

Engineering 45  
The Structure and Properties of Materials  
Midterm Exam  
March 19, 2013

**Problem 1: (25 points)**

(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?

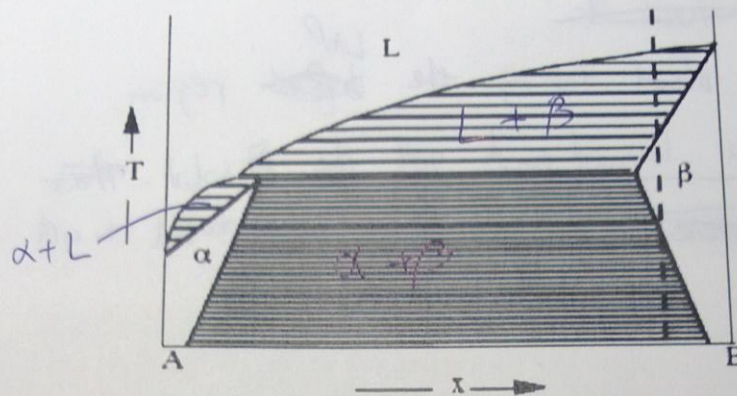
(c) How is the  $\alpha$ -ZnS structure related to the HCP?

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**Problem 2 (25 points):**

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 3 (25 points):**

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

$$\delta S = \left(\frac{1}{T}\right)\delta E + \left(\frac{P}{T}\right)\delta V - \sum_k \left(\frac{\mu_k}{T}\right)\delta N_k$$

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

**Problem 4: (25 points)**

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

$$D = x_v D_v$$

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?