Department of

MATERIALS SCIENCE AND ENGINEERING

Doctoral Written Exam

Day 2

Core Areas covered:

MSE 532
MSE 535
MSE 560

Friday, January 30, 2004

Department of Materials Science and Engineering

DOCTORAL WRITTEN EXAM – Day 2
January 30, 2004

Your exam packet for day 2 contains a total of nine (9) questions from three (3) core areas, MSE 532 MSE 535, and MSE 560, plus 20 answer sheets. Each question is on a separate page. A copy of the Table of Constants is included for your reference. **You must submit 2 questions from each core area for grading**. You will have 6 hours to complete the questions. You can obtain extra answer sheets from the proctor, if needed. Please use the following procedure:

Write a four (4) digit code of your choice, and your name on the 3 X 5 card provided. Use this code in place of your name to identify all answer sheets you submit for both days of the exam. Renee will keep the code information, sealed in an envelope, until after the exams are graded.

For each answer, use the question sheet as the first page of your answer. If additional pages are required, use the blank answer sheets provided. At the end of the examination, staple each question sheet and corresponding answer sheets for each question separately, put this instruction sheet on top of the questions you are turning in, and place them in one side of your exam folder. Place all other exam pages in the other side of your folder, and return everything to the proctor, or Renee if you finish before 2:30 P.M.

Please be sure to complete the information required on each page.

GOOD LUCK!

CODE NUMBER ________________

CHECK THE 4 QUESTIONS YOU WISH TO HAVE GRADED.

MSE 532:	MSE 535:	MSE 560:
1. ____	4.____	7.____
2. ____	5.____	8.____
3. ____	6.____	9.____

Day 2 – MSE 532 **CODE #________**

1.

(a) A liquid-vapor mixture of water is held isothermally at 300 K in a cylindrical vessel to which a piston is attached and can be used to regulate the pressure in the vessel. The system is maintained at constant temperature (300 K) and pressure (3 atmospheres or about 0.3 MPa) while 750 kJ of heat is transferred to the system. What will happen with respect to the liquid-vapor ratio in the vessel? Calculate the entropy change for the system. Is it positive or negative? Explain.

(b) In some generic process A, a heat source at 800 K loses 2000 kJ of heat to a sink at 500 K. In a similar process B, the same heat source at the same temperature loses the same amount of heat to a sink at 750 K. Calculate the entropy changes for the source, for the sink, and for the total process for both heat transfer processes A and B. Which entropy changes are positive and which are negative? Why? Which of the two heat transfer processes is more irreversible? Why? Is there any method by which these irreversibilities for both processes could be eliminated? Explain briefly.

2.

The activity coefficient of Zn, γ_{Zn}, in liquid brass is given by the following equation for the temperature range 1000-1500 K

$$RT\ln\gamma_{Zn} = -38300\ X^2_{Cu}$$

where X^2_{Cu} is the mole fraction Cu. Calculate the heat required to form a liquid solution and the partial pressure of Zn over a solution of 45 mole % Cu and 55 mole % Zn at 1180 K.

Data:

Zinc

$\Delta H_m = 7322J$

$\Delta H_b = 115331J$

$C_p(s) = 21.33 + .01164T + 52720T^{-2}$ *298.15<T<692.73*

$C_p(l) = 31.38$ *692.73<T<1180*

$\ln(p(s)) = -15755/T - 0.755\ln(T)+19.25$

$\ln(p(l)) = -15205/T - 1.255\ln(T)+21.79$

Copper

$\Delta H_m = 13{,}054$ J

$\Delta H_b = 300{,}791$ J

$C_p(s) = 22.64 + 6.28\times10^{-3}T$ 298.15<*T*<1357.6

$C_p(l) = 32.64$ 1357.6<*T*<2839

3.

a.) Knowing nothing else, estimate the entropy change of the following reaction at 1 atm pressure:

$$2AB_{(solid)} \Rightarrow 2A_{(solid)} + B_{2\,(gas)}$$

b.) b) Knowing that the compound AB and element A are in equilibrium at 800°K when the ambient partial pressure of B_2 is 25 kPa, calculate the free energy of formation of AB and the enthalpy of formation of AB.

4.

You want to bond together two sheets of wood by melting a sheet of plastic between them. Each sheet of wood is 12.6 mm thick and the plastic sheet is 6.3 mm thick. You stack the two pieces of wood on top of each other with the plastic sheet in between and place them onto a heated surface at 177˚C. The thermal conductivity of the wood is 0.43 W/mK and of the plastic is 0.17 W/mK. The air temperature is 21˚C and the heat transfer coefficient between the wood and the air is 22 W/m^2K. The melting temperature of the plastic is 121˚C. Show whether the plastic will melt and glue the pieces of wood together. (Assume the plastic thickness is always 6.3 mm.)

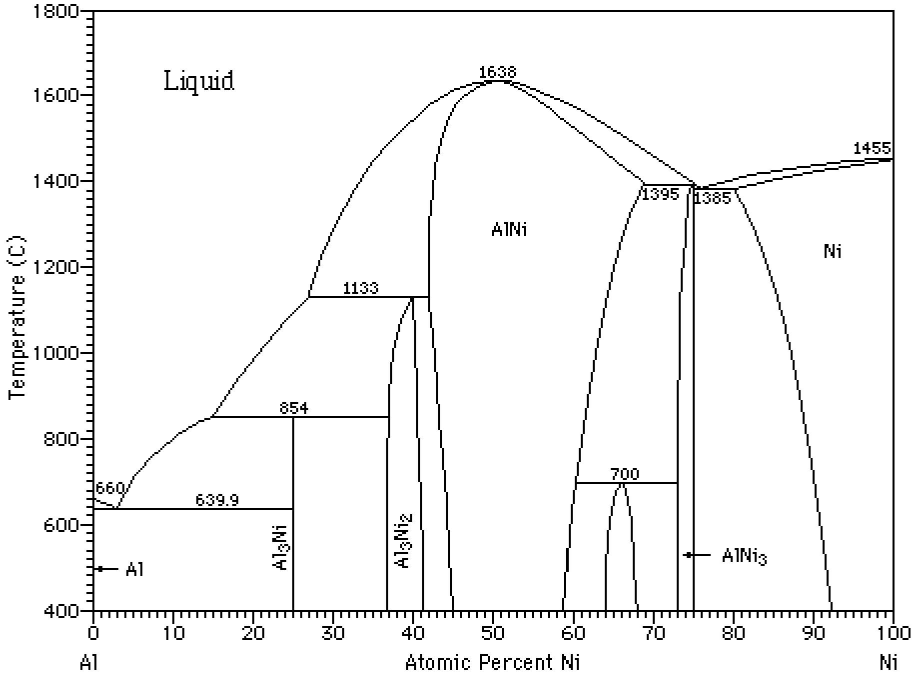
5.

A new type of aluminide coating for nickel alloys is under development. It consists of a two step process. In the first step, a 7 micron layer of ruthenium (Ru) is electroplated onto the nickel substrate and then diffused into the nickel with an annealing treatment at 1100˚C. In the second part of the process, Al is diffused into the Ru–enriched sample surface via exposure to an Al vapor of constant concentration at the sample surface.

Consider a sample of nickel with a surface area of 10 cm^2. The appropriate diffusion coefficient for Ru into the nickel is $D = 2 \times 10^{-10}$ cm^2/s. The density of the nickel is 8.5 g/cm^3 and the density of ruthenium is 12.4 g/cm^3. Assume that diffusivity is not dependent on concentration.

a) Following a 4 hour annealing treatment in the first step of the process, at what depth into the Ni will the Ru concentration fall to 5 wt% in the nickel? The maximum solubility of Ru in Ni at this temperature is 40wt%. State any assumptions.

b) Using the binary phase diagram on the next page sketch schematically the layers that will appear in the coating following exposure to the Al vapor at 1100˚C. Assume that the presence of Ru does not substantially alter Ni-Al phase equilibria.


Liquid
1638
1455
1395
1385
AlNi
Ni
1133
854
700
660
639.9
Al
Al_3Ni
Al_3Ni_2
$AlNi_3$
Temperature (C)
1800
1600
1400
1200
1000
800
600
400
0
10
20
30
40
50
60
70
80
90
100
Al
Atomic Percent Ni
Ni

6.

a.) Derive the expression for the size of a critical nucleus of a solid phase in a liquid. Sketch the temperature dependence of this critical radius and discuss the behavior when approaching the melting point of the substance.

b.) Calculate the temperature for which one critical nucleus can be found for every 10^{10} atoms in a specimen. Given: the enthalpy of transformation $\Delta H_V = 2.4 \cdot 10^9$ J/m^3, the specific surface energy $\gamma = 0.3$ J/m^2, and the melting point $T_m = 1200$ K.

c.) Once these nuclei have begun to grow, estimate an average time before two neighboring grains, initiated at the locations of such nuclei, impinge upon each other. The activation free energy for migration across the interface is 300 kJ/mol and the molar volume of either phase is 21 cm^3/mol. The fundamental vibrational frequency of an atom at the interface is 10^{13} Hz. The product of the interfacial surface density and sticking coefficient is about 10 nm^{-2}.

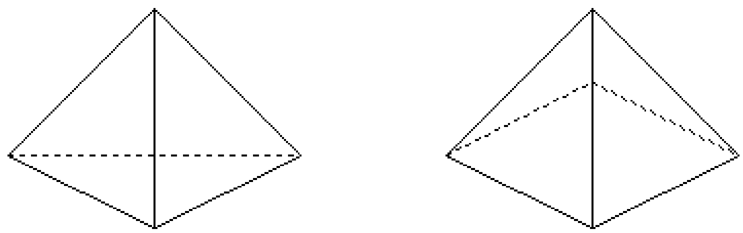
7.

(a) Describe the characteristics of the electron diffraction patterns of single crystals (with electron beam parallel to a zone axis), polycrystalline materials, oriented (textured) polycrystals, and amorphous materials. Use both *words* and *drawings*.

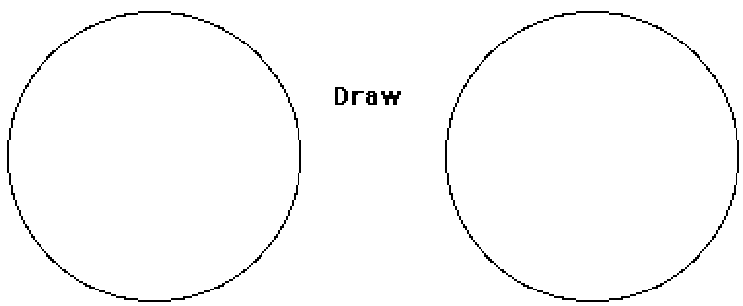
(b) Explain why electron diffraction is more sensitive to a weak structural modulation in crystal than X-ray diffraction.

8.

Give answers to the symmetry problems directly below. Figure (a) indicates a pyramid with four isosceles triangles. [3pts] Figure (b) is a pyramid with four triangles meeting at the apex and the base is a square. Draw the symmetry elements in the circles. [3pts] For part (c) the symmetry element is given. Draw a structure corresponding to it on the right hand side.[4pts]

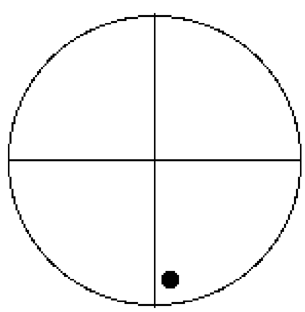


(a) (b)



Draw symmetry elements in circles above for structures indicated in Figs. (a) and (b)

(c)



Draw structure here corresponding to (c).

9.

(a) Calculate the structure factor of CsCl, which has the structure shown below. List all five reflections (and their corresponding intensities) which may be present. Show your work.

(b) If Cs^+ is replaced by K^+, compare the corresponding structure factor with that of a bcc crystal.