MSE-2001B 3rd April 2015

Exam-3: Chapters 7 ~ 8

Name: ______ ____

Some useful equations and a phase diagram are at the end.

Part	Points	Maximum
A		50
B		20
C		15
D		15
Total		100

Your initial ______________________

PART A. MULTIPLE-CHOICE QUESTIONS (50 points, 2 points each)

1. On cooling, a liquid transforming to a liquid of a different composition and a solid is referred to as a ____________________ reaction.

   (A) eutectic
   (B) eutectoid
   (C) monotectic
   (D) peritectic

2. The phase boundary separating a solid region from a two-phase solid region is the ____________________.

   (A) isotherm
   (B) liquidus
   (C) solidus
   (D) solvus

3. In the phase diagram for water, the point having zero degree of freedom is the _________________.

   (A) boiling point
   (B) melting point
   (C) sublimation point
   (D) triple point

4. In the eutectic phase diagram, the line corresponding to the zero degree of freedom is the _________________.

   (A) eutectic isotherm
   (B) liquidus
   (C) solidus
   (D) solvus

5. An isomorphous system is only possible for a(n) ______________ solid solution.

   (A) interstitial
   (B) substitutional
   (C) two-phase
   (D) eutectic

6. The maximum number of phases that can be in equilibrium in a three-component system at one atmospheric pressure is __________________.
   (A) two
   (B) three
   (C) four
   (D) five

Your initial ______________________

7. It is known that a particular two-component alloy can form an ideal single-phase liquid, but it starts to develop clusters in the solid phases. Then, the phase diagram of this alloy is likely to have a _______________ isotherm.
   (A) eutectic
   (B) hypotectic
   (C) monotectic
   (D) peritectic

8. On cooling when a two-phase liquid plus solid transforms to a solid phase the transformation is _______________ in nature.
   (A) eutectic
   (B) hypotectic
   (C) monotectic
   (D) peritectic

9. Inoculants are ____________________________________.
   (A) one kind of dislocations
   (B) one kind of vacancies
   (C) higher melting temperature particles
   (D) the first solid phases precipitated

10. In the eutectic phase diagram, where can three phases co-exist?
    (A) At the liquidus
    (B) At the solidus
    (C) At the solvus
    (D) At the eutectic isotherm

11. Consider phase transformation from liquid to solid below the melting point. Which item of the following has a positive value?
    (A) ΔG_V^{l-s}.
    (B) ΔH_V^{l-s}.
    (C) ΔS_V^{l-s}.
    (D) None of above.

12. Which contact angle corresponds to complete wetting?
    (A) 0°.
    (B) 90°.
    (C) 180°.
    (D) None of above.

13. Which statement about homogeneous nucleation is **INCORRECT**?

Your initial ______________________

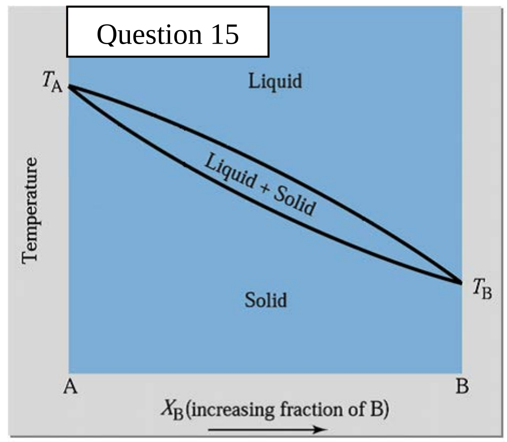
(A) The new phase nucleates randomly in the parent phase.
(B) Homogeneous nucleation leads to uniform distribution of phase structures.
(C) Homogeneous nucleation is driven by thermal fluctuation.
(D) Homogeneous nucleation is enhanced by dislocations.

14. Which statement about the Johnson, Mehl, Avrami (JMA) Equation is **INCORRECT**?

(A) It is an empirical equation.
(B) It is a thermodynamic equation.
(C) It is a rate-dependent equation.
(D) It is a time-dependent equation.

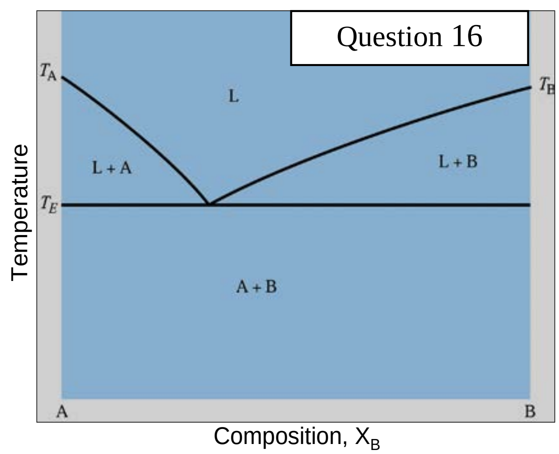
15. In the phase diagram shown on the right, which region has 1 degree of freedom?

(A) The liquid region.
(B) The solid region.
(C) The liquid+solid two-phase region.
(D) Both liquid and solid regions.



16. In the phase diagram shown on the right, can a solid solution be formed?

(A) Yes.
(B) No.
(C) Sometimes.
(D) Not enough information for determination.

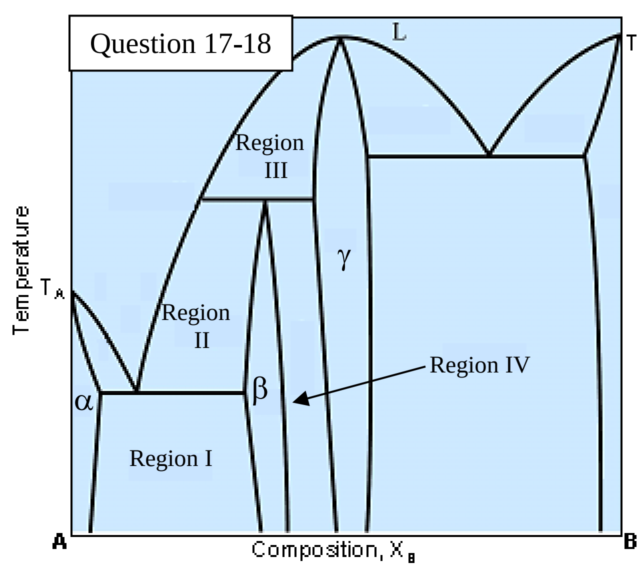


17. In the partially completed phase diagram shown on the right, which region contains L and β?

(A) Region I.
(B) Region II.
(C) Region III.
(D) Region IV.

18. In the phase diagram shown in Question 17, how many eutectic phase points are shown?

(A) Zero.
(B) One.
(C) Two.

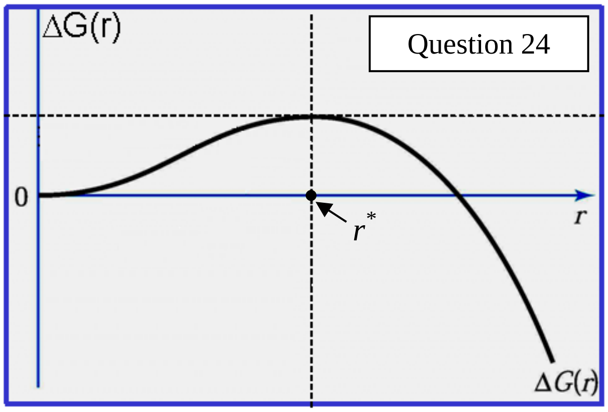


Your initial ____________________

(D) Three.

19. In the figure (shown on the right) about the energy barrier in homogeneous nucleation, at what radius will the nucleus be spontaneously dissolved?

(A) $r < r^*$.
(B) $r = r^*$.
(C) $r > r^*$.
(D) Not enough information for determination.



20. A(n) nucleus is a newly formed phase, which can reduce its Gibbs free energy by either growing or dissolving.

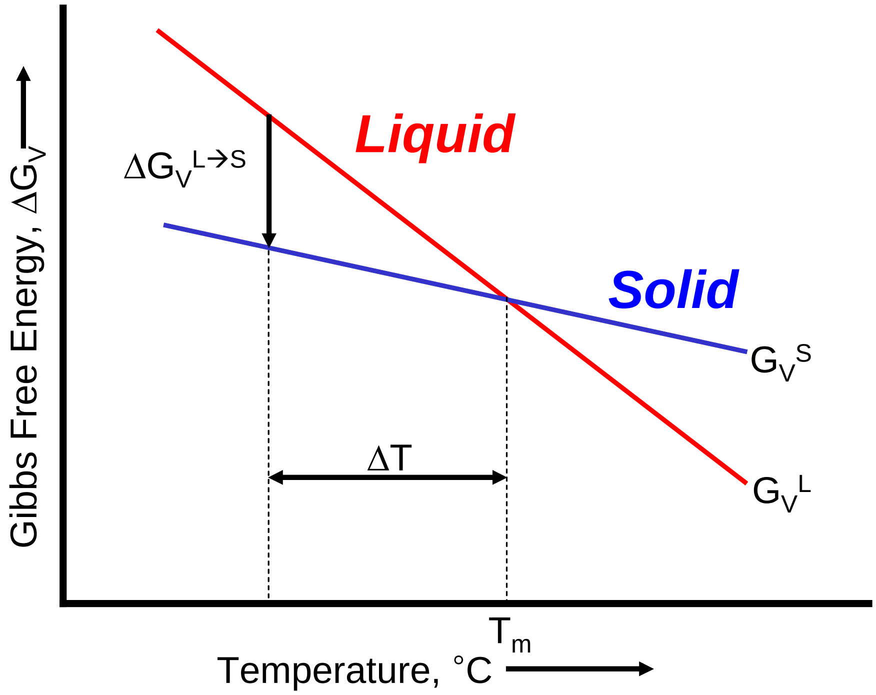
(A) True.
(B) False.
(C) It depends on ΔT.
(D) None of above.

Your initial ______________________

Part A1 (10 Points)

Making use of the plot of ***free energy*** versus ***temperature***, define the quantities "driving force" and undercooling for liquid-to-solid phase transformation. [Make sure you show the plot!]

ΔG_v is the driving for the phase transition - ΔT is undercooling **– The students need to show the plot**



At $T > T_m$: Liquid is stable

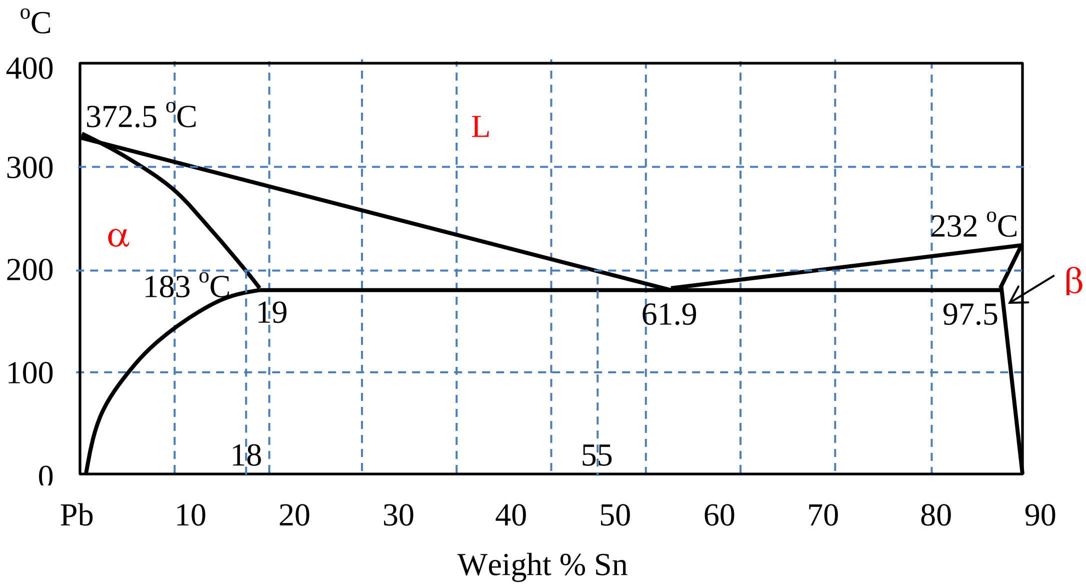
At $T < T_m$: Solid is stable

At $T = T_m$: Solid and Liquid are co-existent

Your initial ______________________

PART B. PROBLEMS (20 points, as marked)

For a phase diagram of Pb+Sn alloy system shown below, answer the following questions.



1. (5 points) For an alloy with 60 wt % Pb + 40 wt % Sn, calculate the fraction and composition (%) of each phase at 300 °C.

   300 °C: 100 % liquid with composition of 40 wt % Sn + 60 wt % Pb

2. (10 points) For an alloy with 60 wt % Pb + 40 wt % Sn, calculate the fraction and composition (%) of each phase at 200 °C.

   200 °C: Liquid + α

   $f_L = \dfrac{40-18}{55-18} \cong 0.59$; composition = 55 wt % Sn + 45 wt % Pb

   $f_\alpha = \dfrac{55-40}{55-18} \cong 0.41$, *or* $f_\alpha = 1 - f_L = 0.41$; composition = 18 wt % Sn + 82 wt % Pb

3. (5 points) What is the maximum solubility of Sn in Pb in solid state? At what temperature will you see it?

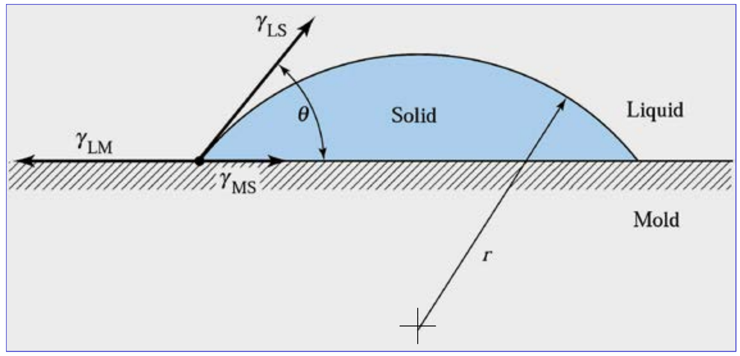
   19 wt % Sn at 183 °C

Your initial ____________________

PART C. PROBLEMS (15 points, 3 points each)

1. Refer to the figure shown on the right. The contact angle θ is determined by the interfacial tensions by

$$\cos\theta = \frac{\gamma_{LM} - \gamma_{MS}}{\gamma_{LS}}.$$



(A) False.
(B) True.
(C) It depends.
(D) None of above.

2. Which of the following statements about the effects of undercooling on nucleation is **INCORRECT**?

(A) As the undercooling increases, the barrier to nucleation reduces.
(B) As the undercooling increases, the critical nucleus radius reduces.
(C) As the undercooling increases, the induction time for nucleation reduces.
(D) As the undercooling increases, the number of nuclei reduces.

3. For heterogeneous nucleation at a mold surface with a contact angle of 180°, which relation of the following is correct?

(A) $\Delta G_{\text{hetero}}^* = \Delta G_{\text{homo}}^*$.
(B) $\Delta G_{\text{hetero}}^* < \Delta G_{\text{homo}}^*$.
(C) $\Delta G_{\text{hetero}}^* > \Delta G_{\text{homo}}^*$.
(D) $\Delta G_{\text{hetero}}^* = 0$.

4. What are liquid marbles?

Liquid marbles are droplets that have a contact angle on the substrate of about 180 degrees – a droplet that does not wet the surface.

5. How do you create liquid marbles or what do you have to do create liquid marbles?

By adding a hydrophobic powder to a droplet of water …(or something like this)

Your initial ____________________

PART D. PROBLEMS (15 points, 3 points each)

Briefly define the following terms.

1. Hypoeutectoid compositon

   Any composition to the left of (or below) the eutectoid composition.

2. Gibbs Phase rule

   The Gibbs phase rule describes the degrees of freedom available to describe a particular system with various phases and substances.

3. Critical Nucleus Size

   Critical nucleus is the size above which there is spontaneous growth of the droplet

4. Hetergeneous nucleation

   Nucleation with preferred sites such as grain boundaries, inoculants, surfaces, etc.

5. Homogeneous nucleation

   Nucleation that occurs randomly due to thermal fluctuations (or something similar to this)

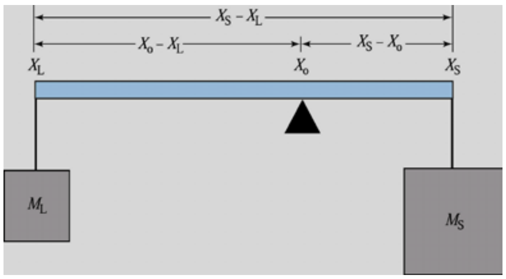
Your initial ____________________

Chapter 7:

Gibbs phase rule: $F = C - P + 2$

$$Atomic\,\%\,of\ A = \frac{wt\,\%\,of\ A / atomic\ wt\,of\ A}{(wt\,\%\,of\ A / atomic\ wt\,of\ A) + (wt\,\%\,of\ B / atomic\ wt\,of\ B)} \times 100$$

$$wt\,\%\,of\ A = \frac{atomic\,\%\,of\ A \times atomic\ wt\,of\ A}{(atomic\,\%\,of\ A \times atomic\ wt\,of\ A) + (atomic\,\%\,of\ B \times atomic\ wt\,of\ B)} \times 100$$



$$\frac{M_L}{M_{total}} = \frac{(X_S - X_0)}{(X_S - X_L)} = f_L$$

$$\frac{M_S}{M_{total}} = \frac{(X_0 - X_L)}{(X_S - X_L)} = f_S$$

Eutectic reaction: $L \Rightarrow \alpha + \beta$; Peritectic reaction: $L + \alpha \Rightarrow \beta$

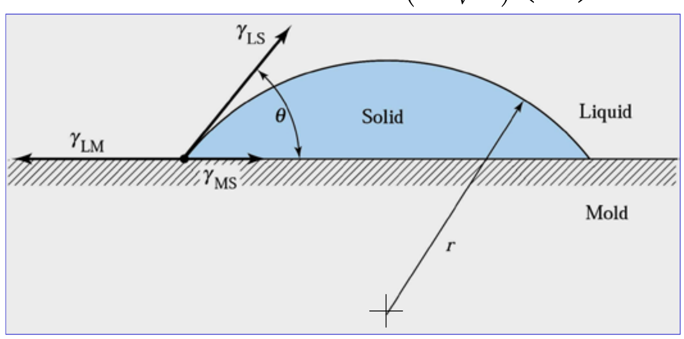
Chapter 8:

At $T = T_m$, $\Delta S_V^{l\to s} = \dfrac{\Delta H_V^{l\to s}}{T_m}$; For any temperature, $\Delta G_V^{l\to s} = \dfrac{\Delta H_V^{l\to s}}{T_m}\Delta T$

Homogeneous nucleation: $\Delta G(r) = \dfrac{4}{3}\pi r^3 \Delta G_V^{l\to s} + 4\pi r^2 \gamma_{s/l}$;

$$r^* = -\frac{2\gamma_{s/l}}{\Delta G_V^{l\to s}} = -\frac{2\gamma_{s/l} T_m}{\Delta H_V^{l\to s}\Delta T}; \qquad \Delta G^*(r) = \frac{16\pi}{3}\frac{(\gamma_{s/l})^3 T^2}{(\Delta H_V^{l\to s})^2 (\Delta T)^2}$$

Young's Equation:
$\gamma_{LM} = \gamma_{MS} + \gamma_{LS}\cos\theta$



Heterogeneous nucleation:

$$\Delta G(r) = \frac{4}{3}\pi r^3 \Delta G_V^{l\to s} + 4\pi r^2 \gamma_{s/l} + \Delta G_{Defect}$$

Relation between free energy barriers for heterogeneous and homogeneous nucleation:

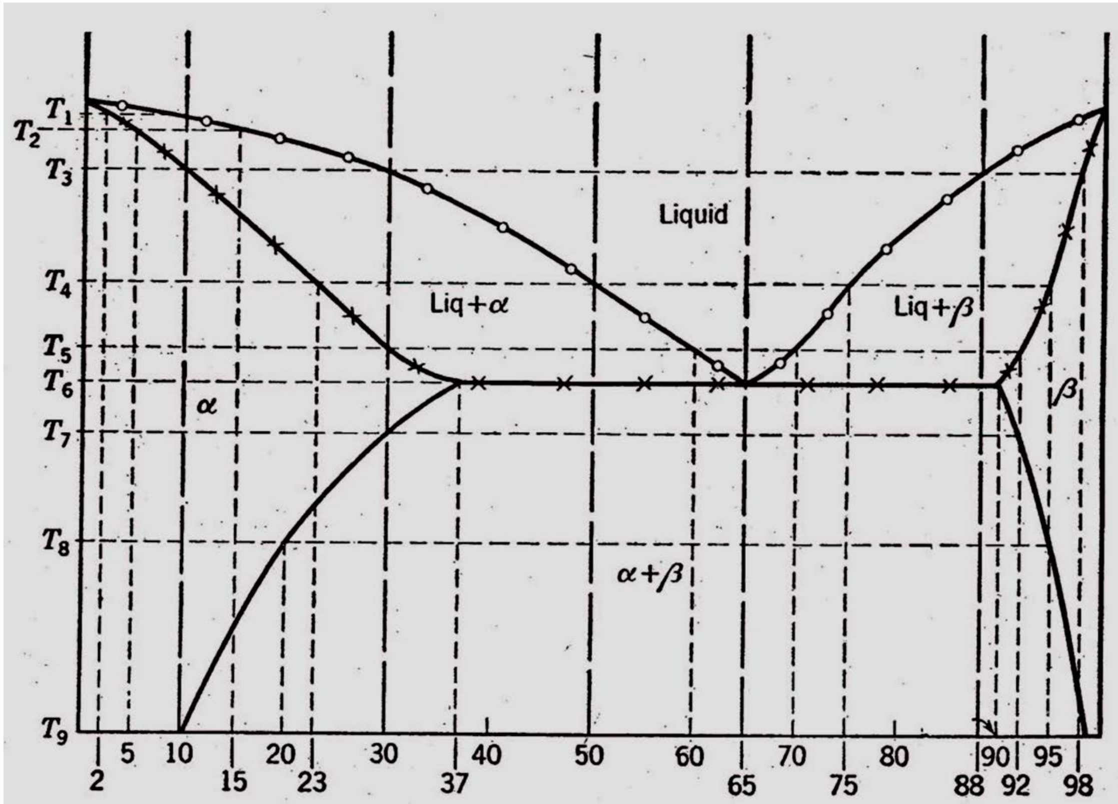
$$\Delta G_{\text{hetero}}^* \propto (\Delta G_{\text{homo}}^*) f(\theta)$$

John, Mehl, Avrami Equation: $X = 1 - \exp[-(kt)^n]$

Your initial ______________________

PART B. PROBLEMS (Total 15 points, 3 points each)

From the phase diagram below, answer the following questions.



a) What is the maximum solid solubility of B in α? **37%**

b) What is the maximum solid solubility of A in β? **10 %**

c) For an alloy containing 88 % B, what is the solid phase and what is its composition at T_4.
β solid with **95 % B** (or 5 % A)

d) For an alloy containing 88% B, calculate the fraction of the solid at T_4. (You can leave your answer as a simplified fraction).

$$f_\beta = \frac{88-75}{95-75} = \frac{13}{20} = 65\ \%$$

e) Again, for the alloy containing 88 % B. At a temperature just below the eutectic temperature, calculate the fraction of primary β in the solid (You can leave your answer as a simplified fraction).