Exercises for Lecture 9.

The exercises are from Callister version 9 – attached below. For references to Tables and Equations please substitute 19.X by 18.X (for version 10) and 20.X by 19.X (for version 10).

Please consider 19.2, 19.5, 19.11, 19.21, 19.25, 19.29, 20.2, 20.4, 20.7, 20.13, 20.14, 20.26. For 19.29 I give you the values for μ_h and μ_e: 0.05 and 0.14 $m^2/(Vs)$, respectively.

From Callister version 9

UESTIONS AND PROBLEMS

hm's Law
ectrical Conductivity

19.1 **(a)** Compute the electrical conductivity of a 5.0-mm diameter cylindrical silicon specimen 50 mm long in which a current of 0.1 A passes in an axial direction. A voltage of 12.5 V is measured across two probes that are separated by 38 mm.

(b) Compute the resistance over the entire 50 mm of the specimen.

19.2 A copper wire 100 m long must experience a voltage drop of less than 1.5 V when a current of 2.5 A passes through it. Using the data in Table 19.1, compute the minimum diameter of the wire.

19.3 An aluminum wire 5 mm in diameter is to offer a resistance of no more than 2.5 Ω. Using the data in Table 19.1, compute the maximum wire length.

19.4 Demonstrate that the two Ohm's law expressions, Equations 19.1 and 19.5, are equivalent.

19.5 **(a)** Using the data in Table 19.1, compute the resistance of a copper wire 5 mm in diameter and 2 m long. **(b)** What would be the current flow if the potential drop across the ends of the wire is 0.05 V? **(c)** What is the current density? **(d)** What is the magnitude of the electric field across the ends of the wire?

Electronic and Ionic Conduction

19.6 What is the distinction between electronic and ionic conduction?

Energy Band Structures in Solids

19.7 How does the electron structure of an isolated atom differ from that of a solid material?

Conduction in Terms of Band and Atomic Bonding Models

19.8 In terms of electron energy band structure, discuss reasons for the difference in electrical conductivity between metals, semiconductors, and insulators.

Electron Mobility

19.9 Briefly tell what is meant by the drift velocity and mobility of a free electron.

19.10 **(a)** Calculate the drift velocity of electrons in germanium at room temperature and when the magnitude of the electric field is 1000 V/m. **(b)** Under these circumstances, how long does it take an electron to traverse a 25-mm length of crystal?

19.11 At room temperature the electrical conductivity and the electron mobility for copper are $6.0 \times 10^7\ (\Omega \cdot m)^{-1}$ and $0.0030\ m^2/V \cdot s$, respectively. **(a)** Compute the number of free electrons per cubic meter for copper at room temperature. **(b)** What is the number of free electrons per copper atom? Assume a density of $8.9\ g/cm^3$.

19.12 **(a)** Calculate the number of free electrons per cubic meter for gold, assuming that there are 1.5 free electrons per gold atom. The electrical conductivity and density for Au are $4.3 \times 10^7\ (\Omega \cdot m)^{-1}$ and $19.32\ g/cm^3$, respectively. **(b)** Now compute the electron mobility for Au.

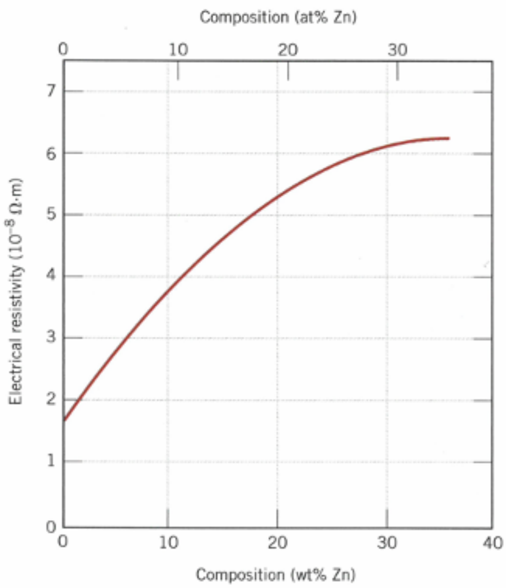

Figure 19.38 Room-temperature electrical resistivity versus composition for copper–zinc alloys. [Adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals,* Vol. 2, 9th edition, H. Baker (Managing Editor), 1979. Reproduced by permission of ASM International, Materials Park, OH.]

Electrical Resistivity of Metals

19.13 From Figure 19.38, estimate the value of A in Equation 19.11 for zinc as an impurity in copper–zinc alloys.

19.14 **(a)** Using the data in Figure 19.8, determine the values of ρ_0 and a from Equation 19.10 for pure copper. Take the temperature T to be in degrees Celsius. **(b)** Determine the value of A in Equation 19.11 for nickel as an impurity in copper, using the data in Figure 19.8. **(c)** Using the results of parts (a) and (b), estimate the electrical resistivity of copper containing 1.75 at% Ni at 100°C.

19.15 Determine the electrical conductivity of a Cu–Ni alloy that has a yield strength of 130 MPa. You will find Figure 9.16 helpful.

19.16 Tin bronze has a composition of 96 wt% Cu and 5 wt% Sn, and consists of two phases at room temperature: an α phase, which is copper containing a very small amount of tin in solid solution, and an ε phase, which consists of approximately 37 wt% Sn. Compute the room temperature conductivity of this alloy given the following data:

Phase	*Electrical Resistivity* ($\Omega \cdot m$)	*Density* (g/cm^3)
α	1.88×10^{-8}	8.94
ε	5.32×10^{-7}	8.25

19.17 A cylindrical metal wire 5 mm in diameter is required to carry a current of 12 A with a minimum of 0.03 V drop per 300 mm of wire. Which of the metals and alloys listed in Table 19.1 are possible candidates?

Intrinsic Semiconduction

19.18 **(a)** Using the data presented in Figure 19.16, determine the number of free electrons per atom for intrinsic germanium and silicon at room temperature (298 K). The densities for Ge and Si are 5.32 and $2.33\ g/cm^3$, respectively.

(b) Now explain the difference in these free-electron-per-atom values.

19.19 For intrinsic semiconductors, the intrinsic carrier concentration n_i depends on temperature as follows:

$$n_i \propto \exp\left(-\frac{E_g}{2kT}\right) \qquad (19.35a)$$

or, taking natural logarithms,

$$\ln n_i \propto -\frac{E_g}{2kT} \qquad (19.35b)$$

'hus, a plot of ln n_i versus $1/T$ $(K)^{-1}$ should e linear and yield a slope of $-E_g/2k$. Using iis information and the data presented in 'igure 19.16, determine the band gap energies or silicon and germanium, and compare these alues with those given in Table 19.3.

3riefly explain the presence of the factor in the denominator of Equation 19.35a.

19.21

At room temperature the electrical conductivity of PbTe is 650 $(\Omega \cdot m)^{-1}$, whereas the lectron and hole mobilities are 0.16 and .080 $m^2/V \cdot s$, respectively. Compute the intrinsic carrier concentration for PbTe at room emperature.

0.080 m²/Vs

s it possible for compound semiconductors o exhibit intrinsic behavior? Explain your nswer.

'or each of the following pairs of semiconuctors, decide which will have the smaller and gap energy, E_g, and then cite the reaon for your choice. **(a)** ZnS and CdSe, **b)** Si and C (diamond), **(c)** Al_2O_3 and ZnTe, **d)** InSb and ZnSe, and **(e)** GaAs and AlP.

c Semiconduction

)efine the following terms as they pertain to emiconducting materials: intrinsic, extrinsic, ompound, elemental. Now provide an examle of each.

19.25

An n-type semiconductor is known to have an lectron concentration of 3×10^{18} m^{-3}. If the lectron drift velocity is 100 m/s in an electric ield of 600 V/m, calculate the conductivity of his material.

a) In your own words, explain how donor npurities in semiconductors give rise to free lectrons in numbers in excess of those generted by valence band–conduction band excitaions. **(b)** Also explain how acceptor impurities ive rise to holes in numbers in excess of those enerated by valence band–conduction band xcitations.

a) Explain why no hole is generated by the lectron excitation involving a donor impurity tom. **(b)** Explain why no free electron is genrated by the electron excitation involving an cceptor impurity atom.

Vill each of the following elements act as a doior or an acceptor when added to the indicated emiconducting material? Assume that the mpurity elements are substitutional.

Impurity	*Semiconductor*
P	Ge
S	AlP
In	CdTe
Al	Si
Cd	GaAs
Sb	ZnSe

19.29 **(a)** The room-temperature electrical conductivity of a silicon specimen is 5.93×10^{-3} $(\Omega \cdot m)^{-1}$. The hole concentration is known to be 7.0×10^{17} m^{-3}. Using the electron and hole mobilities for silicon in Table 19.3, compute the electron concentration. **(b)** On the basis of the result in part (a), is the specimen intrinsic, n-type extrinsic, or p-type extrinsic? Why?

19.30 Germanium to which 5×10^{22} m^{-3} Sb atoms have been added is an extrinsic semiconductor at room temperature, and virtually all the Sb atoms may be thought of as being ionized (i.e., one charge carrier exists for each Sb atom). **(a)** Is this material n-type or p-type? **(b)** Calculate the electrical conductivity of this material, assuming electron and hole mobilities of 0.2 and 0.1 $m^2/V \cdot s$, respectively.

19.31 The following electrical characteristics have been determined for both intrinsic and p-type extrinsic indium phosphide (InP) at room temperature:

	σ $(\Omega \cdot m)^{-1}$	n (m^{-3})	p (m^{-3})
Intrinsic	2.5×10^{-6}	3.0×10^{13}	3.0×10^{13}
Extrinsic (n-type)	3.6×10^{-5}	4.5×10^{14}	2.0×10^{12}

Calculate electron and hole mobilities.

The Temperature Dependence of Carrier Concentration

19.32 Calculate the conductivity of intrinsic silicon at 100°C.

19.33 At temperatures near room temperature, the temperature dependence of the conductivity for intrinsic germanium is found to equal

$$\sigma = CT^{-3/2} \exp\left(-\frac{E_g}{2kT}\right) \qquad (19.36)$$

where C is a temperature-independent constant and T is in Kelvins. Using Equation 19.36, calculate the intrinsic electrical conductivity of germanium at 150°C.

19.34 Using Equation 19.36 and the results of Problem 19.33, determine the temperature at which the electrical conductivity of intrinsic germanium is 22.8 $(\Omega \cdot m)^{-1}$.

19.35 Estimate the temperature at which GaAs has an electrical conductivity of 3.7×10^{-3} $(\Omega \cdot m)^{-1}$, assuming the temperature dependence for σ of Equation 19.36. The data shown in Table 19.3 may prove helpful.

19.36 Compare the temperature dependence of the conductivity for metals and intrinsic semiconductors. Briefly explain the difference in behavior.

Factors That Affect Carrier Mobility

19.37 Calculate the room-temperature electrical conductivity of silicon that has been doped with 5×10^{22} m^{-3} of boron atoms.

19.38 Calculate the room-temperature electrical conductivity of silicon that has been doped with 2×10^{23} m^{-3} of arsenic atoms.

19.39 Estimate the electrical conductivity, at 130°C, of silicon that has been doped with 10^{23} m^{-3} of aluminum atoms.

19.40 Estimate the electrical conductivity, at 85°C, of silicon that has been doped with 10^{20} m^{-3} of phosphorus atoms.

The Hall Effect

19.41 A hypothetical metal is known to have an electrical resistivity of 4×10^{-8} $(\Omega \cdot m)$. A current of 40 A is passed through a specimen of this metal that is 30 mm thick; when a magnetic field of 0.75 tesla is simultaneously imposed in a direction perpendicular to that of the current, a Hall voltage of -1.26×10^{-7} V is measured. Compute **(a)** the electron mobility for this metal and **(b)** the number of free electrons per cubic meter.

19.42 A metal alloy is known to have electrical conductivity and electron mobility values of 2.0×10^{7} $(\Omega \cdot m)^{-1}$ and 0.0025 $m^2/V \cdot s$, respectively. A current of 45 A is passed through a specimen of this alloy that is 40 mm thick. What magnetic field would need to be imposed to yield a Hall voltage of -1.0×10^{-7} V?

Semiconducting Devices

19.43 Briefly describe electron and hole motions in a *p–n* junction for forward and reverse biases; then explain how these lead to rectification.

19.44 How is the energy in the reaction described by Equation 19.21 dissipated?

19.45 What are the two functions that a transistor may perform in an electronic circuit?

19.46 Cite the differences in operation and application for junction transistors and MOSFETs.

Conduction in Ionic Materials

19.47 We noted in Section 6.4 (Figure 6.4) that in FeO (wüstite), the iron ions can exist in both Fe^{2+} and Fe^{3+} states. The number of each of these ion types depends on temperature and the ambient oxygen pressure. Furthermore, we also noted that in order to retain electroneutrality, one Fe^{2+} vacancy will be created for every two Fe^{3+} ions that are formed; consequently, in order to reflect the existence of these vacancies the formula for wüstite is often represented as $Fe_{(1-x)}O$, where x is some small fraction less than unity.

In this nonstoichiometric $Fe_{(1-x)}O$ material, conduction is electronic, and, in fact, behaves as a *p*-type semiconductor. That is, the Fe^{3+} ions act as electron acceptors, and it is relatively easy to excite an electron from the valence band into an Fe^{3+} acceptor state, with the formation of a hole. Determine the electrical conductivity of a specimen of wüstite that has a hole mobility of 1.0×10^{-5} $m^2/V \cdot s$ and for which the value of x is 0.060. Assume that the acceptor states are saturated (i.e., one hole exists for every Fe^{3+} ion). Wüstite has the sodium chloride crystal structure with a unit cell edge length of 0.437 nm.

19.48 At temperatures between 775°C (1048 K) and 1100°C (1373 K), the activation energy and preexponential for the diffusion coefficient of Fe^{2+} in FeO are 102,000 J/mol and 7.3×10^{-8} m^2/s, respectively. Compute the mobility for an Fe^{2+} ion at 1000°C (1273 K).

Capacitance

19.49 A parallel-plate capacitor using a dielectric material having an ε_r of 2.5 has a plate spacing of 1 mm. If another material having a dielectric constant of 4.0 is used and the capacitance is to be unchanged, what must be the new spacing between the plates?

19.50 A parallel-plate capacitor with dimensions of 120 mm by 30 mm and a plate separation of 3 mm must have a minimum capacitance of 38 pF (3.8×10^{-11} F) when an ac potential of 500 V is applied at a frequency of 1 MHz. Which of the materials listed in Table 19.5 are possible candidates? Why?

19.51 Consider a parallel-plate capacitor having an area of 2800 mm^2 and a plate separation of 4 mm, and with a material of dielectric constant 4.0 positioned between the plates. **(a)** What is the capacitance of this capacitor? **(b)** Compute the electric field that must be applied for 8.0×10^{-9} C to be stored on each plate.

19.52 In your own words, explain the mechanism by which charge-storing capacity is increased by the insertion of a dielectric material within the plates of a capacitor.

Field Vectors and Polarization
Types of Polarization

19.53 For NaCl, the ionic radii for Na^+ and Cl^- ions are 0.102 and 0.181 nm, respectively. If an externally applied electric field produces a 5% expansion of the lattice, compute the dipole moment for each Na^+–Cl^- pair. Assume that this material is completely unpolarized in the absence of an electric field.

19.54 The polarization P of a dielectric material positioned within a parallel-plate capacitor is to be 1.0×10^{-6} C/m^2.

(a) What must be the dielectric constant if an electric field of 5×10^4 V/m is applied?

(b) What will be the dielectric displacement D?

19.55 A charge of 4.0×10^{-11} C is to be stored on each plate of a parallel-plate capacitor having an area of 160 mm^2 and a plate separation of 3.5 mm.

(a) What voltage is required if a material having a dielectric constant of 5.0 is positioned within the plates?

(b) What voltage would be required if a vacuum were used?

(c) What are the capacitances for parts (a) and (b)?

(d) Compute the dielectric displacement for part (a).

(e) Compute the polarization for part (a).

19.56 **(a)** For each of the three types of polarization, briefly describe the mechanism by which dipoles are induced and/or oriented by the action of an applied electric field. **(b)** For solid lead titanate ($PbTiO_3$), gaseous neon, diamond, solid KCl, and liquid NH_3, what kind(s) of polarization is (are) possible? Why?

19.57 **(a)** Compute the magnitude of the dipole moment associated with each unit cell of $BaTiO_3$, as illustrated in Figure 19.35.

(b) Compute the maximum polarization that is possible for this material.

Frequency Dependence of the Dielectric Constant

19.58 The dielectric constant for a soda–lime glass measured at very high frequencies (on the order of 10^{15} Hz) is approximately 2.3. What fraction of the dielectric constant at relatively low frequencies (1 MHz) is attributed to ionic polarization? Neglect any orientation polarization contributions.

Ferroelectricity

19.59 Briefly explain why the ferroelectric behavior of $BaTiO_3$ ceases above its ferroelectric Curie temperature.

DESIGN PROBLEMS

Electrical Resistivity of Metals

19.D1 A 95 wt% Pt–5 wt% Ni alloy is known to have an electrical resistivity of 2.5×10^{-7} $\Omega \cdot$m at room temperature (25°C). Calculate the composition of a platinum–nickel alloy that gives a room-temperature resistivity of 2.00×10^{-7} $\Omega \cdot$m. The room-temperature resistivity of pure platinum may be determined from the data in Table 19.1; assume that platinum and nickel form a solid solution.

19.D2 Using information contained in Figures 19.8 and 19.38, determine the electrical conductivity of an 80 wt% Cu–20 wt% Zn alloy at −150°C (123 K).

19.D3 Is it possible to alloy copper with nickel to achieve a minimum tensile strength of 350 MPa and yet maintain an electrical conductivity of 2.5×10^6 $(\Omega \cdot m)^{-1}$? If not, why? If so, what concentration of nickel is required? You may want to consult Figure 9.16*a*.

Extrinsic Semiconduction
Factors That Affect Carrier Mobility

19.D4 Specify an acceptor impurity type and concentration (in weight percent) that will produce a *p*-type silicon material having a room temperature electrical conductivity of 50 $(\Omega \cdot m)^{-1}$.

19.D5 One integrated circuit design calls for diffusing boron into very high-purity silicon at an elevated temperature. It is necessary that at a distance 0.2 μm from the surface of the silicon wafer, the room-temperature electrical

)UESTIONS AND PROBLEMS

eat Capacity

).1 Estimate the energy required to raise the temperature of 2 kg of the following materials from 20 to 100°C (293 to 373 K): aluminum, steel, soda–lime glass, and high-density polyethylene.

).2 To what temperature would 11 kg of a 1025 steel specimen at 25°C (298 K) be raised if 130 KJ of heat is supplied?

).3 **(a)** Determine the room temperature heat capacities at constant pressure for the following materials: aluminum, silver, tungsten, and 70Cu–30Zn brass. **(b)** How do these values compare with one another? How do you explain this?

).4 For aluminum, the heat capacity at constant volume C_v at 30 K is 0.81 J/mol·K, and the Debye temperature is 375 K. Estimate the specific heat **(a)** at 50 K and **(b)** at 425 K.

).5 The constant A in Equation 20.2 is $12\pi^4 R/5\theta_D^3$, where R is the gas constant and θ_D is the Debye temperature (K). Estimate θ_D for copper, given that the specific heat is 0.78 J/kg·K at 10 K.

).6 **(a)** Briefly explain why C_v rises with increasing temperature at temperatures near 0 K. **(b)** Briefly explain why C_v becomes virtually independent of temperature at temperatures far removed from 0 K.

Thermal Expansion

20.7 An aluminum wire 10 m long is cooled from 38 to −1°C (311 to 272 K). How much change in length will it experience?

20.8 A 0.1 m rod of a metal elongates 0.2 mm on heating from 20 to 100°C (293 to 373 K). Determine the value of the linear coefficient of thermal expansion for this material.

20.9 Briefly explain thermal expansion using the potential-energy-versus-interatomic-spacing curve.

20.10 Compute the density for nickel at 500°C, given that its room-temperature density is 8.902 g/cm^3. Assume that the volume coefficient of thermal expansion, α_v, is equal to $3\alpha_l$.

20.11 When a metal is heated its density decreases. There are two sources that give rise to this diminishment of ρ: (1) the thermal expansion of the solid and (2) the formation of vacancies (Section 6.2). Consider a specimen of copper at room temperature (20°C) that has a density of 8.940 g/cm^3. **(a)** Determine its density upon heating to 1000°C when only thermal expansion is considered. **(b)** Repeat the calculation when the introduction of vacancies is taken into account. Assume that the energy of vacancy formation is 0.90 eV/atom, and that the volume coefficient of thermal expansion, α_v, is equal to $3\alpha_l$.

20.12 The difference between the specific heats at constant pressure and volume is described by the expression

$$c_p - c_v = \frac{\alpha_v^2 v_0 T}{\beta} \quad (20.10)$$

where α_v, is the volume coefficient of thermal expansion, v_0 is the specific volume (i.e., volume per unit mass, or the reciprocal of density), β is the compressibility, and T is the absolute temperature. Compute the values of c_v at room temperature (293 K) for copper and nickel using the data in Table 20.1, assuming that $\alpha_v = 3\alpha_l$ and given that the values of β for Cu and Ni are 8.35×10^{-12} and 5.51×10^{-12} $(\text{Pa})^{-1}$, respectively.

20.13 To what temperature must a cylindrical rod of tungsten 10.000 mm in diameter and a plate of 316 stainless steel having a circular hole 9.988 mm in diameter have to be heated for the rod to just fit into the hole? Assume that the initial temperature is 25°C.

Thermal Conductivity

20.14 **(a)** Calculate the heat flux through a sheet of steel 10 mm thick if the temperatures at the two faces are 300 and 100°C (573 and 373 K); assume steady-state heat flow. **(b)** What is the heat loss per hour if the area of the sheet is 0.25 m^2? **(c)** What will be the heat loss per hour if soda–lime glass instead of steel is used? **(d)** Calculate the heat loss per hour if steel is used and the thickness is increased to 20 mm.

20.15 **(a)** Would you expect Equation 20.7 to be valid for ceramic and polymeric materials? Why or why not? **(b)** Estimate the value for the Wiedemann–Franz constant L [in $\Omega\cdot\text{W}/(\text{K})^2$] at room temperature (293 K) for the following nonmetals: silicon (intrinsic), glass-ceramic (Pyroceram), fused silica, polycarbonate, and polytetrafluoroethylene. Consult Tables B.7 and B.9 in Appendix B.

20.16 Briefly explain why the thermal conductivities are higher for crystalline than noncrystalline ceramics.

20.17 Briefly explain why metals are typically better thermal conductors than ceramic materials.

20.18 **(a)** Briefly explain why porosity decreases the thermal conductivity of ceramic and polymeric materials, rendering them more thermally insulative. **(b)** Briefly explain how the degree of crystallinity affects the thermal conductivity of polymeric materials and why.

20.19 For some ceramic materials, why does the thermal conductivity first decrease and then increase with rising temperature?

20.20 For each of the following pairs of materials, decide which has the larger thermal conductivity. Justify your choices.

(a) Pure copper; aluminum bronze (95 wt% Cu–5 wt% Al)

(b) Fused silica; quartz

(c) Linear polyethylene; branched polyethylene

(d) Random poly(styrene-butadiene) copolymer; alternating poly(styrene-butadiene) copolymer

20.21 We might think of a porous material as being a composite wherein one of the phases is a pore phase. Estimate upper and lower limits for the room-temperature thermal conductivity of a magnesium oxide material having a volume fraction of 0.30 of pores that are filled with still air.

20.22 Nonsteady-state heat flow may be described by the following partial differential equation:

$$\frac{\partial T}{\partial t} = D_T \frac{\partial^2 T}{\partial x^2}$$

where D_T is the thermal diffusivity; this expression is the thermal equivalent of Fick's second law of diffusion (Equation 7.4b). The thermal diffusivity is defined according to

$$D_T = \frac{k}{\rho c_p}$$

In this expression, k, ρ, and c_p represent the thermal conductivity, the mass density, and the specific heat at constant pressure, respectively.

(a) What are the SI units for D_T?

(b) Determine values of D_T for aluminum, steel, aluminum oxide, soda–lime glass, polystyrene, and nylon 6,6 using the data in Table 20.1. Density values are included in Table B.1, Appendix B.

Thermal Stresses

20.23 Beginning with Equation 20.3, show that Equation 20.8 is valid.

20.24 **(a)** Briefly explain why thermal stresses may be introduced into a structure by rapid heating or cooling. **(b)** For cooling, what is the nature of the surface stresses? **(c)** For heating, what is the nature of the surface stresses?

5 **(a)** If a rod of 1025 steel 0.5 m long is heated from 20 to 80°C (293 to 353 K) while its ends are maintained rigid, determine the type and magnitude of stress that develops. Assume that at 20°C the rod is stress free. **(b)** What will be the stress magnitude if a rod 1 m long is used? **(c)** If the rod in part (a) is cooled from 20 to −10°C (293 to 263 K), what type and magnitude of stress will result?

6 A copper wire is stretched with a stress of 70 MPa at 20°C (293 K). If the length is held constant, to what temperature must the wire be heated to reduce the stress to 35 MPa?

20.27 If a cylindrical rod of nickel 100.00 mm long and 8.000 mm in diameter is heated from 20°C to 200°C while its ends are maintained rigid, determine its change in diameter. You may want to consult Table 8.1.

20.28 The two ends of a cylindrical rod of 1025 steel 75.00 mm long and 10.000 mm in diameter are maintained rigid. If the rod is initially at 25°C, to what temperature must it be cooled to have a 0.008-mm reduction in diameter?

20.29 What measures may be taken to reduce the likelihood of thermal shock of a ceramic piece?

SIGN PROBLEMS

mal Expansion

1 Railroad tracks made of 1025 steel are to be laid during the time of year when the temperature averages 10°C (283 K). If a joint space of 4.6 mm is allowed between the standard 11.9-m- long rails, what is the hottest possible temperature that can be tolerated without the introduction of thermal stresses?

mal Stresses

2 The ends of a cylindrical rod 6.4 mm in diameter and 250 mm long are mounted between rigid supports. The rod is stress free at room temperature [20°C (293 K)]; upon cooling to −40°C (233 K), a maximum thermally induced tensile stress of 125 MPa is possible. Of which of the following metals or alloys may the rod be fabricated: aluminum, copper, brass, 1025 steel, and tungsten? Why?

3 **(a)** What are the units for the thermal shock resistance parameter (*TSR*)? **(b)** Rank the following ceramic materials according to their thermal shock resistance: glass-ceramic (Pyroceram), partially stabilized zirconia, and borosilicate (Pyrex) glass. Appropriate data may be found in Tables B.2, B.4, B.6, and B.7 of Appendix B.

20.D4 Equation 20.9, for the thermal shock resistance of a material, is valid for relatively low rates of heat transfer. When the rate is high, then, upon cooling of a body, the maximum temperature change allowable without thermal shock, ΔT_f, is approximately

$$\Delta T_f \cong \frac{\sigma_f}{E\alpha_l}$$

where σ_f is the fracture strength. Using the data in Tables B.2, B.4, and B.6 (Appendix B), determine ΔT_f for a glass-ceramic (Pyroceram), partially stabilized zirconia, and fused silica.