflections at the entrance and exit, how thick should a thin film of silver be to attenuate the incident light by 63.2 percent?
   c) Will the actual thin film need to be thicker or thinner than calculated in part b)?

114. A sample of a 1.13wt% carbon steel is heated to 1650°F, held at 1650°F for 1000 hours, cooled in less than 0.1 s to 700°F, held at 700°F for 100 s, and cooled rapidly to room temperature.
   a) Sketch and label the microstructure, and give approximate percentages for each microconstituent.
   b) Describe qualitatively the physical properties of the resultant steel.

   Another sample of a 1.13wt% carbon steel is heated to 1650°F, held at 1650°F for 1000 hours and cooled at a rate of 0.01°F/s to room temperature.
   c) Sketch and label the microstructure, and give approximate percentages for each microconstituent.
   d) Describe qualitatively the physical properties of the resultant steel.

115. Slip in iron (Fe) occurs not only along the {110} family but also along the {211} and the {321} families. But in all three systems slip occurs in the <111> family.
   a. Do the (110), the (211) and the (321) all contain the $[\bar{1}11]$? (Hint: What is the dot product of perpendicular vectors?)
   b. If a stress is applied along the $[12\bar{2}]$ in a single crystal of iron, on which of the three systems in part "a" will slip occur first?

116. Most of us have had the experience of accidentally knocking a glass off a counter, watching it bounce twice and then shatter on the third bounce. Why does this happen? Be as quantitative as possible. Table 13.4 on p. 406 and Table 8.1 on p. 195 may help (then again…).

117. You need to specify the material for a pressure vessel in an aircraft. The equation for the maximum stress in the wall of a thin-walled spherical pressure vessel is:

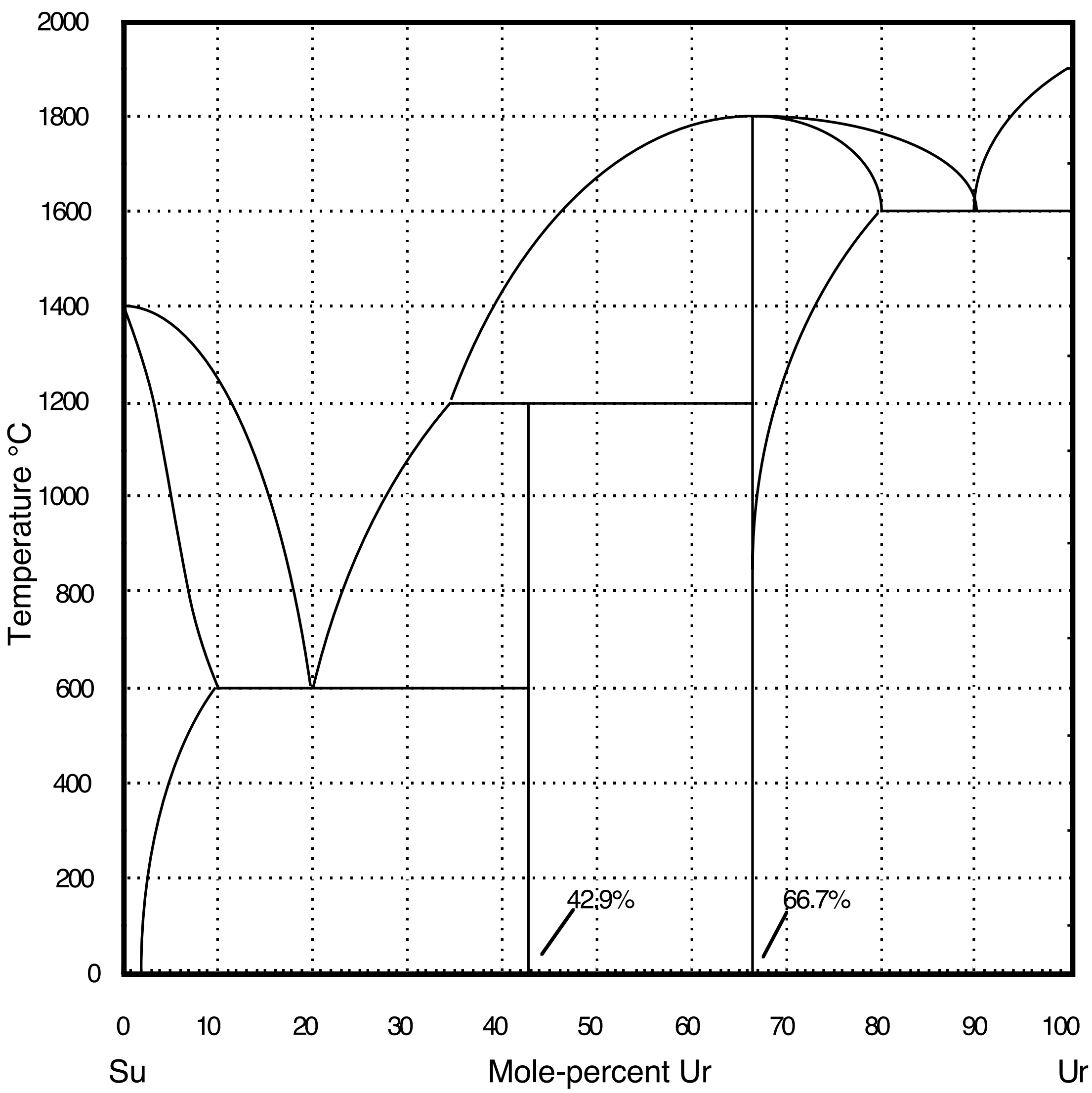
$$\sigma = \frac{PR}{2w},$$

where P is the pressure difference between the inside and outside of the vessel, R is the radius of the sphere and w is the wall thickness. As a reminder for a spherical shell:

$$m = 4\pi R^2 w \rho,$$

where m is the mass and ρ is the density. Determine which of the four materials listed in the table towards the bottom of page 379 would be best for the vessel.

118.



The binary phase diagram for urbium – suburbium alloys is shown above. Urbium (an upscale element) is HCP and suburbium (below urbium in the periodic table) is BCT. With respect to the above diagram answer the following questions:

a) Label the phases present in all one and two phase regions on the above diagram. The Su–rich phase is α, the Ur–rich phase is δ, the high-melting intermetallic is γ and the other intermetallic is β. Also label any invariant reactions.

b) Give the stoichiometric formulas for β and γ, *e.g.*, Cu_3Ag.

c) For a 40%-Ur – 60%-Su mixture, describe what phases are present and approximately at what temperature they appear as the mixture is slowly cooled from 2000 °C.

119. Beginning with a bar of fully annealed plain-carbon steel at room temperature, describe a complete thermal history for producing a final bar with a Rockwell C hardness above 50 and good fracture toughness or impact resistance. You also need to specify the alloy you will use.

120. You need to specify the material for a cantilever beam in an aircraft. The beam must support a load of force F applied at the end of the beam and deflect by no more than an amount δ at the end. The equation for the elastic deflection of a square cantilever beam is:

$$\delta = \frac{4l^3F}{Et^4},$$

where l is the length of the beam, and t is the beam thickness. As a reminder for a parallelepiped with a square cross section:

$$m = lt^2\rho,$$

where m is the mass and ρ is the density. Determine which of the four materials listed in the table towards the bottom of page 379 (additional information in Table 6.1 on page 118) would be best for the beam.

121. 3.401 g of H_2O_2 were added to 20.83 kg of styrene. A new laboratory technician measured the molecular weight distribution given below for the product. Should the technician be promoted or fired?

Table 2: Product Molecular Weight Distribution

Mean M_i [g/mol]	x_i
175,000	0.490
225,000	0.353
275,000	0.157

122. Gallium arsenide (GaAs) can be made an extrinsic semiconductor by doping

with either gallium or arsenic. The chemical formula can then be written as $Ga_{1+\delta}As$ where $\delta > 0$ for gallium doping and $\delta < 0$ for arsenic doping.

a) To form a p-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\ \mathrm{m})^{-1}$, what are the sign and magnitude of δ?
b) To form an n-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\ \mathrm{m})^{-1}$, would the magnitude of δ be greater or less than in part a)?

123. An optical company desires to use aluminum in optics for a neodymium YAG laser (wavelength $\lambda = 1.064\ \mu\mathrm{m}$). They want to use it in mirrors and attenuators (an attenuator decreases intensity by a fixed amount).
   a) For the mirror application, how much energy must the mirror dissipate if the incident laser beam has an intensity of 100 W (assume normal incidence)?
   b) For the attenuator, neglecting reflections at the entrance and exit, how thick should a thin film of aluminum be to attenuate the incident light by 63.2 percent?
   c) Will the actual thin film need to be thicker or thinner than calculated in part b)?

124. Calculate the homogeneous nucleation rate [nuclei/m^3/s] in liquid copper at an undercooling of 200 K. $\Delta H_f = 1826\times10^6\ \mathrm{J/m^3}$, $\gamma = 0.177\ \mathrm{J/m^2}$.

125. For the following steels and thermal histories sketch the microstructure, label the microconstituents, and calculate the relative amounts of the microconstituents present at the final state.
   a) A 1020 steel (0.2 wt% C) that was maintained at 1000°C for 1000 hr. and slowly cooled to 30°C.
   b) A 1080 steel (0.77 wt% C) that was maintained at 800°C for 1000 hr., cooled in less than a second to 600°C, held at 600°C for 3 seconds. and then very rapidly cooled to 30°C.

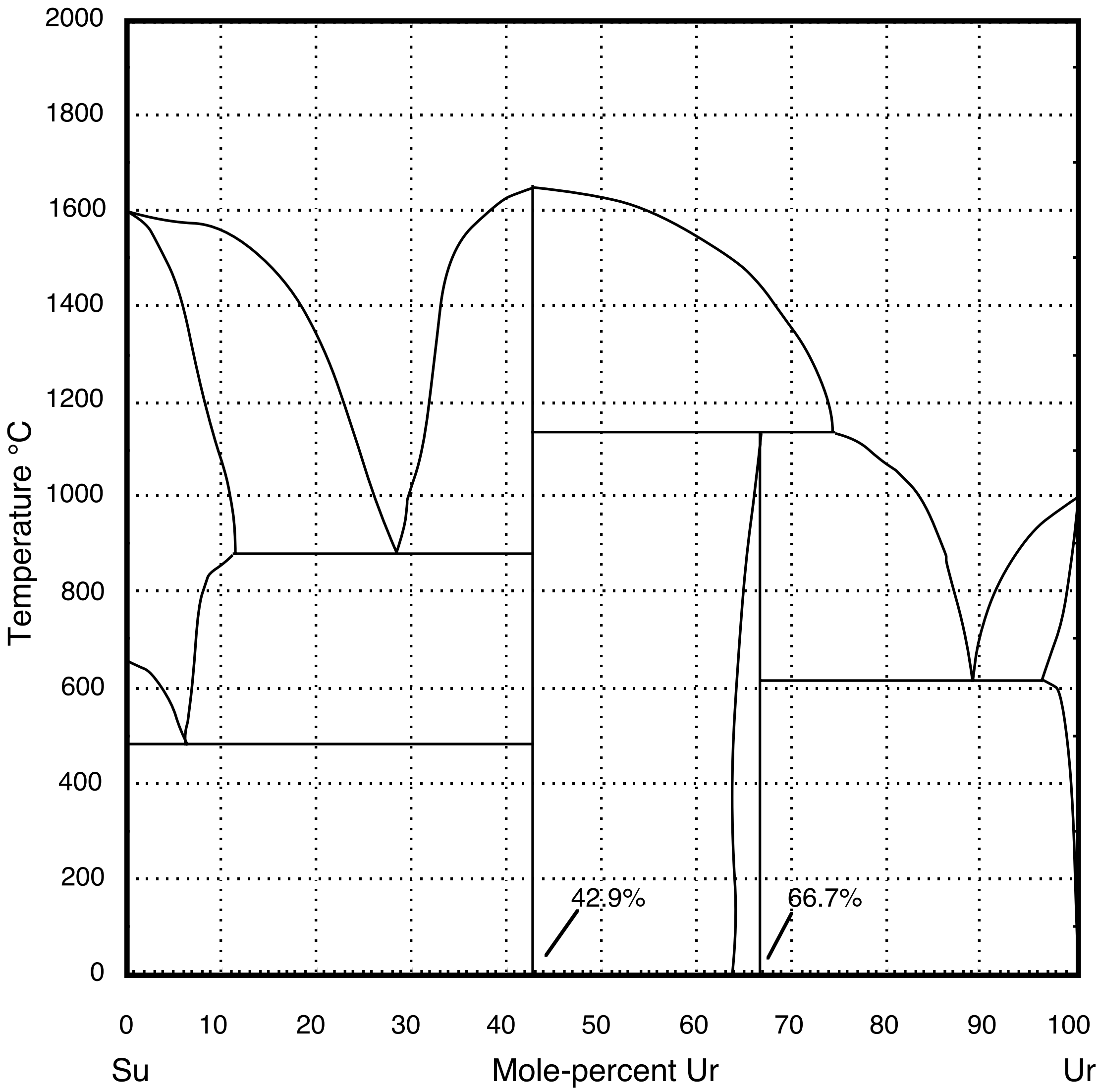
126. A stress of 67 MPa is applied in the [001] direction of a unit cell of a BCC iron single crystal. Calculate the resolved shear stress for the following slip systems:
   a) (211) $[\bar{1}11]$
   b) (321) $[\bar{1}11]$

127. 0.3 wt% H_2O_2 has been added to 100 lbs. of a mixture of 50 wt% acrylonitrile, 25 wt% butadiene, and 25 wt% styrene prior to polymerization.
   a) Calculate the average degree of polymerization of the ABS polymer.
   b) How many pounds of sulfur are required to completely cross link the polymer?

128. A strip of brass 0.500 inches thick, 5.00 inches wide and 50 inches long is to be rolled to one-half its original thickness. The rolling will be accomplished by pass-

ing the strip through two rolling mills. Both rolling mills accomplish the same percentage cold work. What is the thickness after the first rolling pass?

129.



The binary phase diagram for uruglium – suramium alloys is shown above. Uruglium (a no-nonsense element) is HCP and suramium (first discovered in Brooklyn) is FCC at high temperatures and BCT at lower temperatures. With respect to the above diagram do the following:

a) Label the phases present in all one and two phase regions on the above diagram. The high-T Su–rich phase is α, the low-T Su phase is β, the Ur–rich phase is ε, the high-melting intermetallic is γ and the other intermetallic is δ. Also label all invariant reactions.

b) Give the stoichiometric formulas for γ and δ, *e.g.*, Cu_3Ag.

c) For a 40%-Ur – 60%-Su mixture, describe what *phases* are present and approximately at what temperature they appear as the mixture is slowly cooled from 2000 °C.

130. Describe a heat treatment for obtaining a microstructure of ~50% pro-eutectoid ferrite and ~50% bainite in a thin 4130 steel plate.

131. Magnetite, Fe_3O_4 is an inverse spinel because the divalent metal ions are in six-fold sites in the FCC O^{2-} lattice and the trivalent metal ions are split equally between four-fold and six-fold sites in the FCC O^{2-} lattice. In a normal spinel, the divalent ions are in four-fold sites and the trivalent ions are all in six-fold sites. $MnFe_2O_4$ for example, is a normal spinel.

a) Calculate the planar density [#/m^2] of Mn^{2+} on the (110) plane in $MnFe_2O_4$.

b) Calculate the net magnetic moment per unit cell on the (110) plane in $MnFe_2O_4$ in a single domain.

132. In Fe at room temperature slip can occur not only on the {110} planes in the <111> directions but also on the {211} planes in the <111> directions and on the {321} planes in the <111> directions. For this problem assume that the value of the critical resolved shear stress doesn't depend on the slip system.

a) If a pure tensile stress is applied to a single crystal of Fe in the [001] direction, on which plane will slip occur first, the (011), the (112), or the (123)?

b) In what direction will the slip occur?

(Hint: The dot product of orthogonal vectors is zero)

133. In a material the critical resolved shear stress is 100 MPa on the (312) plane in the $[\bar{1}11]$ direction. Calculate the yield stress in the $[1\bar{2}1]$ direction for this slip system.

134. Calculate the maximum allowable surface crack size for a material where the applied tensile stress is 200 ksi, and $K_{Ic} = 40 \text{ ksi}\sqrt{\text{in}}$. Assume plane strain and $Y = 1.025$.

135. A 1040 steel rod is to be hot drawn (pulled through a die while hot), slowly cooled, and then cold drawn. The initial rod is 1/4-inch stock. The final rod should have a diameter of 0.100 inches and a Brinell hardness of 246. Calculate the diameter after the first drawing operation (Pages 255 & 217 in Callister may help).

136. Calculate the maximum radius and wall thickness of a spherical pressure vessel made of Ti-6Al-4V Titanium alloy periodically pressurized to 500 kPa, so that it will leak before breaking. Use data on Table 9.1 on p. 298 of Callister.

137. With reference to Figure 10.22 on p. 390 of Callister, given a mixture of 80 wt% Al_2O_3 and 20 wt% MgO at 2000°F, determine the phases present, their compositions, and their relative amounts.

138. With reference to Figure 10.6 on p. 373 of Callister, given a mixture of 83.7 wt% silver and 16.3 wt% copper cooled slowly from 1000°C to 778°C, determine the most likely microconstituents present and their relative amounts.

139. Determine the flexural strength of a piece of chalk that is 3/8 inches in diameter, supported by fingers that are 2 inches apart and breaks at an applied finger-force of 15 pounds.

140.

a. A thin piece of 4130 steel is heated to 850°C for 1000 hours, cooled in less than a second to 675°C, held there for 600 s, then rapidly cooled to room temperature. Determine the microconstituents present, their approximate relative amount, and the Rockwell C hardness of the sample.

b. A sample of 4340 steel is held at 800°C for 1000 hours, oil-quenched to room temperature, heated to 400°C for 1 hour, and then cooled to room temperature. Estimate the microconstituents present and the approximate Rockwell C hardness of the sample. (Potentially useful pages are 441, 446, 453, 591, & 218 in Callister. You may not need them all.)

141. Do problem 10.45 (b) on page 415 of Callister. The possibilities are Al^{3+} vacancies, Mg^{2+} vacancies, or O^{2-} vacancies

142. A 10Ω copper ($\rho = 1.72 \times 10^{-8} \Omega\text{m}$) wire-wound resistor has a total wire length of 100 m. Calculate the wire diameter.

143. Germanium ($A_{\text{Ge}} = 72.59\ \text{g/mol}$, $\rho = 5.32\ \text{g/cm}^3$, $\mu_e = 0.38\ \text{m}^2\text{/V-s}$, $\mu_h = 0.18\ \text{m}^2\text{/V-s}$) is doped with 0.12×10^{-6} atomic fraction gallium. Calculate the conductivity of the doped germanium.

144. A flat-plate capacitor with dimensions $2\ \text{m} \times 0.5\ \text{m}$ has a plate separation of 1 mm and a capacitance of 0.0425 µF. Calculate the dielectric constant of the dielectric in the capacitor.

145. The performance index for a material exposed to fluctuating temperatures is the thermal shock resistance.

$$P = TSR = \frac{k\sigma_f}{E\alpha_l},$$

where k is the thermal conductivity, σ_f is the failure strength, E is Young's modulus, and α_l is the linear coefficient of thermal expansion. Determine which material: A36 Steel, Soda-Lime Glass, Sintered Silicon Nitride, or Dry Nylon 6,6, is best for fluctuating-temperature applications. The properties can all be found in Appendix B of Callister. If a range of properties is given for a material, use the most favorable value.

146. 37.5 kg of nylon 6,6 is produced by reacting adipic acid and hexamethylenediamine. Data are in supplementary problem 76.
   a. What masses of adipic acid and hexamethylenediamine were required?

   b. What other by-product was produced? What was its mass?

147. A sheet of continuous and aligned fiber-reinforced aramid-fiber polycarbonate-matrix composite consists of 70 vol% fibers and 30 vol% matrix (data are in Problem 15.8 on page 664 of Callister. Note: Your problem has exactly reversed vol% from Problem 15.8). The fibers are aligned in the x-direction and the y-direction is transverse to the fibers. Assume $\nu_{lt} = 0.3$.
   a. Calculate E_{cl} and E_{ct} for the composite.

   b. Calculate ϵ_x, ϵ_y, and γ_{xy} for applied tensile stresses of $50\ \mathrm{MPa}$ in the x-direction and $5\ \mathrm{MPa}$ in the y-direction.

148. A BCC metal slips along the $(1\bar{3}2)$ in the [111] at an applied tensile stress of 97 MPa in the [212]. Calculate τ_{crss} for this metal.

149. A sheet of 4340 alloy steel tempered at 425°C (properties on page 298 of *Callister*) with an interior through crack of 0.080 inches fails at an applied stress of 150 ksi. Calculate the geometric factor for this sheet. Assume the sheet was in a plane-strain condition.

150. With reference to Figure 10.6 on p. 373 of *Callister*, given a mixture of 23.2 wt% silver and 76.8 wt% copper cooled slowly from 1200°C to 778°C, determine the most likely microconstituents present and their relative amounts.

151. A relatively large sheet of steel was exposed to cyclic tensile and compressive stresses of magnitudes 100 MPa and 50 MPa respectively. The sheet failed after 3.86×10^{5} cycles resulting in a lawsuit. The steel's plane-strain fracture toughness is $25\ \mathrm{MPa}\sqrt{\mathrm{m}}$ and the values of m and A are 3.0 and 1.0×10^{-12}, respectively, for $\Delta\sigma$ in MPa and a in m. Assume that the parameter Y is independent of crack length and has a value of 1.0. Upon investigation, it was discovered that a

technician had ultrasonically inspected the plate and had certified that the longest flaw in the plate was less than 1.5 mm in length and the head engineer had then certified that the plate was good for at least 5×10^6 cycles. Who should be made the scapegoat, the technician or the head engineer? What was the likely mistake?

152. A thin sample of air-cooled plain carbon steel was tested and found to have a tensile strength of 100 ksi, a Rockwell B hardness of 90, and a ductility of 42% reduction in area. Quantitatively describe the expected microstructure of the sample. Pages 217 and 448 in *Callister* may help.

153. Given the IT diagram for 4340 steel (Fig. 11.24 on p. 441 of Callister), quantitatively describe a thermal history for a thin sheet of 4340 steel to yield a microstructure of approximately 50% proeutectoid ferrite, 25% bainite, and 25% Martensite.

154. Plot the hardness profile for an austenitized and water-quenched 8630 alloy steel rod that is 3 inches in diameter.

155. Test samples of a ceramic had a volume of $0.001\ \mathrm{m}^3$ and had an experimental σ_0 of 69.0 MPa. 25% of the production items seem to survive stresses of 46.09 MPa, while 75% seem to fail. The volume of the production item is $0.035\ \mathrm{m}^3$. What is the Weibull modulus for this ceramic?

156. How many grams of hydrogen peroxide ($M_{H_2O_2} = 34.01474$ g/mol) need to be added to 10 kg of methyl methacrylate ($M_{MMA} = 100.11831$ g/mol) to create a polymer with a number-averaged molecular weight of $\overline{M}_n = 314565$ g/mol? What is the number-averaged degree of polymerization?

157. The maximum nonstoichiometry on the Al_2O_3-rich side of the mullite phase (Figure 10.24 on p. 392 of Callister) occurs at about $1890°C$.
   a) Determine the type of vacancy defect that is produced and the percentage of vacancies that exist at this composition.
   b) Under what conditions is mullite a stoichiometric compound?

158. Do Problem 14.24 on p. 623 of Callister.
   5 points extra credit - Explain the relationship between η in Chapter 14 and E_c in Chapter 7 of Callister.

159. A spherical pressure vessel is subjected to a periodic pressure of 800 kPa. The vessel radius is 1.5 m, and the material has a yield strength of 120 MPa. To ensure leak-before-break conditions, what is the minimum fracture toughness of

the vessel? What should the wall thickness be?

160. What is the expected coordination number for Ti^{4+} ions in TiI_4?

161. At what load will a cylindrical soda-lime glass sample break? Conditions: $\sigma_f = 69\text{ MPa}$, $L = 33\text{ cm}$, $r = 3\text{ mm}$, simply supported ends, concentrated load in center.

162. A platinum RTD ($\sigma = 9.43\times10^{6}(\Omega\text{m})^{-1}$) has a resistance of $100.0\ \Omega$, and is constructed from a wire that is 8.322 m in length. What is the diameter of the wire?

163. Germanium ($A_{Ge} = 72.59\text{ g/mol}$, $\rho = 5.32\text{ g/cm}^3$, $\mu_e = 0.38\text{ m}^2\text{/V-s}$, $\mu_h = 0.18\text{ m}^2\text{/V-s}$) is doped with arsenic. Calculate the atomic fraction of arsenic if the conductivity of the doped germanium is $2718\ (\Omega\text{ m})^{-1}$.

164. A flat-plate capacitor with dimensions $2\text{ m} \times 0.5\text{ m}$ has a plate separation of 1 mm. The dielectric constant of the material between the plates is 4.8. Calculate the capacitance of the capacitor.

165. Pressure vessels are sometimes protected from catastrophic failure with a rupture disc, a thin circular disk of radius r and thickness t that is designed to fail or rupture at a given pressure. Often the discs are scored along a diameter with a thin groove of depth a to provide a rupture point. The maximum deflection δ, and maximum tensile stress σ, in a disk subject to pressure p, are reasonably approximated by:

$$\delta = \frac{2r^4p}{3Et^3}, \text{ and } \sigma = \frac{5r^2p}{4t^2}.$$

For a fixed radius r, groove depth a, and pressure p, which steel, 17-7PH, or 4340 tempered at 425°C, would make the least expensive rupture disk?

166. An indium-doped sample of bavarium (a fictitious Group-IV semiconductor) has a conductivity at saturation of $106\ (\Omega\text{m})^{-1}$. The bavarium is doped with 1.0×10^{-7} atom-fraction indium. For bavarium $\mu_h = 0.21\text{ m}^2\text{/V-s}$, $\mu_e = 0.45\text{ m}^2\text{/V-s}$ and $\rho_{Bv} = 5.545\text{ g/cm}^3$. What is the atomic weight of bavarium?

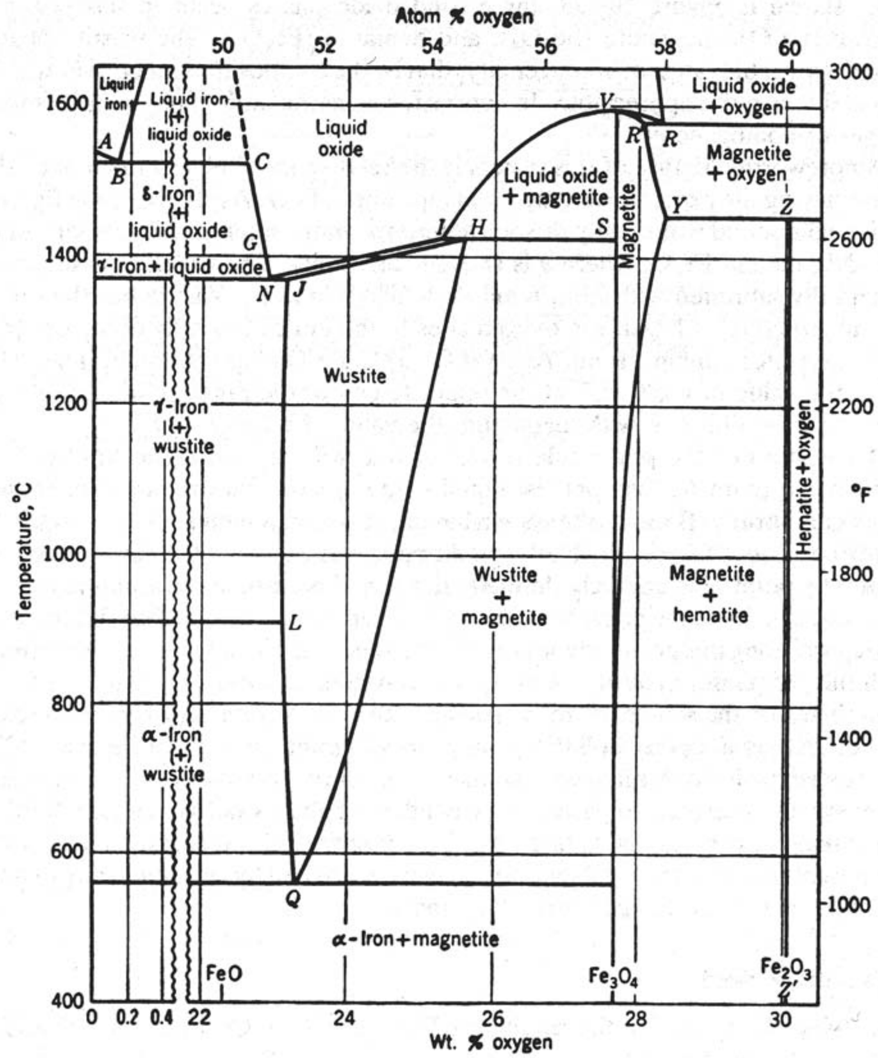


Table 3: Iron-Oxygen Phase Diagram

Point	°C	wt% O	at% O		Point	°C	wt% O	at% O
A	1536	0.00	0.00		*N*	1371	22.91	50.92
B	1528	0.16	0.56		*Q*	560	23.26	51.41
C	1528	22.60	50.48		*R*	1583	28.30	57.94
G	1392	22.84	50.82		*R'*	1583	28.07	57.67
H	1424	25.60	54.57		*S*	1424	27.64	57.14
I	1424	25.31	54.19		*V*	1597	27.64	57.14
J	1371	23.16	51.27		*Y*	1457	28.36	58.02
L	911	23.10	51.18		*Z*	1457	30.04	59.98

167. The Iron-Oxygen phase diagram is shown above. Wüstite (FeO) has the NaCl crystal structure.

a) What are the minimum and maximum Fe^{2+}/Fe^{3+} ratios in wüstite?
b) What are the minimum and maximum (mol vacancy)/(mol O) ratios in wüstite?
c) What are the minimum and maximum theoretical densities for wüstite assuming that the ionic radius for iron doesn't change with oxidation state or temperature, the ionic radius of oxygen doesn't change with temperature, and Fe vacancies change only the number of Fe's, not the lattice constant?

168. What length of 0.2 mm diameter Nickel 200 wire (properties on p.A26 of Callister) is needed to create a 1234 Ω wirewound resistor?

169. A cantilever beam is to be constructed from one of the materials in the table below. If the objective is to minimize mass and the constraint is the maximum load on the beam, which of the below materials is best?

Table 4: Data for Problem #169

Material	E (GPa)	ν	YS (MPa)	TS (MPa)	ρ (g/cm^3)	K_{Ic}	C_p (J/kg K)
1040 steel	200	0.30	600	750	7.87	51	444
silicon nitride	304	0.24	N/A	1000	3.30	5	750
nylon 66	2.8	0.41	N/A	82.7	1.15	3	1670
Douglas fir	13.4	0.30	N/A	85.5	0.50	13	2900

170. An aluminum-doped silicon sample is an extrinsic semiconductor with a conductivity of $1200(\Omega\text{m})^{-1}$. In order to create a diode, the sample is heated to 1350°C and held for 2 hours. While at temperature, one surface of the sample is exposed to a gaseous mixture that maintains the surface concentration of Al at its bulk value and causes a surface concentration of phosphorus of 2.878×10^{23} atoms/m^3. The sample is then cooled. Assume that the diffusivity of phosphorus in silicon is the same as that of boron in silicon given in Problem 12.D5 on p.529 of Callister.

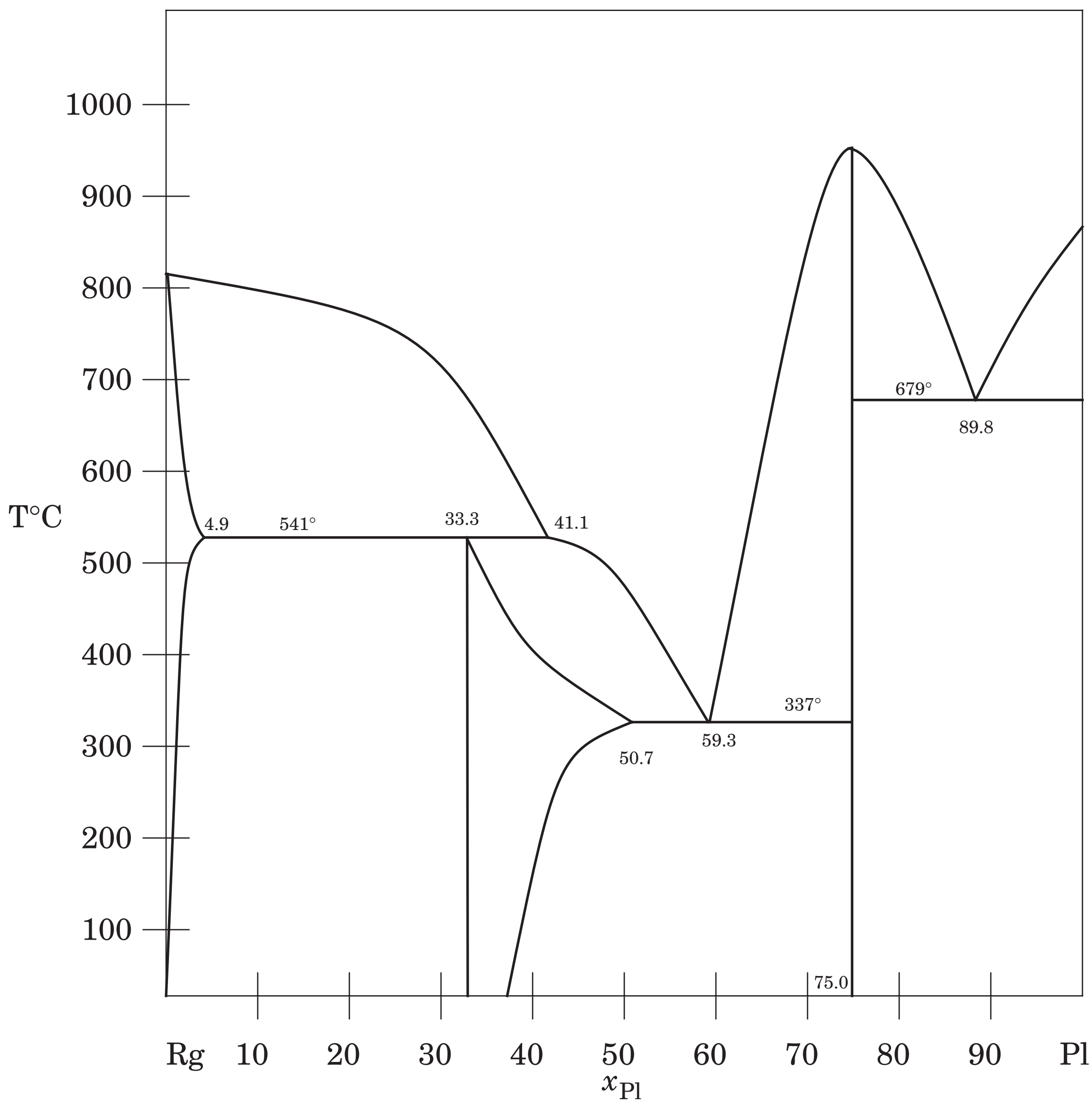
a) What is the room-temperature conductivity of the exposed surface?
b) At what depth (in µm) is the p-n junction?

171. An initially $1\text{ cm} \times 1\text{ cm} \times 1\text{ cm}$ cubic sample of an aramid composite (properties in Table 15.5 on p 648 of Callister, assume $\nu_{lt} = 0.2$) has continuous fibers aligned in the x-direction. A tensile force of 800 N is applied along the x-direction. A tensile force of 300 N is applied along the y-direction. A compressive force of

500 N is applied along the z-direction. Calculate the change, $(\Delta l\text{'s})$, in the dimensions of the cube.

172. An engineer wants to design a toaster with a nichrome heating element $(\rho = 1000\times10^{-9}\Omega\ \mathrm{m}[1 + 0.0004(T - 20°\mathrm{C})])$. The power draw at room temperature should be 115 W.
   a) What diameter should the heating element be if it has a total length of $1.000\ \mathrm{m}$?
   b) What would the power draw be at the operating temperature of 500°C?
   c) What would the heating element length be at 500°C?

173. The plattium-regurgium phase diagram is shown on the next page. Composition is in atomic percent.
   a. Label all of the one-phase regions. The Rg-rich phase is α, the Pl-rich phase is δ, the incongruently-melting phase is β, and the congruently-melting intermetallic is γ.
   b. Label all of the two phase regions, *e.g.*, $l+\alpha$.
   c. Write down all three-phase invariant reactions with the temperatures at which they occur, *e.g.*, $\alpha + \beta \rightarrow \gamma$ at 1124°C.
   d. For a 10 atomic-percent Pl mixture which has been cooled from 1000°C to 300 °C list the *phases* present at 300°C and calculate their relative amounts.
   e. For a 68 atomic-percent Pl mixture which has been cooled from 1000°C to 336 °C list the *microconstituents* present at 336°C and calculate their relative amounts.
   f. What is the chemical formula for the congruently-melting intermetallic?



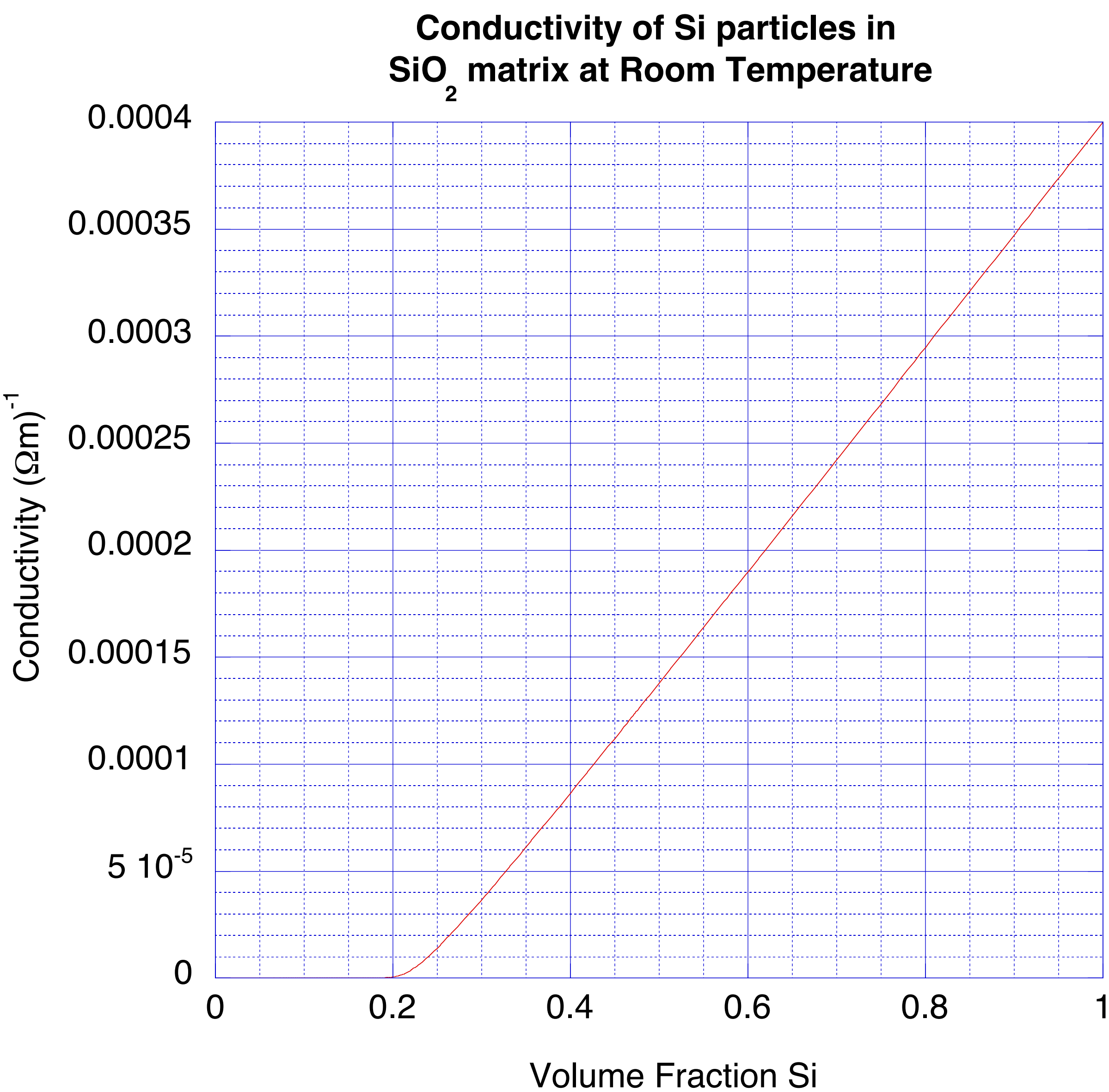
174. The energy necessary to generate a dislocation is proportional to the square of the length of the Burgers vector, $|\mathbf{b}|^2$. This means that the most stable (lowest energy) dislocations have the minimum length, $|\mathbf{b}|$. For the bcc metal structure, calculate (relative to $E_{\mathbf{b}\,=\,[111]}$) the dislocation energies for $E_{\mathbf{b}\,=\,[110]}$ and $E_{\mathbf{b}\,=\,[100]}$.

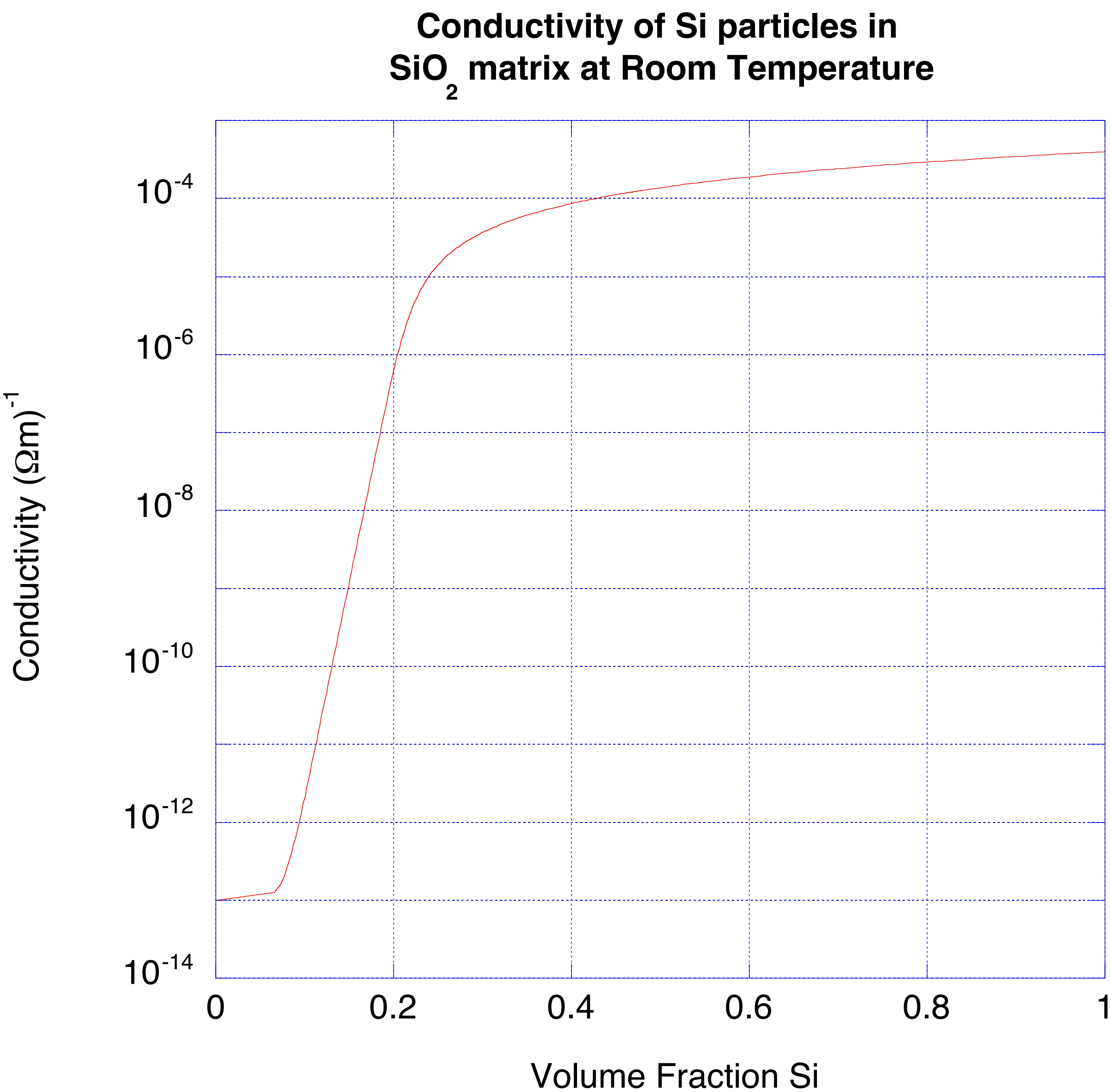
175. The (pseudo-)experimental results for measurement of the conductivity of a composite consisting of intrinsic silicon spheres in a fused silicon-dioxide matrix is shown below on both linear and semi-logarithmic scales.
   a) Sketch as accurately as possible the limiting cases on the graph with the lin-

ear scale.

b) Explain the shape and unusual features of the graph. Be as quantitative as possible.

c) Estimate the conductivity of a 60% Si - 40% SiO_2 composite at $200°C$.

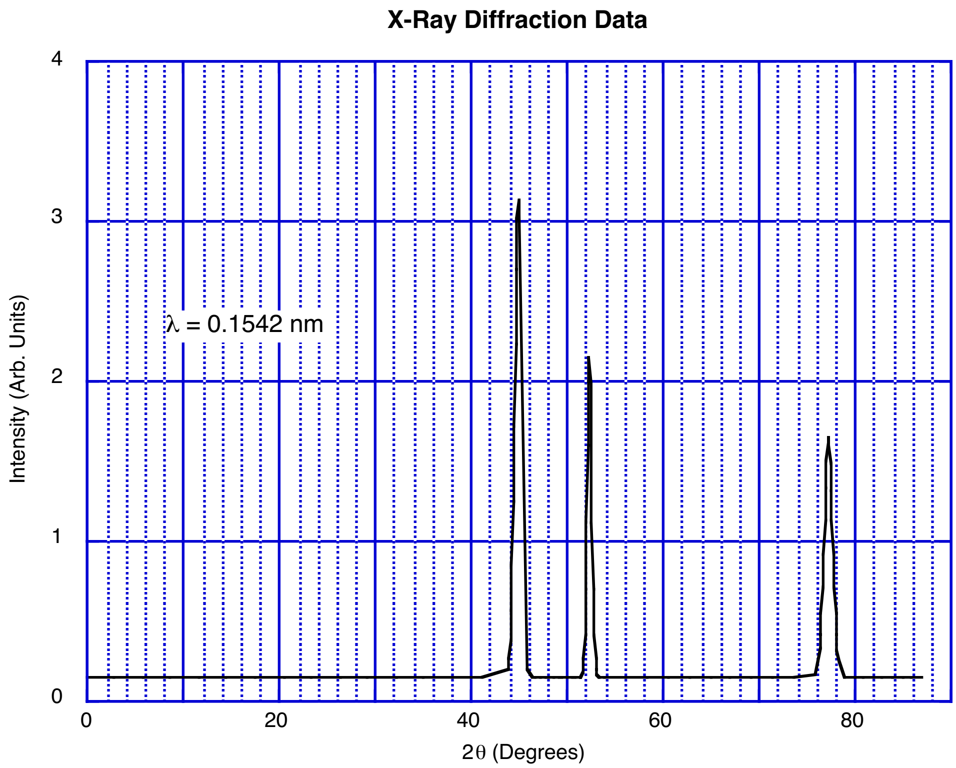




176. Gallium luminide is a III-V compound semiconductor with the zinc blende structure. Gallium has an ionic radius of 0.062 nm and an atomic weight of 69.72. Luminous has an atomic weight of 76.106. Gallium luminide has a theoretical density of 5.358 g/cm^3. What is the ionic radius of the luminide ion?

177. Suberbium is a metal that packs in one of the cubic array structures. The experimental x-ray diffraction data for suberbium in Cu_{K_α}-radiation is given below.

Determine if suberbium is fcc or bcc and calculate the lattice constant, a .

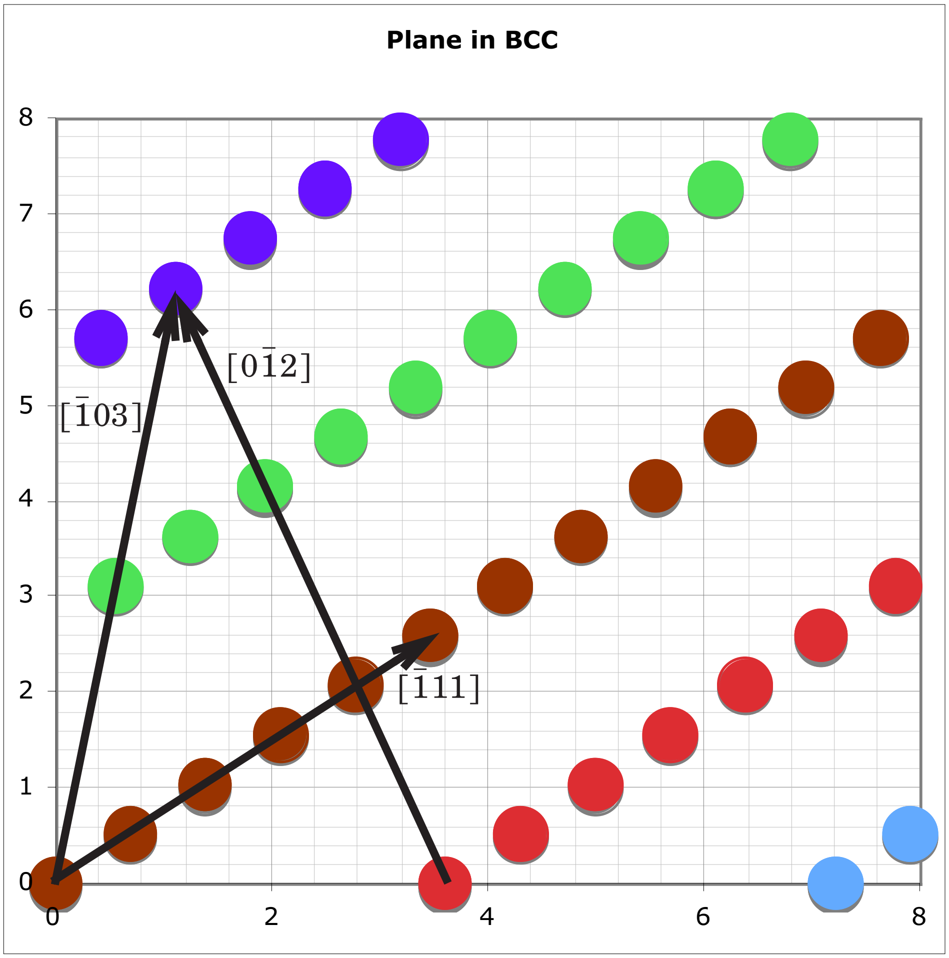


178. 0.5327 g of H_2O_2 ($M = 34.0147$) is added to 836.9 g of vinyl chloride ($M = 62.4985$). What are the number-averaged molecular weight and number averaged degree of polymerization of the resulting polymer?

179. A steady-state flux of $1.0\times10^{5}\,\mathrm{atom/m^2s}$ of copper pass through a 500 nm thick region in a piece of nickel (data in Table 6.2 on p.164 of *Callister*). The concentration of copper in the 500 nm region varies from $6.0\times10^{20}\,\mathrm{atom/m^3}$ to $2.0\times10^{20}\,\mathrm{atom/m^3}$. At what temperature is the piece of nickel?

180. The graph below shows the locations of atoms on a plane in a bcc structure. The x-axis is the $[\bar{2}30]$ direction. Three other directions in the plane are labeled on the graph. The scales on the axes are in units of the lattice constant, a . The *Review of Vectors and Dot Products* on the website may assist your calculations.
   a. Calculate the planar density on this plane for niobium.
   b. Determine the Miller indices for the plane. A sketch in a cubic unit cell may

help.



181. A sample of polymer has become separated from much of its manufacturing data. It is believed that the weight-averaged degree of polymerization is 407. The following molecular weight data were also reported for the sample:

Table 5: Molecular Weight Data

Molec. Wt. Minimum	Molec. Wt. Maximum	Molec. Wt. Average	Weight Fraction
10500	11600	11050	0.3045
11600	13800	12700	0.3000
13800	14900	14350	0.3955

From plant-processing data, the sample is either pure polyethylene or a 75:25 polyethylene-polypropylene copolymer.

a) Calculate the weight-averaged molecular weight.

b) Assuming the degree of polymerization is correct, calculate the number-averaged molecular weight.

c) Assuming part b is correct, calculate the number-averaged degree of polymerization.

d) Assuming the given data are correct, is it PE or a PE-PP blend?

182. A 2.50 mm cube has a compressive force of 6.25 N applied on the x-faces, a tensile force of 37.5 N applied on the y-faces, a force of 37.5 N applied in the positive z-direction on the front x-face, and a force of 6.25 N applied in the positive z-direction on the back y-face, as well as sufficient additional forces to keep the cube from accelerating or spinning. Determine the stress tensor (in MPa) for this cube.

183. In usage, 90-percent of production samples of a hot-pressed SiN part survive when exposed to a tensile stress of 76.1 ksi or less. The production samples have a volume of 5.125 in^3. The test samples had a volume of 0.300 in^3, and the Weibull modulus was 7.5. At what stress level did 36.79-percent of the test samples survive?

184. The yield strength of annealed 4340 steel is 68.5 ksi. What is the critical resolved shear stress in annealed 4340 in the $[120]$, if slip occurs in the $[111]$ on the $(21\bar{3})$?

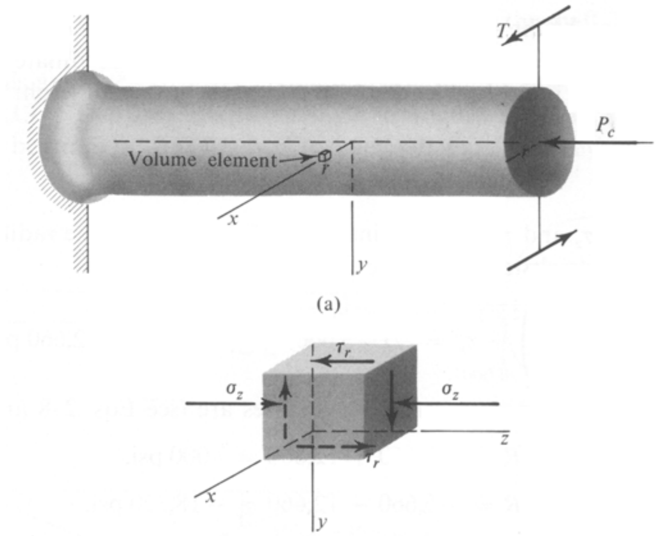
185. A spherical pressure vessel is subject to a periodic pressure of 2000 psi. The material has a yield strength of 255 ksi and the vessel has a radius of 20.0 in. To ensure leak-before-break conditions, what is the minimum required plane-strain fracture toughness for the material in $\mathrm{ksi}\sqrt{\mathrm{in}}$? What is the maximum wall thickness?

186. You have been asked to select the material for a thin-walled pressure vessel in an aircraft. Equation (9.15) on page 301 relates the hoop stress in a spherical pressure to the dimensions of the vessel. At this stage in the design, you have been asked to ignore flaws and cracks in the vessel and consider only when the vessel would fail by yielding.

a) Rank the four materials in Problem 13.D2 on page 577 from most to least desirable in this application.

b) What additional information would you need to include the possibility of fast fracture in your design calculations? Do not derive but simply describe.

187. A cantilever beam made of annealed Nickel 200 (properties in Appendix B) has



a length of 6.000 inches and a diameter of 1.000 inch. The beam is subject to a distributed compressive load, $P_c = F$, with F in lb_f, and a torque, $T = F \times 1.000\mathrm{in}$, again with F in lb_f. At what value of F will the beam begin to plastically deform?

188. Quantitatively describe the microstructure of a mixture of 1.45 weight% carbon in iron that is slowly cooled from $1600°\mathrm{C}$ to $800°\mathrm{C}$. The Fe-C phase diagram is on page 396 of *Callister.*

189. Quantitatively describe the microstructure of a sample of 4340 steel that is heated to above $727°\mathrm{C}$ for 100 hours, cooled rapidly to $650°\mathrm{C}$, held there for $3\times10^4\mathrm{s}$ and then rapidly cooled to room tempreature. The relevant IT diagram is on page 441 of *Callister.*

190. Calculate the conductivity of the wire in a wirewound resistor with a total length of 20 m, a diamter of 0.511 mm, and a resistance of 10.6Ω.

191. Silicon is doped with 20.0 ppm (by atomic fraction, not mass fraction) of indium. At $400°\mathrm{C}$ the material has a conductivity of $1140\ (\Omega\mathrm{m})^{-1}$. For reference the atomic weight of Si is 28.0855 g/g-atom, and the density is $2.33\ \mathrm{g/cm}^3$. What is the carrier mobility at this temperature and dopant level?

192. Do Problem 15.8 (a) on page 664 of *Callister.*

193. Electrolytic tough pitch copper (C11000) has a density of $8.89\ \mathrm{g/cm}^3$, a heat capacity of 385 J/kg K, and a thermal conductivity of 388 W/m K. A long copper

rod is insulated along its length. The rod is initially at a uniform temperature. At the start of an experiment the temperature at the front surface of the rod is heated to a constant $100°C$. After 44.05 seconds, the temperature 106 mm from the end of the rod registers $46.66°C$. What is the thermal diffusivity of the copper and what was the initial temperature of the rod?

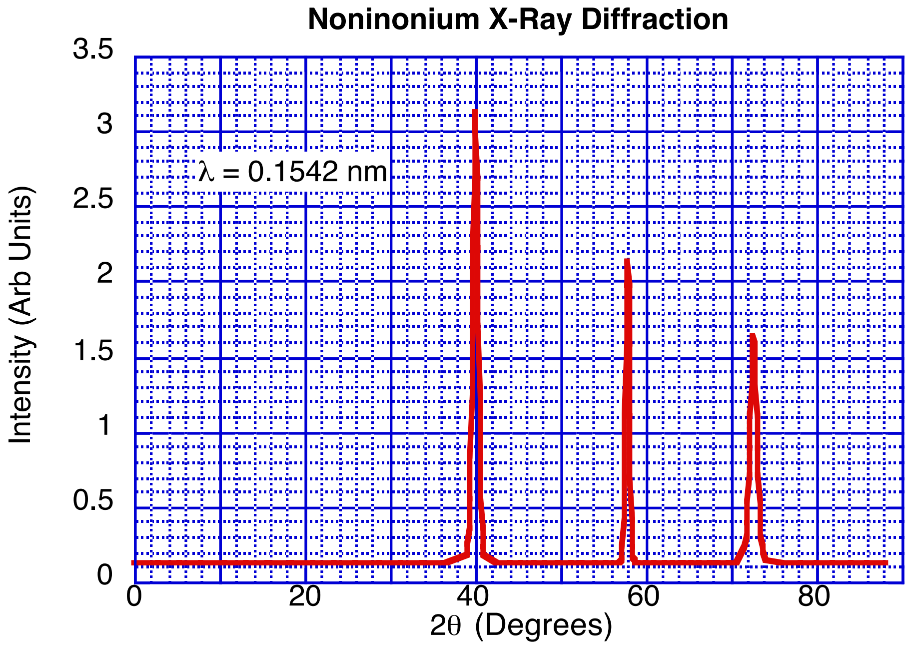
194. A carbon-fiber reinforced epoxy is desired with high-modulus fibers (data in Table 15.6 on page 650) Parallel cylindrical fibers (all of equal diameter) are to be laid in the longitudinal direction.
    a) What is the maximum volume fraction possible for the fibers? An answer of 1.00 or 100% will result in a score of 0 for this problem so don't be tempted.
    b) Assume that the actual volume fraction will be 80 percent of the maximum. Fill in as many values in the 3×3 compliance matrix as possible. Enter any unknowns as the appropriate variable names.
    c) Describe what experiments and measurements would have to be performed, and what calculations would have to be made in order to determine the values of the unknowns in the compliance matrix in part b.

195. Austrium and lunicon are fictitious Group IV elements used to dope III-V compound semiconductors. Data on III-V semiconductors is found on page 488 of *Callister*. Austrium always replaces the Group III element and lunicon always replaces the Group V element.
    a) Determine the dopant element (austrium or lunicon) and quantity (in parts per million, ppm) required to form a p-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\text{m})^{-1}$ from gallium phosphide, GaP.
    b) Determine the dopant element (austrium or lunicon) and quantity (in parts per million, ppm) required to form an n-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\text{m})^{-1}$ from indium antimonide, InSb. The ionic radii of indium and antimony are 0.092 nm and 0.090 nm respectively.

196. Thorium Oxide, ThO_2, packs in the CaF_2 structure. The density of ThO_2 is $10.00\ \text{g/cm}^3$. The atomic weights of Th and O are 232.0381 and 15.9994 respectively. The ionic radius of oxygen in ThO_2 is 0.123 nm. What is the ionic radius of thorium in ThO_2?

197. Noninonium is a metal that packs in one of the cubic array structures. The experimental x-ray diffraction data for noninonium in Cu_{K_α}-radiation is given below. Determine if noninonium is FCC or BCC and calculate the lattice con-

stant, a.



198. How many grams of H_2O_2 ($M = 34.0147$) were added to 10.00 kg of styrene ($M = 104.1515$) to create polystyrene with a number-averaged molecular weight of 208,340 g/mol? What is number-averaged degree of polymerization of the resulting polymer?

199. Kovar is 54 weight percent iron ($M = 55.8450$), 29 weight percent nickel ($M = 58.6934$), and 17 weight percent cobalt ($M = 58.9332$). What is the composition of Kovar in atomic percent?

200. Do Problem 3.69 on Page 90 of *Callister*.
   d. Calculate the planar density on the (001) plane for this hypothetical metal.
   e. Invent a properly punny name for this hypothetical metal.

201. *Callister* reports the density of copper at $20°C$ as $8.94\ \text{g/cm}^3$ on the inside front cover and the density at $1000°C$ as $8.40\ \text{g/cm}^3$ on page 125.
   a. What fraction of the change in density is due to the creation of vacancies?
   b. What is the cause of the remaining change in density? A simple plot with explanatory text may be sufficient.

202. Calculate the carburization time for a piece of 1020 (0.20 wt% C) steel at $1100°C$ where the diffusivity is $5.3\times10^{-11}\text{m}^2/\text{s}$. The surface concentration is held at 1.30 wt% C and the process is complete when the carbon concentration at a depth of 0.495 mm is 0.68 wt% C.

203. Ten percent of production samples of alumina survive to a stress level of 273 MPa. The test samples had a volume of 50 mm^3 and demonstrated a σ_0 of 360 MPa and a Weibull modulus of 8. What is the volume of the production samples?

204. The critical resolved shear stress in wargsten is 33.3 MPa. What is the yield strength in wargsten in the [111] if slip occurs in the $[1\bar{1}1]$ on the (121)?

205. A metal sample failed by fatigue after 5.0×10^7 cycles. The initial crack size was $10\ \mu m$ and the crack size at failure was 1.5 mm. The minimum in the cyclic stress was 20 MPa, and $A = 5.12\times10^{-12}$ and $m = 5$ with the stress in MPa and the crack length in meters. Y can be assumed to be 1.0.
   a. What was the maximum stress applied to the sample?
   b. What are the units of A?

206. Hydrogen is diffusing through a sample of somnamium at $700°C$. At this temperature the diffusivity of hydrogen in somnamium is $3.3\times10^{-8}\ m^2/s$. A new advanced analytical method instantaneously measures the concentration profile of hydrogen and finds that the concentration can be describes by the relationship
   $C_H = 3 - 0.01x - 0.001x^2$
   where C_H is in g/m^3 and x is the distance from the surface in μm. The equation is valid to a depth of $50\ \mu m$.
   a. Is the process steady state or transient? How do you know?
   b. What is the flux of hydrogen at a depth of $10\ \mu m$ from the surface?
   c. If the process is transient, determine how the accumulation rate of hydrogen, in $g/(m^3 s)$, varies from the surface to a depth of $50\ \mu m$.

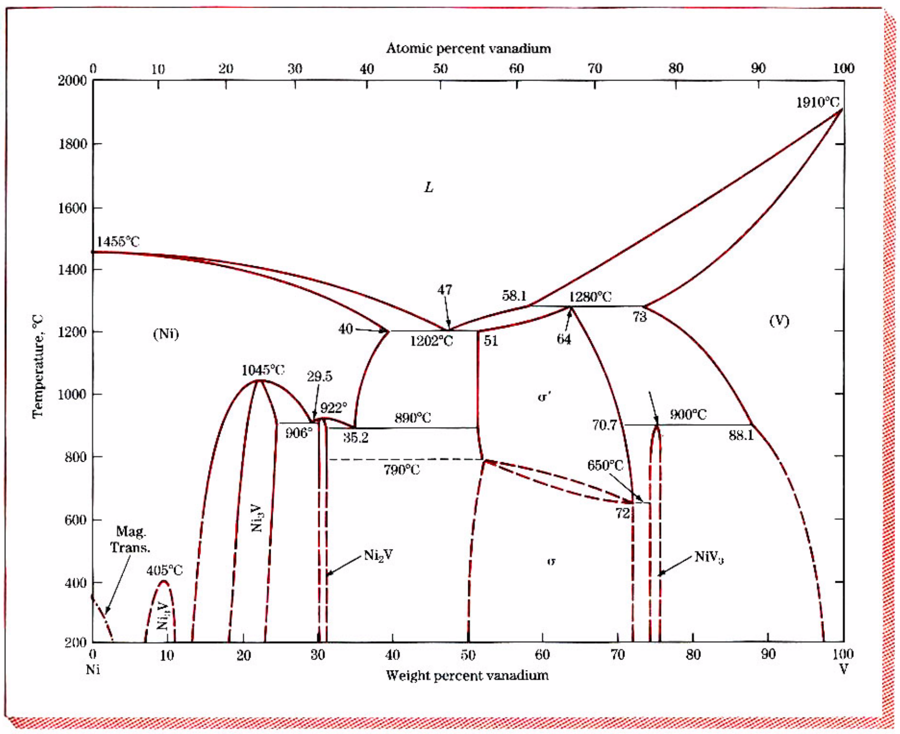
207. A Clinic team is testing thin wires for hydrogen embrittlement. In each test the wire under test must be loaded to 80 percent of its tensile strength. For a specific test they are using a 1 mil (0.001 inch) diameter wire of precipitation-hardened stainless alloy 17-7PH that is 36 inches long. The properties can be found in Appendix B of *Callister*.
   a. What weight must they suspend from the end of the wire to properly load it?
   b. What is the change in length of the wire when it is loaded?
   c. What is the change in cross-sectional area of the wire when it is loaded?
   d. Every wire has small nicks and cracks on the surface. What is the maximum allowable surface crack size on the wire? State any assumptions.
   e. Is fast fracture a concern?

208. A mixture of 70 weight percent vanadium and 30 weight percent nickel is cooled from $1800°C$ to $1279°C$. State what phases are present and their relative

amounts at $1279°C$.

209. A mixture of 22 weight percent vanadium and 78 weight percent nickel is cooled from $1800°C$ to $900°C$. State what microconstituents are present and their relative amounts at $900°C$.

FIGURE 8.34 Nickel-vanadium phase diagram. (*After Binary Phase Diagrams, ASM Int., 1986, p. 1773.*)



210. A sample of 1.13 wt% C plain carbon steel is fully austenitized at $900°C$. It is then cooled rapidly to $675°C$, held there for 2 seconds, and then cooled rapidly to room temperature. Determine what microconstituents are present and their rela-

tive amounts.

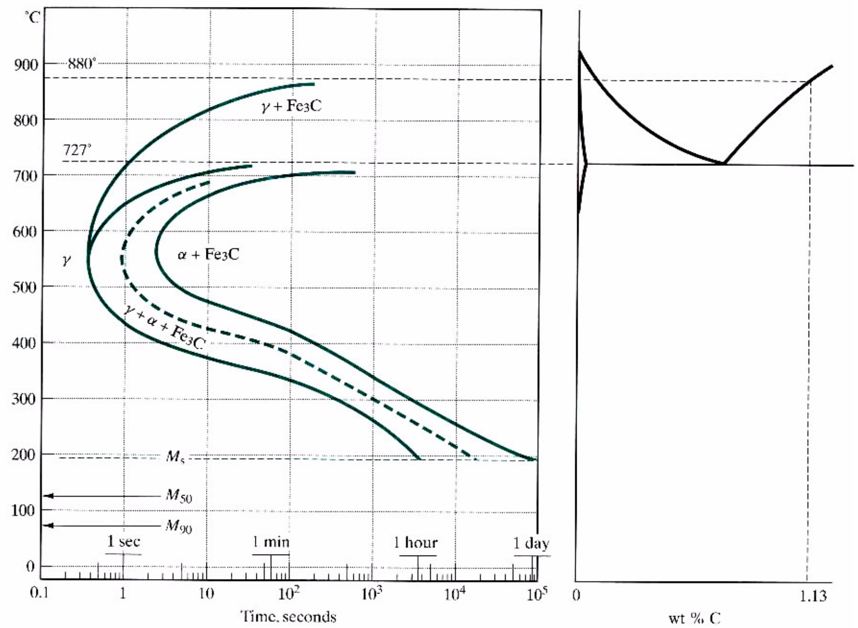


Figure 10-15 *TTT diagram for a hypereutectoid composition (1.13 wt % C) compared to the Fe–Fe$_3$C phase diagram. Microstructural development for the slow cooling of this alloy was shown in Figure 9–40. (TTT diagram after* Atlas of Isothermal Transformation and Cooling Transformation Diagrams, *American Society for Metals, Metals Park, Ohio, 1977.)*

211. A cylindrical rod in an aerospace application is to support a tensile load, F. The rod needs to be length, L, and elongate by no more than δ. Rank the four materials in Table 6 from best to worst for this application.

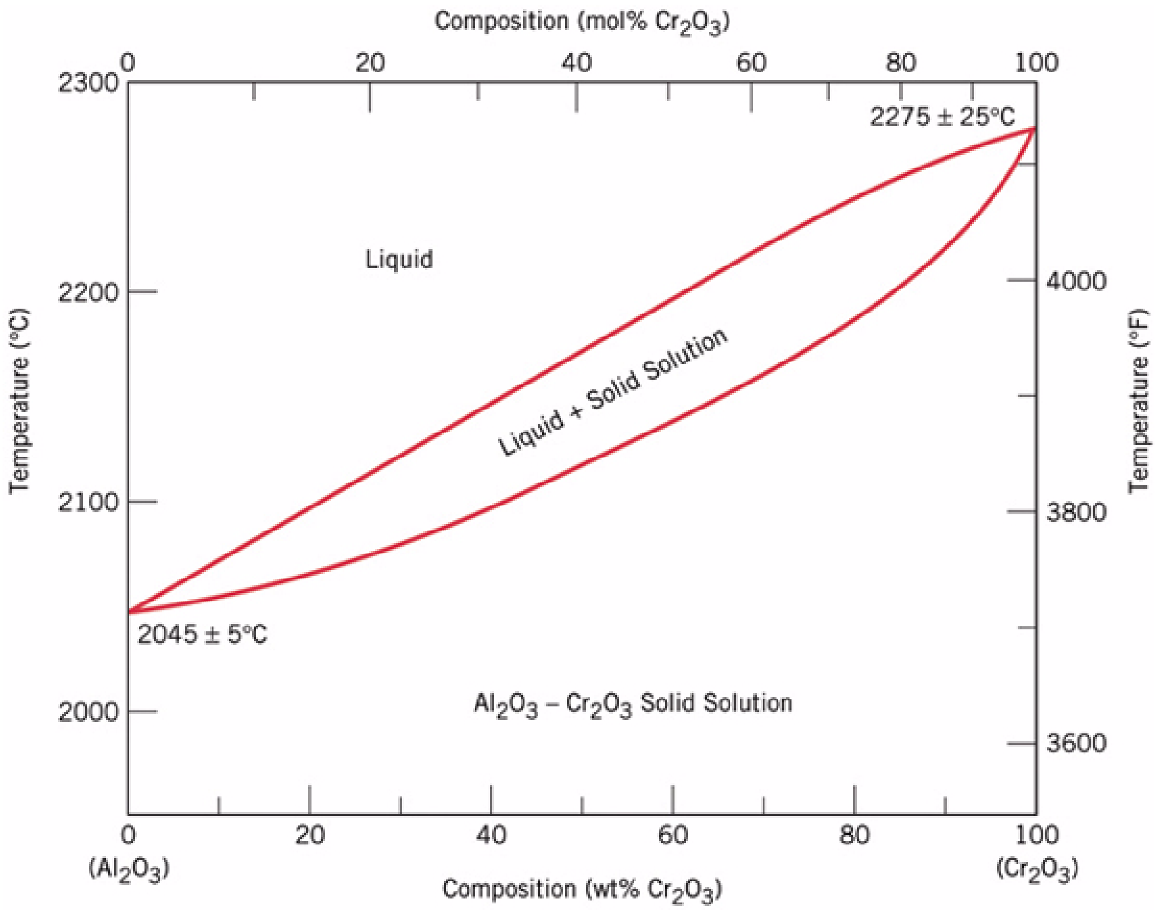
Table 6: Materials Properties

Material	Modulus of Elasticity (GPa)	Poisson's Ratio	Yield Strength (MPa)	Tensile Strength (MPa)	Density g/cm^3
Brass	100	0.35	415	420	8.5
Steel	207	0.27	860	550	7.9
Aluminum	70	0.33	310	420	2.7
Titanium	105	0.36	550	650	4.5

212. It is possible to separate a mixture of two substances by partial solidification. A mixture of 60 wt% Cr_2O_3 - 40 wt% Al_2O_3 is melted and then slowly cooled until it is 25% solid. The solid portion is extracted, remelted, and then slowly cooled until it is 25% solid.
a. What is the temperature at the end of the first partial solidification?
b. What are the compositions of the liquid and solid at the end of the first partial

solidification?

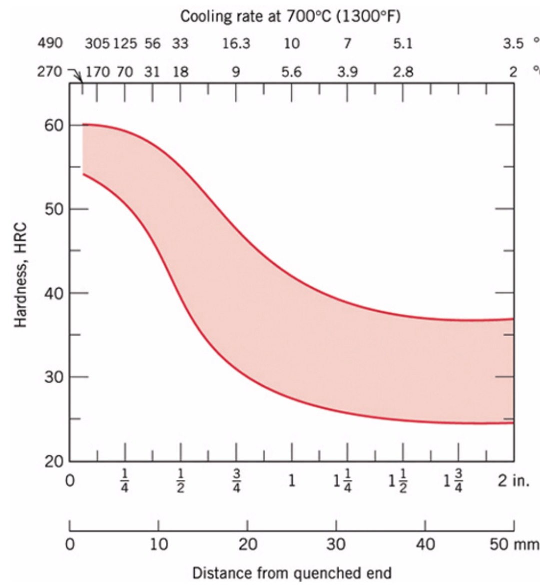
c. What is the temperature at the end of the second partial solidification?
d. What are the compositions of the liquid and solid at the end of the second partial solidification?
e. If you desire 45 kg of solid at the end of the second partial solidification, how much of the original material must you start with?

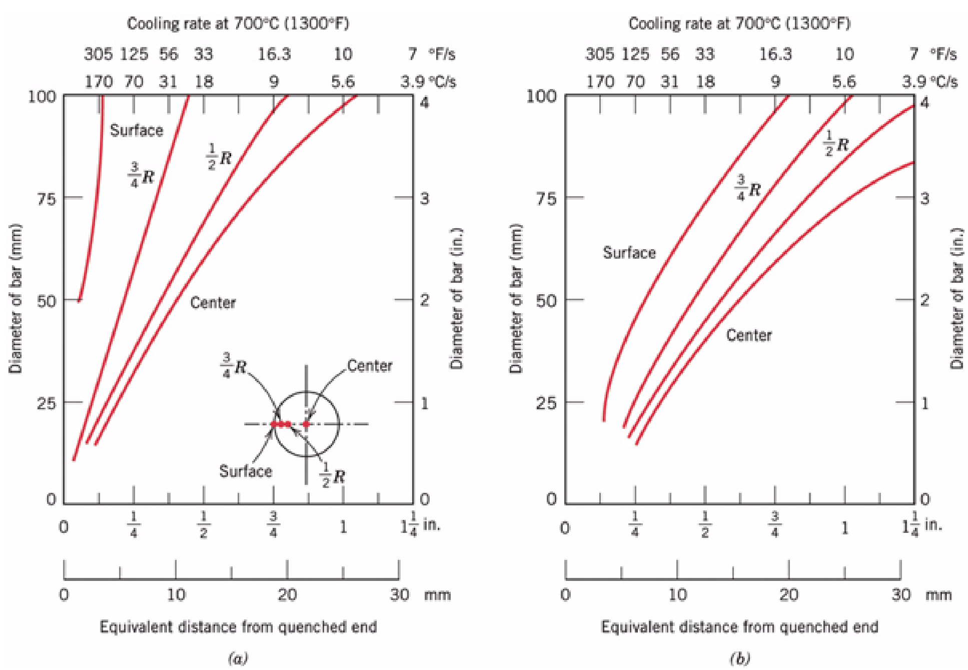


213. Hardenability curves show quite a spread unlike the single curves we've used in class. For a 3 inch diameter oil-quenched rod of 8640 steel:

a. Plot the hardness profile assuming that the hardness is at the bottom of the range.
b. Plot the hardness profile assuming that the hardness is at the top of the range.
c. What is the approximate tensile strength of the rod in part (a)?
d. What is the approximate tensile strength of the rod in part (b)?
e. Comment on the consequences of this analysis in designs using hardened steel

parts.





214. The energetics of the ionic bond in CaF_2 are adequately described by

$$E_N = -\frac{C}{r} + D\exp\left(-\frac{r}{\rho}\right),$$

where $D = 67.14$ eV, $\rho = 0.08704$ nm, the bond length is 0.233 nm, and E_N is in electron volts. What is the theoretical elastic modulus for CaF_2? Be sure to include units.

215. A 3/8-inch diameter piece of chalk with a failure strength of 29 psi (yes, psi) fails in a three-point bending test at a load of 0.200 lb. What is the length of the piece of chalk?

216. Germanium is doped with 0.612 ppm (by atomic fraction, not mass fraction) of indium. At 400 K the material has a conductivity of 3893 $(\Omega\text{m})^{-1}$. For reference the atomic weight of Ge is 72.6100 g/g-atom, and the density is 5.323 g/cm^3. What is the carrier mobility at this temperature and dopant level?

217. A flat-plate capacitor has a capacitance of $47\mu\text{F}$, a length of 7 m, a width of 2 m, and a plate separation of 0.010 mm. What is the dielectric constant of the dielectric in the capacitor?

218. Do Problem 15.12 (b) on page 664 of *Callister*. The volume fraction of fibers in the composite is 0.418.

219. A sample of a polymer with a linear coefficient of thermal expansion of $122\times10^{-6}(°\text{C})^{-1}$ is rigidly attached to two immovable walls and then heated from $25°\text{C}$ to $100°\text{C}$ where it experiences an compressive stress of 21.8 MPa. What is the elastic modulus of the polymer?

220. A carbon-fiber reinforced epoxy is desired with high-modulus fibers (data in Table 15.6 on page 650) Parallel cylindrical fibers (all of equal diameter) are to be laid in the longitudinal direction.
    a) What is the maximum volume fraction possible for the fibers? An answer of 1.00 or 100% will result in a score of 0 for this problem so don't be tempted.
    b) Assume that the actual volume fraction will be 80 percent of the maximum. Again, an answer that uses $V_f \approx 0.8$ will result in a score of 0 for the problem. Calculate the values of E_{cl} and E_{ct} for this composite.

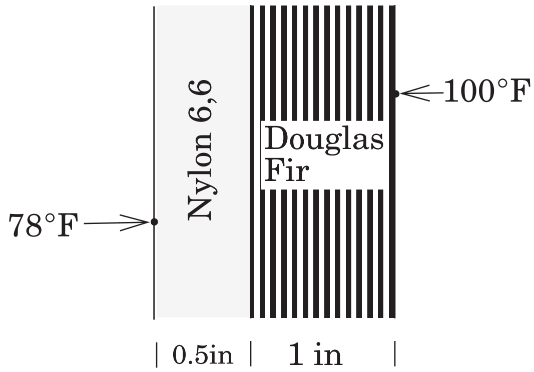
221. Austrium and lunicon are fictitious Group IV elements used to dope III-V compound semiconductors. Data on III-V semiconductors is found on page 488 of *Callister*. Austrium always replaces the Group III element and lunicon always replaces the Group V element. Determine the dopant element (austrium or lunicon) and quantity (in parts per million, ppm) required to form a p-type extrinsic semiconductor with a conductivity, $\sigma = 100\ (\Omega\text{m})^{-1}$ from gallium phosphide, GaP. The Ga-P bond distance is 0.236 nm.

222. The exterior wall of a rather unusual house consists of a 1/2-inch thick layer of nylon 6,6 on the inside and a 1-inch thick layer of Douglas fir on the outside. The grain of the wood runs vertically in the wall. The wall is 8 feet high and 12 feet wide. On a Summer day, the temperature in the room (and on the inside surface of the wall) is $78°\text{F}$ and the temperature outside (and on the outside surface of

the wall) is $100°F$.

a) Will a 7000 BTU/hr room air conditioner be sufficient to keep the room at $78°F$?

b) What is the temperature at the nylon-wood interface?



223. Describe quantitatively a process for creating an N-P-N bipolar transistor given the following conditions:

1) A Si wafer 250 μm thick uniformly doped with 0.000004 a/o antimony (Sb)
2) The ability to provide any desired surface concentration of antimony or boron.
3) An adjustable furnace
4) Desired junction depths of 12μm from the surface and 8 μm from the surface.
5) The total dopant concentration cannot exceed 0.000032 a/o at any location during the processing.

(Neglect metallization and masking)

Data: Sb in Si $D_0 = 5.6\times10^{-4} m^2/s$ $Q_d = 91$ kcal/mol

B in Si $D_0 = 10.5\times10^{-4} m^2/s$ $Q_d = 85$ kcal/mol