1. (a) Young's modulus for steel is $20.8 \times 10^{10}$ N/m$^2$. A 2.5 mm diameter steel wire, 12 cm long, carries a load of 450 N, determine the strain at this condition.
   (b) What will be the diameter of an aluminum wire being 12 cm long carrying the same load and strained the same amount as previously? ($E = 7.0 \times 10^{10}$ N/m$^2$ for Al.)

2. Calculate the value of Poisson's ratio for the condition of constant volume. When does this condition occur?

3. Explain why a second hardness measurement made adjacent to a previous measurement indicates a higher hardness.

4. Calculate the volume change for a material which transforms from a simple cubic structure to a hexagonal close-packed structure. Assume the atoms behave as hard spheres.

5. BaO has the NaCl crystal structure with a lattice parameter of 5.50 Å. Calculate the number of atoms per unit cell and density of BaO.

6. (a) Calculate the acute angle between the [100] and [111] directions in a cubic crystal.
   (b) Again calculate the acute angle between the [100] and [110] directions.

   $$\frac{1}{d_{hkl}^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

7. The interplanar spacing, $d_{hkl}$, of (hkl) planes for a crystal having orthogonal axes is given by:
   where $a, b, c$ are the lattice parameters.
   (a) What does this equation reduce to for a cubic crystal?
   (b) Calculate the spacing between close-packed planes in terms of the lattice parameter for an FCC metal. How does this compare with the nearest neighbour interatomic spacing?

8. Gold has an FCC crystal structure with a lattice parameter of 4.07 Å. Calculate the Bragg angle $\theta$ for the (112) diffraction peak for X rays with a wavelength of 1.0 Å and for electrons with an energy of 100,000 eV.

9. (a) For a metal with FCC and BCC allotropes, compute the atomic radius for the BCC form in terms of the atomic radius for the FCC form. Assume atomic volume remains constant.
   (b) Pure iron transforms from BCC to FCC at 912°C with a 1.06% decrease in volume. In terms of the FCC atomic radius, what is the BCC atomic radius?
   (c) Pure Ti transforms from HCP to BCC at 833°C with a 0.55% decrease in volume. Does the atomic radius increase or decrease?
10. An engineer claims to have observed five separate phases in a ternary (three-component) alloy all at the same time. Is the observation accurate? Explain.

11. (a) Is a combination of ice and water a single-phase or multiphase system?
(b) Is water, containing a small amount of salt (NaCl), a single-phase or multiphase system?
(c) In the microstructure of steel, iron carbide (Fe₃C) particles are found in a matrix of almost pure iron. Is this a single-phase or multiphase system?
(d) Distinguish between homogeneous and heterogeneous systems.

12. Describe the phases that appear as an iron-0.5 weight percent carbon alloy is slowly cooled from the melting temperature. Describe the composition of the phases and the weight fractions of each phase at each of the following temperatures: 1430°C, 1100°C, 740°C, and 500°C. At what temperature will the austenite in this alloy have the highest carbon content? When the alloy is held at 700°C, what is the weight fraction of the ferrite phase that formed in the alloy before the eutectoid reaction had taken place?

\[ L(23.5 \text{ wt } \% \text{ Ni}) - \alpha(0 \text{ wt } \% \text{ Ni}) + Mg_2Ni(54.6 \text{ wt } \% \text{ Ni}) \text{ at } 507 \text{ °C} \]

13. One eutectic reaction in the Mg-Ni system is
Consider two alloys of composition C₁ and C₂ containing less and more Ni respectively than the eutectic composition. The fractional amount of primary microconstituent by weight is the same in each alloy, but the fractional amount of total α in alloy C₁ is 2.5 times the fractional amount of total α in alloy C₂. Calculate the compositions C₁ and C₂ in terms of wt % Ni.

14. How much ferrite, austenite, and cementite by weight are in 0.1 kg of Fe-C alloy containing 0.5 wt% C at the following temperatures, 1000°C, 724°C, and room temperature?

15. Why would one expect alloys of iron and carbon, with carbon content greater than about 2.0 weight percent, to behave differently from alloys with lower carbon content?

16. As a pure liquid is supercooled below its equilibrium freezing temperature (T_m), the free energy difference between solid and liquid becomes increasingly negative. The variation of \( \Delta G \) with temperature is given approximately by \( \Delta G = (\Delta H_m/T_m)(T_m - T) \), where \( \Delta H_m(<0) \) is the latent heat of solidification. Using this expression, show that \( e^{-\Delta G*/RT} \) is a maximum where \( T = T_m/3 \). Explain why the maximum nucleation rate occurs at a temperature greater than \( T_m/3 \).

17. (a) Consider a eutectic diagram for two components, one of which is metallic in nature and the other is covalent or semi-metallic in nature (e.g., Al-Si). In such a system it is observed frequently that nucleation of the nonmetallic solid phase is difficult in comparison to nucleation of the metallic phase. Consequently, under conditions of rapid solidification, the effective liquidus temperature of the nonmetallic phase lies below the equilibrium liquidus. Since the eutectic point can be defined as the temperature at which the two liquidus lines (i.e., L/L + α and L/L + β) intersect. Show that the effective eutectic temperature is decreased and the effective eutectic composition is displaced toward compositions richer in the nonmetallic component if solidification is rapid. Show your result in terms of an effective phase diagram superimposed on the equilibrium diagram.
(b) Consider alloys containing more of the metallic component than is contained in the eutectic composition. With reference to your answer in part (a), is the fraction of primary microconstituent resulting from rapid solidification greater or less than what would be present under equilibrium conditions?

18. Plot schematically a TTT diagram showing the start and finish curves for the recrystallization of a metal subjected to a fixed amount of prior cold work. Why does your diagram not exhibit C-curve kinetics?
19. It is found empirically that the extent of softening due to tempering of martensite is almost a unique function of a tempering parameter, \( P_T = T(\log t + C) \), where \( T \) is the absolute tempering temperature, \( t \) is the tempering time, and \( C \) is a constant for a given steel. Briefly restated, each hardness value corresponds to a specific value of \( P_T \), regardless of what the particular temperature and time combination happens to be. Knowing that tempering depends on diffusion, justify the form of the tempering parameter.

20. It is known that lattice vacancies in silicon can seriously affect the electrical properties of semiconductors. Suppose that a transistor is being made with thin wafers that are produced by vapour deposition onto an inert substrate. The process is successful in producing single crystals of silicon, but the concentration of lattice vacancies is always very high (\( \sim 10^{15} \) vacancies/cm\(^3\)) just after deposition. Attempts to remove the vacancies by heating the wafers to just below the melting temperature have failed because the films cool so quickly after the anneal that the vacancy concentration is still too high. It is suggested that the wafers be heated to just below the melting temperature of silicon and that they be slowly cooled to a temperature where the equilibrium vacancy concentration falls below \( 10^{12} \) vacancies/cm\(^3\). Calculate the temperature to which the crystals should be slowly cooled. The formation energy for vacancies in silicon is 2.3 eV/vacancy. Explain why it is all right to rapidly cool the wafers once they have reached the critical temperature.

\[ c = 42.7 \cdot p^{1/2} \cdot \exp \left( \frac{-6500}{RT} \right) \]

21. The concentration of hydrogen in alpha iron is given by the equation

where \( c \) is in parts per million by weight and \( p \) is the external hydrogen pressure in units of atmospheres. The diffusivity of hydrogen in alpha iron is

\[ D = 1.4 \times 10^{-4} \exp \left( -\frac{3200}{RT} \right) \text{ cm}^2 / \text{sec} \]

Suppose that a thin iron membrane, \( 10^{-2} \) cm thick, separates a large reservoir of hydrogen at a pressure of 200 atm from another large reservoir at a pressure of 2 atm at 200°C. What is the flux of hydrogen through the membrane in units of moles per square centimetre per second?

22. The electrical conductivity of ionic crystals at high temperatures is principally due to the diffusion of charged ions. The conductivity \( \sigma \) varies with temperature \( T \) as

\[ \sigma = \left( \frac{c}{T} \right) D \]

where \( D \) is the diffusion coefficient of the mobile ion. The conductivity of ZrO\(_2\) is \( 3 \times 10^{-4} \) (ohm-cm\(^{-1}\)) at 700°C and \( 2 \times 10^{-4} \) (ohm-cm\(^{-1}\)) at 1100°C. What is the conductivity at 1000°C?

23. Suppose that nuclei formed during a phase transformation are cubic in shape rather than spherical. If \( a \) is the dimension of the cube, compute a value for \( a^* \) and \( \Delta G^* \) in terms of \( \gamma \) and \( \Delta E \).

24. (a) The surface energy of NaCl is 0.3 J/m\(^2\). Calculate the size of salt particles at which the surface energy is 10% of the magnitude of the binding energy of NaCl.

(b) Explain why salt is hard to pour when it becomes moist.

25. How could you salvage a batch of aluminum - 4% copper rivets that had been inadvertently age-hardened prior to being driven?
26. During studies of age hardening in aluminum alloys it was noted that maximum hardness could be achieved by aging for 10 hrs at 327°C or 280 hrs at 227°C. How long would it take at 257°C?

27. Why is it preferable to precipitation harden alloys (such as Al-4.5% Cu) by first quenching to a low temperature and then reheating rather than by quenching directly to the precipitation-hardening temperature?

28. Why is carburizing treatment of steel carried out when the steel is austenitic rather than ferritic?

29. It is possible for two elements to form a complete series of substitutional solid solutions over the whole composition range. Is this behaviour possible for two elements that form an interstitial solid solution?

30. If $\Delta H_v = 84$ kJ/mol, what is the fraction of vacant sites at 1000 K? At 1500 K?

31. Assuming that there are no iron atom vacancies, find the maximum amount of carbon that could be dissolved interstitially in an FCC arrangement of iron atoms. Take the carbon atoms to occupy only the largest interstitial sites. If your answer is different from the experimentally observed value of 2.1 weight percent, give a possible explanation.

32. Calculate the dislocation spacing in a symmetric 2° tilt boundary in an FCC metal crystal that has a lattice parameter equal to 0.361 nm.

33. Substitutional solute atoms have a strain field about themselves, the sign of the strain depending on the size of the atom compared to a matrix atom. This strain field of a substitutional atom can interact with the stress field of an edge dislocation. Draw a schematic picture of an edge dislocation, and indicate the position around the dislocation where large and small substitutional atoms would be found. Where would interstitial atoms be found?

34. What are the most stable (lowest energy) Burgers vectors for the body centred tetragonal, base centred orthorhombic, and triclinic Bravais lattices?

$$\frac{a}{2}[111] + \frac{a}{2}[\overline{1} \overline{1} \overline{1}] \rightarrow a[001]$$

35. In the cubic crystal system, is the following dislocation reaction energetically favourable?

36. Suppose a copper crystal has a dislocation density of $10^{11}$ cm/cm$^3$. Calculate the strain energy associated with this dislocation density if $G = 4 \times 10^{11}$ dynes/cm$^2$ and $b = 2.5 \times 10^{-8}$ cm$^2$. If all this strain energy were converted to heat, how many degrees Celsius would the temperature of the copper rise? The heat capacity of copper is 0.09 cal/g°C, and the density is 8.96 g/cm$^3$. 

It has been found experimentally that the resolved shear stress (or shear flow stress) during plastic flow for various FCC and BCC single crystals and polycrystals is related to dislocation density, \( p \), as

\[ \tau = \tau_o + \alpha Gb\sqrt{p} \]

In this equation \( \tau_o \) is the stress to move a dislocation in the absence of interfering dislocations (i.e., essentially the critical resolved shear stress if the initial dislocation density is less than about \( 10^4 \) cm of line/cm\(^3\)), \( \alpha \) is a constant (\( \approx 0.5 \)), \( G \) is the shear modulus, and \( b \) is the Burgers vector magnitude.

(a) If \( \tau_o = 0.69 \) MPa for Cu single crystals with an initial dislocation density of \( p = 10^5 \) cm\(^{-2}\), what will be the observed critical resolved shear stress? (Data for Cu: \( G = 41.3 \) GPa, \( b = 0.256 \) nm.)

(b) Repeat part (a) for initial dislocation densities of \( 10^6 \) cm\(^{-2}\) and \( 10^8 \) cm\(^{-2}\).

Consider moving dislocations being pinned at the mean interdislocation spacing \( l \approx \frac{1}{\sqrt{p}} \), where \( p \) is the dislocation density in cm of line/cm\(^3\). Assume that for motion to continue, dislocation segments must be extruded in the same manner as the segment of a dislocation source, so that the shear flow stress is given by the following equation:

\[ \tau_c \approx \frac{2Gb}{l} \]

Calculate the dislocation density in a Cu single crystal that has been strain hardened to the stage where the applied tensile stress causes the resolved shear stress to be 14 MN/m\(^2\). (For Cu, \( G = 4.13 \times 10^{10} \) N/m\(^2\) and \( b = 0.256 \) nm.)

Suppose that the grains in a molybdenum tensile specimen are cubical in shape. If the grain size hardening is 690 MPa when 625 grains are present in 1 mm\(^2\) of cross section, what is the grain size hardening when 10,000 grains appear in 1 mm\(^2\)?

\[ \sigma_y = 113,000 - 500T \]

The yield strength (in psi) of a low-carbon steel having a grain size \( d = 0.16 \) mm varies with temperature (in K) as

\[ \sigma_y = \sigma_o + kd^{1/2} \]

below 175 K. At a given temperature, the yield strength also varies with grain size as where \( k = 13,000 \) psi \cdot mm\(^{1/2}\).

(a) If the plastic work associated with crack propagation is given by \( \gamma_p = 200 \) J/m\(^2\), what is the transition temperature for this steel? (For steel, \( E = 20.8 \times 10^{10} \) N/m\(^2\); conversion factor: 145 psi = 1 MN/m\(^2\).)

(b) Assuming the plastic work term (\( \gamma_p \)) is independent of temperature, calculate the transition temperature for grain sizes of 0.1 mm, 0.5 mm, and 1 mm.

(a) A glass plate has sharp surface cracks whose sizes range up to 1 \( \mu \)m in length. Calculate its strength when tested in tension. (\( E = 6.9 \times 10^{10} \) N/m\(^2\); \( \gamma = 0.3 \) J/m\(^2\).)

(b) Explain why the strength of glass can be increased by etching off a thin surface layer with hydrofluoric acid.