Engineering 45
The Structure and Properties of Materials
Midterm Examination
October 26, 1987

Problem 1:

(a) The compound CsCl is an ordered arrangement of Cs and Cl over the sites of a BCC lattice. Draw the unit cell.

(b) Show that each atom in the CsCl structure has eight nearest neighbors.

(c) Most materials that have the CsCl structure are metals or insulators. Why would you expect this?

Problem 2:

(a) Define and distinguish between a glass and a crystal.

(b) SiO_2 can be made into a glass by rapid cooling. However, almost all commercial glasses have ionic impurities added to the SiO_2 base material, in part to make the glass easier to process. Why?

Problem 3:

(a) A binary system of atoms of types A and B has a simple eutectic phase diagram. The A-rich solid solution (α) has a maximum solubility of 8 atom percent B at the eutectic temperature (500 K), but dissolves much less than 1 atom percent B at room temperature (273 K). The B-rich solid solution (ß) has a maximum solubility of 5 atom percent A at the eutectic temperature, and dissolves 2 atom percent A at room temperature. Show the qualitative form of the phase diagram and label the phase fields.

(b) A liquid solution of 6 atom percent B solidifies into a chemically inhomogeneous solid when it is solidified at any practical cooling rate. Why?

(c) You wish to process it into a homogeneous (supersaturated) a solid solution at room temperature. Describe a thermal processing sequence that might achieve this, and explain why it might work.

Problem 4:

A pipe of essentially pure copper is joined to a steel water line to supply water to a house.

(a) If the junction is buried in the ground, the steel pipe corrodes rapidly near the junction, while if the junction is made inside the house the rate of corrosion is very slow. Why?

(b) Assuming that the junction must be in the soil, propose two ways to protect the junction from corrosion.

Problem 5:

Explain the following observations concerning the electrical conductivity of metals:

(a) the current density, j, increases linearly with the magnitude of the applied electric field;

(b) the resistivity of a metal increases with temperature;

(c) the resistivity of a metal increases if a small amount of solute is added to it, irrespective of the solute species.

Engineering 45
The Structure and Properties of Materials
Midterm Examination
October 26, 1988

Problem 1:

The element A crystallizes in the diamond cubic structure.

(a) Give the positions of the atoms in the unit cell.

(b) Show that each atom in the diamond cubic structure has four nearest neighbors.

(c) All elements that crystallize in the diamond cubic structure are either semiconductors or insulators. Why are they one or the other and why can they be either?

(d) If A is cooled very quickly it forms an amorphous structure. Would you expect it to be a semiconductor, insulator or metal?

Problem 2:

The element B is a substitutional solute in the polygranular solid A.

(a) Plot the expected variation of the diffusivity of B as a function of temperature. Explain the shape of the curve in terms of the mechanisms of diffusion.

(b) Assume that a sample of the solution is held at a relatively high temperature and then quenched to room temperature. Plot the expected variation of the diffusivity of B with the time. Explain your plot.

Problem 3:

(a) A binary system of atoms of types A and B has a phase diagram that includes a liquid phase at high temperature and a solid solution of A and B at all compositions at low temperature. Show the qualitative form of the phase diagram and label the phase fields.

(b) A liquid solution of $\approx 30\%$ B is solidified by cooling at a moderate rate. The product is found to be inhomogeneous in composition on a fine scale. Why would you expect this?

(c) The inhomogeneity in the composition is discovered after the solid has been formed into a part. It is necessary to homogenize it to restore its properties. Assuming that you know the composition profile in the solid, at what temperature would you homogenize the part?

Problem 4:

(a) It is desired to form a liquid film on a solid surface. The liquid-vapor interfacial tension is s_{LV}, the solid-liquid tension is s_{SL}, and the solid-vapor interfacial tension is s_{SV}. For what relative values of these quantities should a film form spontaneously?

(b) The interfacial tensions are such that the film does not form spontaneously. Suggest two practical ways to modify them to promote wetting.

Problem 5:

Explain the following observations concerning the martensitic transformation in a particular steel:

(a) The martensite transformation initiates at a given value of the temperature, M_s, irrespective of the cooling rate.

(b) The martensite transformation is not completed until the steel is cooled to a much lower temperature, M_f, irrespective of the cooling rate.

(c) The electrical conductivity of the freshly formed martensite is very low.

Engineering 45
The Structure and Properties of Materials
Midterm Examination
October 25, 1989

Problem 1:

The element A crystallizes in the body-centered cubic structure.

(a) Give the positions of the atoms in the unit cell (you may simply draw the cell).

(b) Identify the closest-packed planes and closest-packed directions in the unit cell.

(c) Identify the positions of the octahedral voids in the BCC structure.

(d) If iron that contains a small amount of interstitial carbon is cooled slowly its high-T FCC structure transforms into a two-phase mixture of BCC iron and carbide (Fe_3C). However, if it is quenched rapidly the FCC structure transforms to a body-centered tetragonal (BCT) structure that is like BCC but has one cell edge longer than the other two. Why is the product BCT rather than BCC?

(e) If the quenched Fe-C alloy of part (d) is heated to slightly above room temperature for some time (tempered) the tetragonal distortion of the unit cell is gradually lost and the iron becomes BCC. Why?

Problem 2:

The Second Law of Thermodynamics states that the entropy of an isolated system can only increase. The change in entropy in an infinitesimal change of state is

$$dS = \frac{1}{T}\left[dE + PdV - \sum_k \mu_k dN_k\right] \qquad 2.1$$

where T is the temperature, E is the internal energy, P is the pressure, V is the volume, μ_k is the chemical potential of the k^{th} component and N_k is the mole number of the k^{th} component.

(a) Let two solids have fixed volumes and chemical contents, and let their temperatures be different. Show that if they interact only with one another energy (heat) flows from the solid with higher T to the solid with lower T. [Hint: Remember that energy is conserved. If the solids interact only with one another, $dE_1 + dE_2 = 0$.]

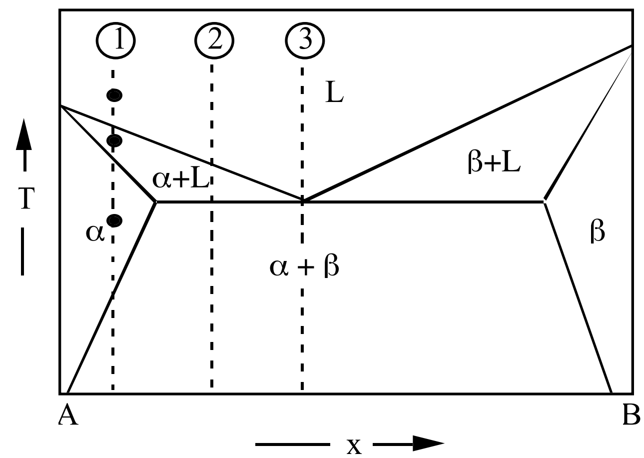
(b) Let a solid have a fixed chemical content and be in thermal and mechanical contact with a reservoir that fixes its temperature and pressure. Show that the equilibrium of the system is governed by its Gibbs free energy,

$$G = E - TS + PV \qquad 2.2$$

which must decrease in any spontaneous change. [Hint: Let the solid and the reservoir together form an isolated system. Then the energy and volume are conserved in any interaction between them. Moreover, the reservoir is, by definition, so large that its temperature and pressure remain constant when it interacts with the system.]

Problem 3:

A binary system of atoms A and B has the simple eutectic phase diagram drawn below.



(a) Give the phases present, their compositions and their mole fractions at each of the three points indicated by dots in the phase diagram. (Assume an overall composition x = 0.1 and give plausible estimates for any other compositions you need.)

(b) Show schematically how the temperature varies with the time when samples of the three compositions indicated by the dotted lines are cooled from the liquid phase at a rate slow enough that chemical equilibrium is preserved.

(c) Draw the expected microstructure of the solid that forms when a sample of composition 3 is cooled from the liquid phase. Explain why this microstructure should form.

Problem 4:

(a) A nominally uniform piece of carbon steel rusts rapidly when immersed in sea water. What constitutes the anode and the cathode in the galvanic corrosion cell? Why is the rate of corrosion roughly constant with time?

(b) Steel sheet is often galvanized (coated with zinc) to prevent corrosion. Describe the two ways in which the zinc coating protects the underlying steel.

(c) A nominally uniform piece of aluminum does not normally corrode when immersed in water, even though aluminum is less stable with respect to oxidation than steel is. Why doesn't it rust?

(d) Oxide ceramics such as silica glass (nominally SiO_2) and magnesia (MgO) may be chemically attacked by water but are not liable to galvanic corrosion. Why not?

Engineering 45
The Structure and Properties of Materials
Midterm Exam
October 31, 1990

Problem 1:

(a) Describe how the Cu_3Au, NaCl and ß-ZnS structures are derived from FCC.

(b) Binary compounds with the Cu_3Au structure are invariably metals, those with the ß-ZnS structure are usually semiconductors, and those with the NaCl structure are usually insulators. Why might you expect this behavior?

Problem 2:

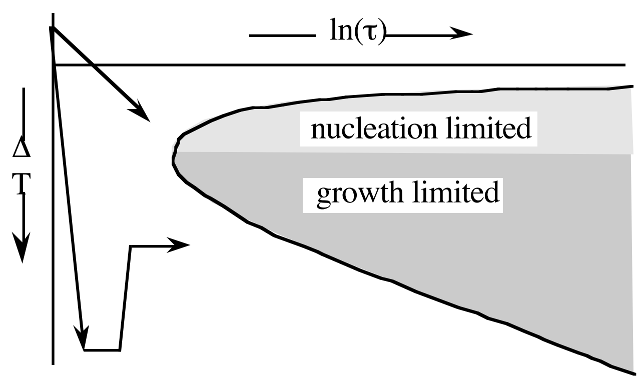
The Debye temperature of copper is about 315 K, while that of diamond is nearly 2000 K.

(a) At room temperature the specific heat of copper is much greater than that of diamond. Why?

(b) At room temperature the thermal conductivity of diamond is greater than that of copper. Why?

Problem 3:

The kinetics of precipitation of a phase ß from a polygranular α phase are described by the kinetic diagram given below, where τ is the time required to initiate the transformation and ΔT is the undercooling below the temperature at which ß precipitation becomes thermodynamically possible.



(a) If the material is cooled as indicated by the upper arrow, the final microstructure contains nuclei of ß almost exclusively in the grain boundaries of the α grains. Why might you expect this?

(b) If the material is cooled and then heated, as indicated by the lower path in the figure, the final microstructure consists of a dense distribution of ß precipitates in the interiors of the α grains. Why?

Problem 4:

Explain the following observations concerning the martensitic transformation in a particular steel:

(a) The martensite transformation initiates at a given value of the temperature, M_s, irrespective of the cooling rate.

(b) The martensite transformation is not completed until the steel is cooled to a much lower temperature, M_f, irrespective of the cooling rate.

Engineering 45
The Structure and Properties of Materials
Midterm Exam
October 30, 1992

Problem 1:

(a) Describe the ß-ZnS structure and show how it is related to the FCC structure.

(b) The ß-ZnS structure is adopted by many covalently bonded compounds, like GaAs. Why would this structure be favored? [Ga has valence 3, As has valence 5.]

(c) The ß-ZnS structure is also adopted by some ionic compounds, like AgI. What characteristic of these compounds would favor ∫-ZnS over other ionic structures?

Problem 2:

(a) Draw an edge dislocation in a simple cubic crystal.

(b) Show how the glide of that dislocation produces plastic deformation.

(c) Explain why it is difficult for an edge dislocation to climb unless the temperature is high.

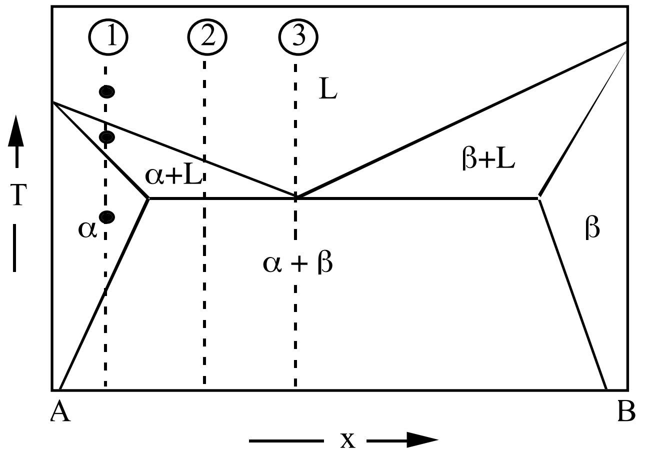
Problem 3:

(a) A one-component material has three possible structures, α, ß and γ. At high T the system is α. If it is cooled slowly it transforms to ß at $T_{\alpha\beta}$, and remains ß for all lower temperatures. If it is cooled quickly it transforms to γ at $T_{\alpha\gamma} < T_{\alpha\beta}$. Sketch plausible forms of the G vs. T curves for the three phases that might lead to this behavior.

(b) Explain why it is plausible to suppress the transformation $\alpha \rightarrow$ ß of part (a) by cooling rapidly to low temperature, but is ordinarily impossible to suppress the reverse transformation, ß $\rightarrow \alpha$, by heating rapidly to high temperature.

Problem 4:

A binary system of atoms A and B has the simple eutectic phase diagram drawn below.



(a) Give the phases present, their compositions and their mole fractions at each of the three points indicated by dots in the phase diagram. (Assume an overall composition x = 0.1 and give plausible estimates for any other compositions you need.)

(b) Draw the expected microstructure of the solid that forms when a sample of composition 3 is cooled from the liquid phase. Explain why this microstructure should form.

(c) A sample of composition (1) is solidified by cooling from the liquid into the α field. Its microstructure contains A-rich dendrites. Explain why these might form.

Engineering 45
The Structure and Properties of Materials
Midterm Exam
October 20, 1993

Problem 1:

(a) Materials that crystallize in the CsCl structure are ionic or metallic in their bonding, never covalent. Why would you expect this?

(b) Materials that crystallize in the Cu_3Au structure are never ionic. Why would you expect this?

(c) Materials that crystallize in the ß-ZnS structure are covalent or ionic. Why would you expect this?

Problem 2:

(a) What chemical and geometric characteristics are desirable in a polymer that is to be used to make a good elastomer?

(b) What chemical and geometric characteristics are desirable in a polymer that is to be used in a rigid, thermosetting plastic?

Problem 3:

(a) Plot the expected variation of the diffusivity with temperature for a substitutional solute in a polygranular solid, and explain the shape of the graph.

(b) Let the diffusivity of a substitutional specie in a given solid be measured at temperature T, under two conditions: (1) the solid has uniform temperature, T; (2) the solid has a temperature gradient, and T is an intermediate temperature. Would the two measurements differ? How and why?

Problem 4:

A binary system of atoms A and B has the phase diagram drawn below.

(a) For given T and x, three pieces of information can be read from any phase diagram: (1) the phases present, (2) the compositions of the phases present, and (3) the fractions of the phases present. Briefly explain how this is done.

(b) Only the one-phase fields are shown in the phase diagram above. Outline and label the two-phase fields.

(c) Assume the composition indicated by the arrow, and describe how the system evolves if it is cooled from the liquid phase field to the lowest temperature on the plot slowly enough that equilibrium is always preserved.

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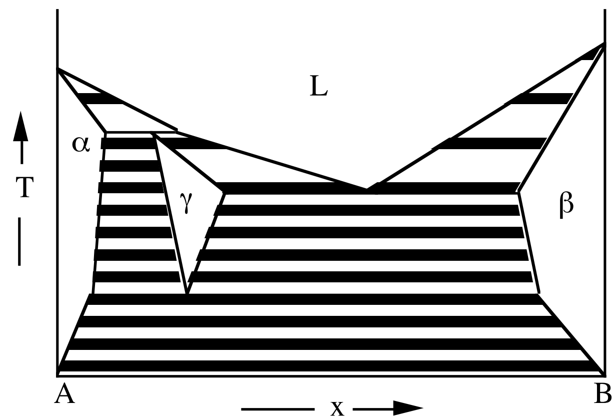

L
α
γ
β
T
A
B
x

Engineering 45
The Structure and Properties of Materials
Midterm Examination
October 26, 1994

Problem 1:

(a) Give a brief, 1-2 sentence description of each of the four basic types of chemical bonding.

(b) How might you increase the electrical conductivity of a covalently bonded material (e.g., Si) without changing its basic crystal structure?

(c) How might you increase the electrical conductivity of an ionically bonded material (e.g., NaCl) without changing its basic crystal structure?

Problem 2:

The Second Law of Thermodynamics states that the entropy of an isolated system can only increase. The change in entropy in an infinitesimal change of state is

$$dS = \frac{1}{T}\left[dE + PdV - \sum_k \mu_k dN_k\right]$$

where T is the temperature, E is the internal energy, P is the pressure, V is the volume, μ_k is the chemical potential of the k^{th} component and N_k is the mole number of the k^{th} component.

(a) Let two solids have fixed volumes and chemical contents, and let their temperatures be different. Show that if they interact only with one another energy (heat) flows from the solid with higher T to the solid with lower T.

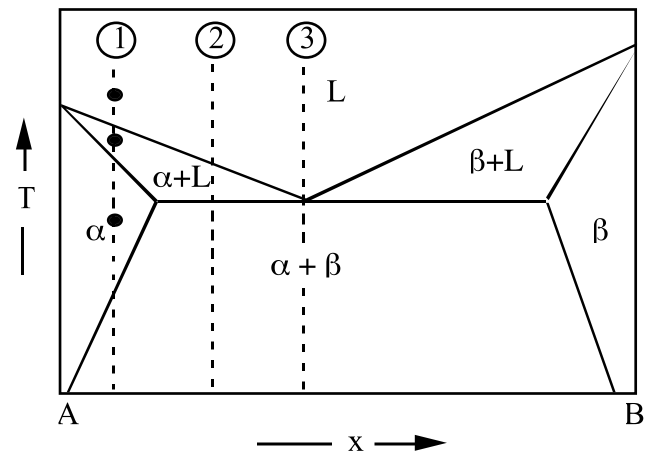
(b) Let a solid have a fixed chemical content and be in thermal and mechanical contact with a reservoir that fixes its temperature and pressure. Show that the equilibrium of the system is governed by its Gibbs free energy,

$$G = E - TS + PV$$

which must decrease in any spontaneous change.

Problem 3:

A binary system of atoms A and B has the simple eutectic phase diagram drawn below.



(a) Give the phases present, their compositions and their mole fractions at each of the three points indicated by dots in the phase diagram. (Assume an overall composition x = 0.1 and give plausible estimates for any other compositions you need.)

(b) Draw the expected microstructure of the solid that forms when a sample of composition 3 is cooled from the liquid phase. Explain why this microstructure should form.

(c) Suppose that a sample of composition 1 is held for a long time at the temperature indicated by the dot in the å-field, and is then cooled to room temperature. What microstructure is likely if the sample is cooled very rapidly? What microstructure if it is cooled slowly? Why?

Problem 4:

(a) Why doesn't Ni burn when you touch a lighted match to it in air?

(b) When Cu and Ni are joined together in sea water, the Ni corrodes rapidly. Why?

(c) When Cu and Ni are together in sea water, but separated by a thin layer of Al_2O_3, the rate of corrosion of the Ni is dramatically lower than in case (b). Why?

(d) In the situation described in (b), Cu does not corrode. But in the situation described in (c), it does, albeit slowly. Why?

Engineering 45
The Structure and Properties of Materials
Midterm Examination
November 1, 1995

Problem 1:

(a) Almost all of the elements that crystallize in the hexagonal close-packed structure are metallic conductors. Why?

(b) There are at least a couple of elements that crystallize in the hexagonal close-packed structure and are electrical insulators. How can this be?

(c) The largest sphere that can be placed in a tetragonal void in a face-centered close-packed crystal of rigid, spherical atoms has radius

$$r_{tet} = 0.225\ R$$

where R is the radius of the spheres that make up the FCC lattice. What is the radius of the largest sphere that can be placed in a tetrahedral void in an HCP lattice of rigid spheres?

Problem 2:

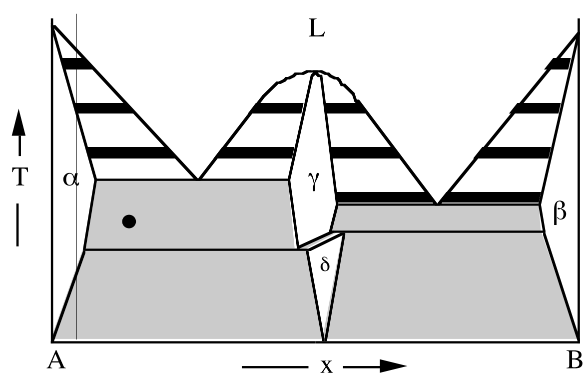
(a) Carbon diffuses through BCC iron much more rapidly than nickel does. Why?

(b) At low to moderate temperature, nickel diffuses through polycrystalline iron more rapidly than through single crystal iron. Why?

(c) If an iron-nickel alloy is quenched from high temperature, the diffusivity of nickel has an anomalously high value for a short time after the quench, but eventually decreases to its expected value. Why?

Problem 3:

A binary system of atoms A and B has the complex phase diagram drawn below.



(a) A possible state of the system is indicated by the dot on the left-hand side of the diagram. Give the phases present, estimate the compositions of the phases, and estimate their fractions when the system is at equilibrium in the state shown by the dot.

(b) Let a liquid with the composition indicated by the vertical line on the left of the phase diagram be cooled slowly enough to preserve equilibrium. Describe the evolution of the system as it is cooled.

(c) Suppose that you are given the assignment of growing a single crystal of γ phase that is to be used at room temperature (which, we shall assume, is the temperature at the bottom of the phase diagram). While it may not be possible to do this, it may be possible. Describe the process you would try and explain why it might work.

Problem 4:

Liquid silica (SiO_2) can solidify into crystalline quartz or into a glass.

(a) Sketch the expected form of the kinetic diagram (initiation time vs. temperature below melting point) that governs the solidification of liquid silica.

(b) Why is it always necessary to cool slightly below the melting point to initiate solidification?

(c) To promote glass formation it is common to add ionic species such as Na^+ to the silica melt. Why do these ionic species promote glass formation? How do they change the kinetic diagram for the transformation?

Engineering 45
The Structure and Properties of Materials
Midterm Examination
April 3, 1997

Problem 1:

(a) Describe the ß-ZnS structure, either in words or pictures.

(b) The ß-ZnS structure is a common structure for compound semiconductors, such as GaAs. Why might you expect this?

(c) The ß-ZnS structure is also adopted by ionic compounds, including some of the silver halides. Why might you expect this? Suggest a simple criterion that explains why some ionic compounds might prefer the ß-ZnS structure to the CsCl or NaCl.

Problem 2:

The Second Law of Thermodynamics states that the entropy of an isolated system can only increase. The change in entropy in an infinitesimal change of state is

$$dS = \frac{1}{T}\left[dE + PdV - \sum_k \mu_k dN_k\right] \qquad 2.1$$

where T is the temperature, E is the internal energy, P is the pressure, V is the volume, μ_k is the chemical potential of the k^{th} component and N_k is the mole number of the k^{th} component.

(a) Let two solids have fixed volumes and chemical contents, and let their temperatures be different. Show that if they interact only with one another energy (heat) flows from the solid with higher T to the solid with lower T.

(b) Let a solid have a fixed volume and chemical content and be in thermal contact with a reservoir that fixes its temperature. Show that the equilibrium of the system is governed by its Helmholtz free energy,

$$F = E - TS \qquad 2.2$$

which must decrease in any spontaneous change.

(c) A one-component solid has the phase α at low temperature and the phase ß at high temperature. Show that (at least at low T) $E^{\alpha} < E^{ß}$, while (at least at higher T), $S^{\alpha} < S^{ß}$.

Problem 3:

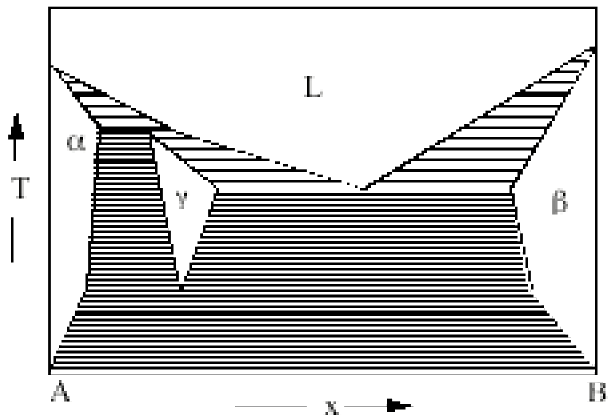
(a) Draw an edge dislocation in a simple cubic crystal.

(b) Show how the glide of that dislocation produces plastic deformation.

(c) Describe the mechanism by which an edge dislocation acts as a source or sink for vacancies.

Problem 4:

A binary system of atoms A and B has the phase diagram drawn below.



(a) Only the one-phase fields are shown in the phase diagram above. Outline and label the two-phase fields.

(b) A competitor of your company is selling a material that is γ-phase, with the grain interiors decorated with α-phase precipitates, for use at room temperature (the lowest temperature in the diagram). Given that it is very difficult to cast a sample of homogeneous γ-phase (because of chemical segregation during solidification), how do you think they do it? [Hint: do this in three steps - get a homogeneous γ-phase template in a composition that permits decoration by α-phase precipitates, decorate with α-phase in the interiors of grains, preserve this structure at room temperature. Since you know the material is being made, it is likely that the most plausible kinetics work out.]

Engineering 45
The Structure and Properties of Materials
Midterm Exam
March 18, 1998

Problem 1:

(a) Describe how the Cu_3Au, NaCl and ß-ZnS structures are derived from FCC.

(b) Only one of these structures is commonly found in compound semiconductors. Which? Why?

Problem 2:

An interface between two phases is an open system with work function

$$\Omega^S = \sigma A \qquad 2.1$$

where A is the area of the interface and σ is its interfacial tension. Given this equation explain the following observations.

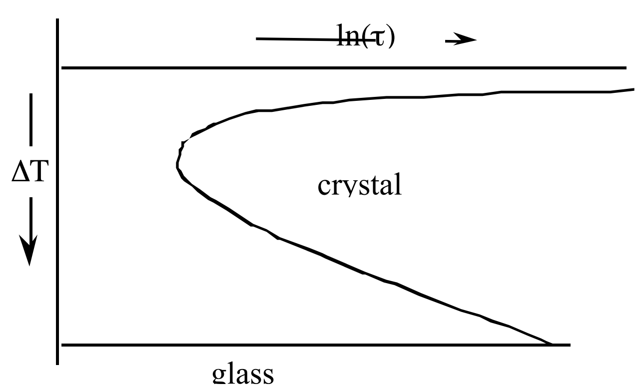
(a) A drop of water in free fall takes a spherical shape.

(b) A particle of table salt takes a cubic shape.

(c) It is a good idea to clean superficial oxides and adsorbed films off of a surface before trying to wet it or bond to it.

Problem 3:

The solidification of SiO_2 is governed by kinetic relations that are roughly reproduced in the figure below, where τ is the time necessary to initiate solidification and ΔT is the undercooling below the melting point.



(a) Briefly explain why the kinetics of crystallization of SiO_2 are governed by a c-curve like that shown in the figure.

(b) Why is the liquid-glass transformation governed by a horizontal line (at the "glass transition temperature", T_g) as shown in the figure?

(c) "Glass-forming" species such as Na are added to SiO_2 to promote glass formation. What is their most important effect on the kinetic relations shown in the figure?

Problem 4:

The diffusivity of a substitutional component in a crystal with a random distribution of vacancies is given by a relation that can be written in the form

$$D = x_v D_v \qquad 4.1$$

where x_v is the mole fraction of vacancies and D_v is the diffusivity of a vacancy.

(a) Explain why this relation holds.

(b) If the material is cooled quickly from high temperature, D has an anomalously high value for some time after the quench. Why?

(c) If the material is deformed severely enough to force some dislocation climb, D is anomalously high during the deformation. Why?

Engineering 45
The Structure and Properties of Materials
Midterm Examination
April 2, 1999

Problem 1:

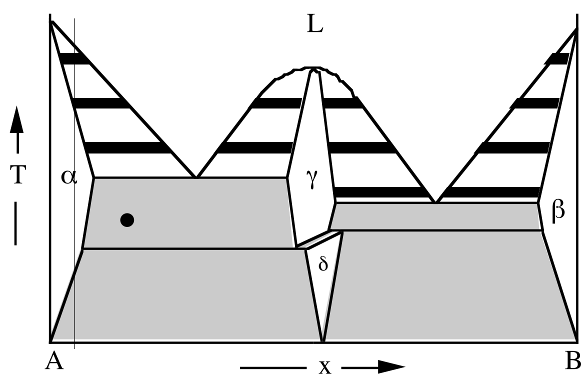
(a) Almost all of the elements that crystallize in the hexagonal close-packed structure are metallic conductors. Why would you expect this?

(b) There are at least a couple of elements that crystallize in the hexagonal close-packed structure and are electrical insulators. How can this be?

(c) How is the α-ZnS structure related to the HCP?

Problem 2:

A binary system of atoms A and B has the complex phase diagram drawn below. Only the single-phase fields are labelled; the shaded areas are two-phase fields.



(a) A possible state of the system is indicated by the dot on the left-hand side of the diagram. Give the phases present, estimate the compositions of the phases, and estimate their fractions when the system is at equilibrium in the state shown by the dot.

(b) Let a liquid with the composition indicated by the vertical line on the left of the phase diagram be cooled slowly enough to preserve equilibrium. Describe the evolution of the system as it is cooled.

(c) Suppose that you are given the assignment of growing a single crystal of γ phase that is to be used at room temperature (which, we shall assume, is near the bottom of the phase diagram). While it may not be possible to do this, it may be possible. Describe the process you would try and explain why it might work.

Problem 3:

The Second Law of Thermodynamics states that the entropy of an isolated system can only increase. The change in entropy in an infinitesimal change of state is

$$dS = \frac{1}{T}\left[dE + PdV - \sum_k \mu_k dN_k\right]$$

where T is the temperature, E is the internal energy, P is the pressure, V is the volume, μ_k is the chemical potential of the k^{th} component and N_k is the mole number of the k^{th} component.

(a) Let two solids have fixed volumes and chemical contents, and let their temperatures be different. Show that if they interact only with one another energy (heat) flows from the solid with higher T to the solid with lower T.

(b) Let a solid have a fixed volume and chemical content and be in thermal contact with a reservoir that fixes its temperature and pressure. Show that the equilibrium of the solids is governed by its Helmholtz free energy,

$$F = E - TS$$

which must decrease in any spontaneous change.

(c) A one-component solid has the phase ß at low temperature and the phase α at high temperature. Show that (at least at low T) $E^{ß} < E^{\alpha}$, while (at least at higher T), $S^{ß} < S^{\alpha}$.

Engineering 45
The Structure and Properties of Materials
Midterm Exam
March 13, 2000

Problem 1:

(a) Describe the ß-ZnS structure and show how it is related to the FCC structure.

(b) The ß-ZnS structure is adopted by many covalently bonded compounds, like GaAs. Why would this structure be favored? [Ga has valence 3, As has valence 5.]

(c) The ß-ZnS structure is also adopted by some ionic compounds, like AgI, while substitutionally ordered FCC structures, like Cu_3Au are not. Why is ß-ZnS a suitable ionic structure while ordered FCC is not?

Problem 2:

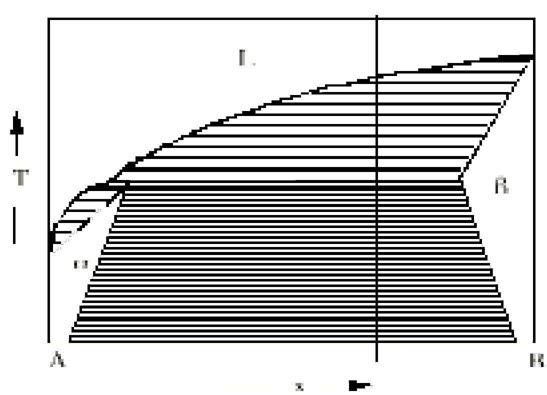
(a) Draw an edge dislocation in a simple cubic crystal.

(b) Show how the glide of that dislocation produces plastic deformation.

(c) Explain why it is difficult for an edge dislocation to climb unless the temperature is high.

Problem 3:

A binary system of atoms A and B has the complex phase diagram drawn below.



(a) Label the two-phase fields in the diagram.

(b) Let a liquid with the composition indicated by the vertical line on the phase diagram be cooled from the liquid slowly enough to preserve equilibrium. Describe the evolution of the system as it is cooled.

(c) Suppose that you are given the assignment of purifying a B-rich solution until it is almost pure B. How would you proceed?

Problem 4:

(a) Silica glass is a good thermal insulator, while Ag is not (have you ever drunk chilled wine from a silver goblet?). Why?

(b) BCC sodium has a higher Debye temperature than HCP sodium. Which of the two phases is likely to be preferred at high temperature? Why?

Engineering 45
The Structure and Properties of Materials
Midterm Exam
March 21, 2001

Problem 1:

(a) Describe the diamond cubic structure and explain why it is a natural structure for group IV semiconductors and insulators (e.g., C, Si, Ge).

(b) If a small concentration of P substitutes for Si in the diamond cubic lattice the conductivity increases significantly. Why?

(c) If diamond transforms to graphite its conductivity increases significantly (in fact, it becomes a metallic conductor). Why?

Problem 2:

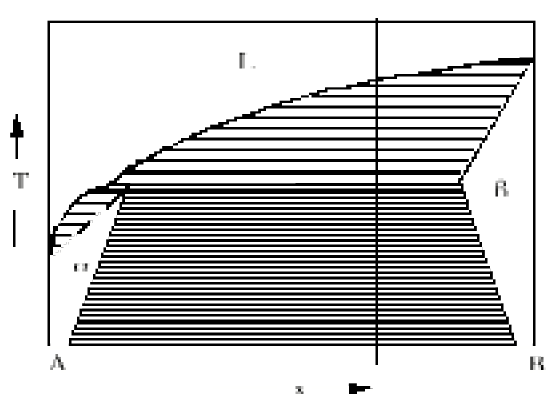
(a) What is meant by the phrase "cross-linking" in a polymer?

(b) Good elastomers, like vulcanized rubber, are cross-linked. Why?

(c) Thermoplastic polymers are not cross-linked (or very lightly cross-linked). Why?

Problem 3:

A binary system of atoms A and B has the complex phase diagram drawn below.



(a) Label the two-phase fields in the diagram.

(b) Let a liquid with the composition indicated by the vertical line on the phase diagram be cooled from the liquid slowly enough to preserve equilibrium. Describe the evolution of the system as it is cooled.

(c) Suppose that you are given the assignment of purifying a B-rich solution until it is almost pure B. How would you proceed?

Problem 4:

(a) Silica glass is a good thermal insulator, while Ag is not (have you ever drunk chilled wine from a silver goblet?). Why?

(b) BCC sodium has a higher Debye temperature than HCP sodium. Which of the two phases is likely to be preferred at high temperature? Why?

Engineering 45
The Structure and Properties of Materials
Midterm Exam
March 18, 2002

Problem 1:

(a) Describe the ß-ZnS structure and show how it is related to the FCC structure.

(b) The ß-ZnS structure is adopted by many covalently bonded compounds, like GaAs. Why would this structure be favored? [Ga has valence 3, As has valence 5.]

(c) The ß-ZnS structure is also adopted by some ionic compounds, like AgI. What feature of the ß-ZnS structure makes it suitable for ionic materials?

Problem 2:

(a) Draw an edge dislocation in a simple cubic crystal. Indicate its "Burgers vector" and its "glide plane".

(b) Show how the glide of an edge dislocation causes plastic deformation.

(c) Now let the dislocation have the form of a circular loop in its glide plane. Show how the expansion of the loop leads to plastic deformation.

Problem 3:

The elements A and B have a simple eutectic phase diagram.

(a) Draw a possible form for the phase diagram and label the phase fields. Which phases are solid solutions?

(b) For any given point in the phase diagram (T,x) you can obtain three pieces of information: the phases present, the compositions of all phases present and the fractions of all phases present. How?

(c) Given the phase diagram that you drew, what is the maximum solubility of B in A at one-half the eutectic temperature? Assuming your diagram is drawn correctly, what is the maximum solubility of B in A in the limit $T \rightarrow 0$?

Problem 4:

(a) The principal contribution to the specific heat of a metal comes from the lattice vibrations. The valence electrons are, ordinarily, much less important. Why?

(b) The entropy of a solid solution of A and B is always higher than the entropy of an ordered compound of the same elements. Why?

(c) While valence electrons do not contribute much to the specific heat of a metal, they are the primary source of its thermal conductivity.

Engineering 45
The Structure and Properties of Materials
Midterm Exam
March 19, 2003

Problem 1:

(a) Describe the ß-ZnS structure and show how it is related to the FCC structure.

(b) The ß-ZnS structure is adopted by many covalently bonded compounds, like GaAs. Why would this structure be favored? [Ga has valence 3, As has valence 5.]

(c) The ß-ZnS structure is also adopted by some ionic compounds, such as AgI. What features of the ß-ZnS structure makes it suitable for ionic materials?

(d) Consider a series of binary compounds (AB) that bond ionically, let R_A be the radius of the A ion and R_B the radius of the B ion. As the ratio R_A/R_B decreases from 1.0, the structure tends to change from CsCl to NaCl to ß-ZnS. Why?

Problem 2:

(a) In a given crystal, interstitial species diffuse much more rapidly than substitutional species. Why?

(b) Plot, schematically ln(D) vs. 1/T for an interstitial and a substitutional species in a polygranular solid, where D is the diffusivity and T is the absolute temperature.

(c) How would you determine the activation energies for diffusion from this plot? Why are the activation energies similar at low temperature?

(d) If you quench a crystalline solid from high temperature, the diffusivity of a substitutional species is very high immediately after quenching, but decreases with time until it asymptotes at the value appropriate to the final temperature. Why?

Problem 3:

A binary system Au and Ni has the complex phase diagram drawn below.

(a) Find the phases present, their compositions and the phase fractions for the following cases (x = weight percent Ni in the overall system):

x = 10	T = 900ºC
x = 10	T = 300ºC
x = 50	T =900ºC
x = 50	T = 1100ºC

(Estimate any numbers you need.)

(b) Au has the fcc crystal structure. Reasoning from the phase diagram, what is the crystal structure of Ni? How do you know?

(c) Reasoning from the phase diagram, do Ni and Au form stronger bonds to themselves (Ni-Ni and Au-Au) or to one another (Ni-Au)? How do you know?

(d) Ni and Au form a solid solution at all compositions at high temperature, but not at lower temperature. Explain this behavior in terms of the interplay of energy and entropy.