UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, April 23, 2001
Second Year Program

MMS 318S – PHASE TRANSFORMATIONS
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1 **(10)**

15 g of gold and 25 g of silver are mixed to form a single-phase ideal solution (atomic weight of Au = 197, atomic weight of Ag = 108).

a) How many moles of solution are there?
b) What are the mole fractions of gold and silver?
c) What is the molar entropy of mixing?
d) What is the molar free energy at 500^0C?

2 **(30)**

PLEASE, ANSWER ON THE EXAMINATION PAPER

The aluminum-lithium alloys possess lower density, higher elastic modulus, and greater fatigue crack growth resistance than conventional aluminum alloys, which make them attractive for applications in aerospace. Fig. 1 shows the equilibrium Al-Li phase diagram.

a) What type of phase is:

- α ____________________________

- LiAl ____________________________

- Li_2Al ____________________________

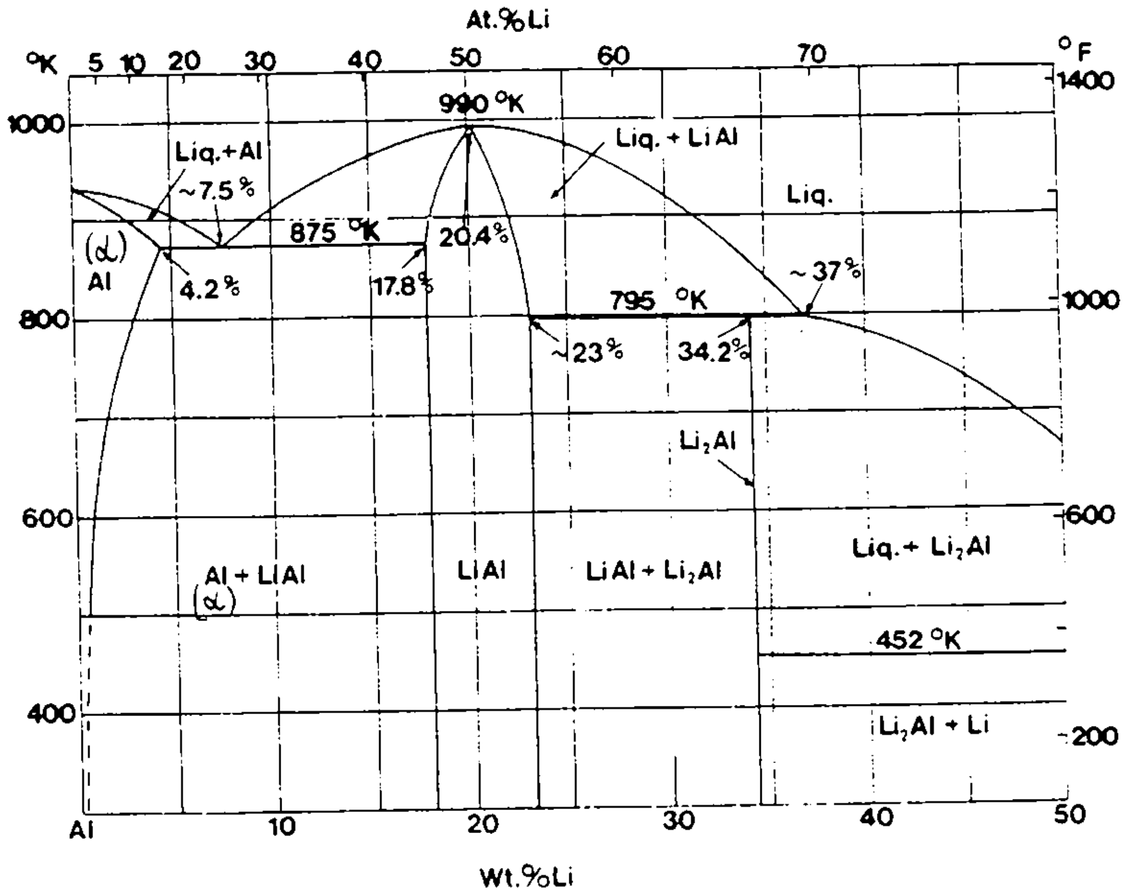


Fig. 1 Al-rich corner of the Al-Li equilibrium phase diagram (L.F. Mondolfo, Aluminum Alloys: Structure and Properties, Butter Worths, London, 1976, p.309)

b) Identify the equilibrium reactions, their type, and the temperature at which they occur. Answer below in the form of a table in order of decreasing temperatures.

Reaction type	Reaction	Composition		Temperature

(b) From the phase diagram presented in Fig. 1, construct the free energy versus composition curves for the following conditions:

Al 50 Li

(i) T = 990 K, compositional range 0 to 50 wt.% Li.

Al 50Li

(ii) T = 950^{0}C, compositional range 0 to 50 wt.%Li

Al 25 Li

(iii) T = 875 K, compositional range 0 to 23 wt.% Li

c) Explain the possibility of addition of lithium to aluminum in order to obtain a precipitation-hardening reaction and thereby strengthen the aluminum. Refer to the phase diagram given in Fig. 1.

(i) If you find the Al-Li alloy shows a good response to the precipitation hardening:

- Which phase is the strengthening phase?____________________
- What is the possible precipitation reaction?

  ____

- What is the chemical composition of the alloy that would achieve this objective:

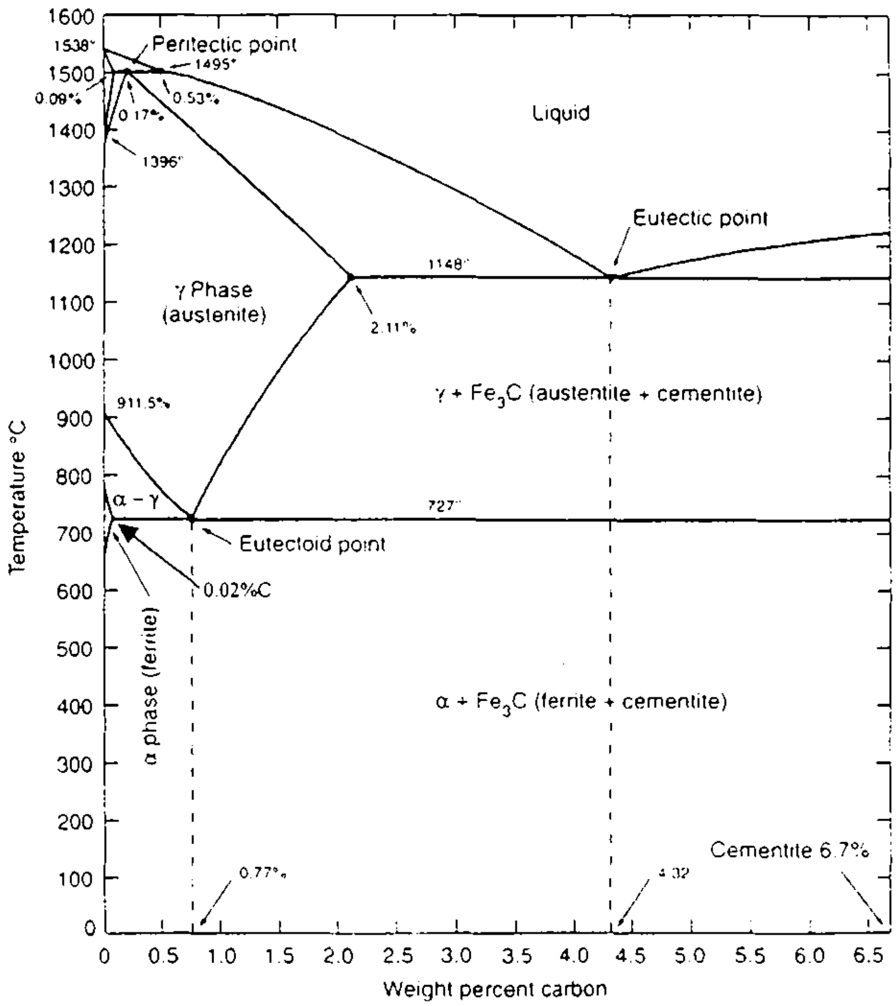
  ____

- Outline schematically the heat-treatment cycle that would achieve this objective:

(ii) If it is not possible to increase the hardness in this alloy system, explain why?

3 **(30)**

After being slowly cooled from the austenite region, a hypoeutectoid iron-carbon steel exhibits a microstructure consisting of 40 percent pearlite and 60 percent ferrite.



The Fe-Fe_3C metastable phase diagram.

a) Estimate the carbon concentration of the steel.

b) Calculate the percentages of ferrite and cementite.

c) Briefly explain the nucleation mechanism and the role of the austenite grain size. Make a sketch of the microstructure.

d) What would b the equilibrium microstructure and properties of this steel if it were heated to 860^0C and rapidly quenched to room temperature in water. Cite major differences between this phase transformation and pearlitic transformation.

e) What would b the equilibrium microstructure and properties if the quenched steel is reheated to 650^0C for approximately 1 hr and slowly cooled to room temperature.

4 ( )

The following data are relative to the freezing of the pure metal copper: the melting point of copper is 1356 K; its latent heat of fusion is 2.117×10^5 J/kg; its atomic weight is 0.0635 kg/mol, the surface energy of the liquid-solid interface is $\gamma_{ls} = 0.177$ J/m^2, and the density is 8350 kg/m^3.

a) Determine the free energy, ΔG_{nc}, associated with a critical nucleus at 1256 K where 1256 corresponds to 100 degrees of supercooling.

b) Now compute ΔG_{nc} if the supercooling is increased to 264 degrees, which corresponds to the maximum amount of supercooling that has been observed in copper.

c) Now discuss the results obtained in parts (a) and (b) of this question with respect to the probability of observing homogeneous nucleation.

d) Does the supercooling influence the critical radius (r_0)? Please illustrate your statement.

Some helpful hints!!

Molar gas constant	$R = 8.314$ J/mol ^{0}K
Boltzmann's constant	$k = 1.381 \times 10^{-23}$ J/^{0}K
Avogadro's number	$N = 6.022 \cdot 10^{23}$

$$N_{n_c} = Ne^{-\Delta G_{n_c}/kT} \qquad r_i = ve^{-\Delta g_a/kT}$$

$$I = ve^{-\Delta g_a/kT}\, Ne^{-\Delta G_{n_c}/kT}$$

$$\Delta G = A_1 r^3 + A_2 r^2 \qquad \Delta G = 4/3\pi r^3 (\Delta g^{vl}/V_l) + 4\pi r^2 \gamma$$

$$\Delta G_n = \Delta g^{ls}\, n + \eta\, \gamma_{ls}\, n^{2/3} \qquad \eta = [(4\pi)^{1/3} (3v_l)^{2/3}$$

$$\Delta g^{ls} = \Delta h^{ls} - T_o \Delta s^{ls} \Rightarrow 0$$

$$\Delta G n_c = \frac{4\eta^3 \gamma_{ls}^3 T_o^2}{27(\Delta h^{ls})^2 \Delta T^2} = \frac{A}{\Delta T^2}$$

$$I = vNe^{-(\Delta g_a + A/\Delta T^2)/kT}$$

$$G^\alpha = n_A^\alpha\, \bar{G}_A^\alpha + n_B^\alpha\, \bar{G}_B^\alpha \qquad G^\beta = n_A^\beta\, \bar{G}_A^\beta + n_B^\beta\, \bar{G}_B^\beta$$

$$G = N_A\, \bar{G}_A + N_B\, \bar{G}_B$$

$$\Delta G = \Delta H - T\, \Delta S$$
$$H = U + PV$$

$$G = G_A^0 N_A + G_B^0 N_B + RT(N_A \ln N_A + N_B \ln N_B)$$

$$G = G_A^0 N_A + G_B^0 N_B + RT(N_A \ln a_A + N_B \ln a_B)$$

$$\bar{G}_A = G_A^0 + RT \ln N_A \qquad \bar{G}_B = G_B^0 + RT \ln N_B$$

$$\Delta\, \bar{G}_A = RT \ln a_A \qquad \Delta\, \bar{G}_B = RT \ln a_B$$