Name: _____SOLUTIONS_________ GTID: ___________________________

MSE 2001 A: Principles and Applications of Engineering Materials

Midterm exam 3, July 15, 2013, 10am – 11am

Please remove everything from your desk except this test itself, writing instruments, and a calculator.

All pages are numbered at the bottom center of the page. Make sure that you have all 6 pages including this cover page (p.1). Work all problems in the spaces below the problem statement. You can use the back side of the pages for scratch, but I will not grade answers written on the back side. Do not remove the staple or tear out any pages except the last page (p.6).

I will not grade your exam if you fail to sign on the line below.

I acknowledge the above terms for taking this exam. I commit to uphold the ideals of honor and integrity by refusing to betray the trust bestowed upon me as a member of the Georgia Tech community. I pledge my honor that I have not violated the Honor Code during this examination.

Student's signature: _____________________________________

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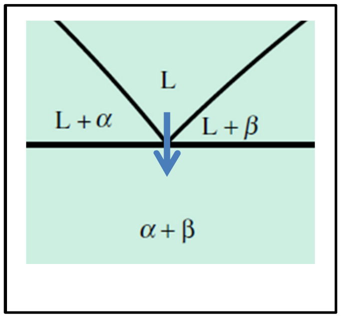
1. Match the correct pairs (17 pts)

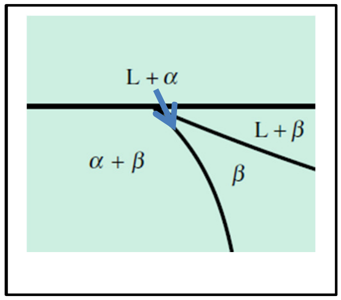
A. Liquidus	_O_ Controlled by diffusion
B. Solidus	_I_ Fe_3C
C. Hypoeutectoid Steel	_A_ Temperature above which only a liquid exists
D. Hypereutectoid Steel	_K_ Re-heating to relieve stresses
E. Martensite	_N_ Interface between different crystal structures
F. Spheroidite	_Q_ Produce solid materials from powders
G. Pearlite	_G_ Layered Structure of $\alpha + Fe_3C$
H. Bainite	_L_ A short heat treatment to regain ductility
I. Cementite	_C_ Contains < 0.77 wt% C
J. Ferrite	_H_ Fe_3C needles in an α phase
K. Tempering	_P_ Formation of a new phase
L. Anneal	_B_ Temperature below which only a solid exists
M. Semicoherent interface	_M_ Solid-slid interface with periodic dislocations
N. Incoherent interface	_F_ Forms when tempering for too long
O. Growth	_J_ α-iron
P. Nucleation	_D_ Contains > 0.77 wt% C
Q. Sintering	_E_ The strongest of all common phases in steels

2. Draw a schematic for each of the following three invariant reactions (3 pts)

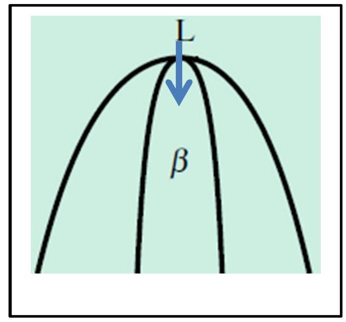
Eutectic



Peritectic



Congruent Melting



3. Using the Mg-Cu phase diagram on the last page, answer the following questions (30 pts)

(a) What are the components of this phase diagram? _______Mg and Cu_________ List their melting points ________Mg: 650°C;   Cu: 1084.87°C _____________________________

(b) How many solid solutions appear in this phase diagram? __4____ Name them:___________ ___Mg, Cu, Mg_2Cu, $MgCu_2$____

(c) What is the maximum solid solubility of Cu in Mg? ___0.013 at% Cu___________________

What is the maximum solid solubility of Mg in Cu? ___100-93.07 = 6.93 at% Mg________

(d) Are there any line compounds? __Yes___ If so, name them ____ Mg_2Cu _______________

(e) Are there any peritectics in this phase diagram? __No___ How many? __________ If yes, indicate the melting point(s) and phase names and write the equation for one of them.

(Note: “equation” means something like L + Solid A → Solid B)

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(f) Are there any eutectics or eutectoids in this phase diagram? __Yes__ How many? __3_____ If yes, indicate their eutectic temperature and compositions. _____

X0=14.5% at T=485°C; X0=42% at T=552°C; X0=76.9% at T=725°C;

Write the equation for one of them ____ For example, the first one is L→ Mg + Mg_2Cu________

(g) Are there any other invariant reactions not yet mentioned? __Yes_ If yes, what are they and at what temperatures and compositions do they occur?

There are two congruent melting reactions:

X0=33% at T=568°C: L→ Mg_2Cu;   X0=66% at T=797°C: L→ $MgCu_2$;

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(h) Using the Gibbs phase rule, calculate the number of degrees of freedom for points A, B, C and D on the Mg-Cu phase diagram.

Point A: x0 = 76.9 at% Cu at 725°C; Point B: x0 = 25 at% Cu at 500°C;

Point C: x0 = 67 at% Cu at 500°C; Point D: x0 = 50 at% Cu at 1000°C.

Point A: ______F_A = 2-3+1=0______________ Point B: ____ F_B = 2-2+1=1_______________

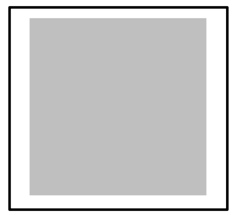
Point C: ______F_C = 2-1+1=2_______________ Point D: ____ F_D = 2-1+1=2_______________

4. Based on the Mg-Cu phase diagram on the last page, for an alloy containing 55% Cu represented by the vertical line, answer the following questions (30 pts)

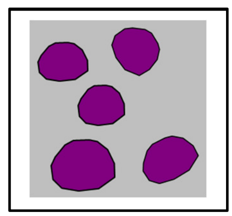
(a) Indicate the phases present, their composition and microstructure at the following temperatures (12 pts)

Phases Present Compositions

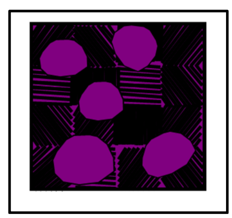
T_1 = 900°C __________L__________ ____$X_L = 55\%$________



T_2 = 650°C ___L and MgCu2_____ $X_L = 48\%; X_{MgCu2} = 65\%$



T_3 = 500°C _Mg2Cu and MgCu2 $X_{Mg2Cu} = 33\%; X_{MgCu2} = 65\%$



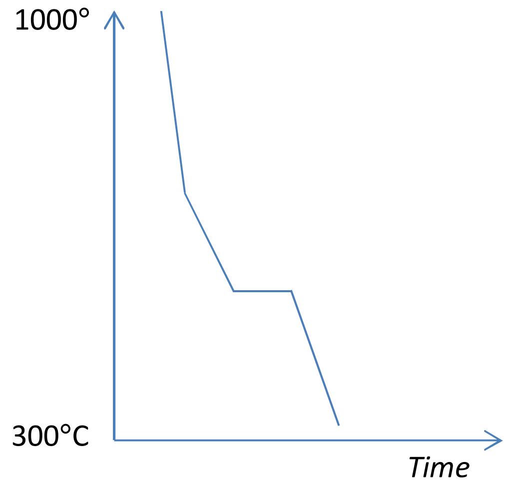
(b) Given 250 g of X_0 = 55 at% Cu, what are the relative amounts of the phases present at 900°C? What are the relative amounts of the phases present at 650°C? Show all of your work. (12 pts)

At 900°C, all is in liquid form. 250 g of L.

At 650°C, L and $MgCu_2$ co-exist. Use lever rule: $X_L = 48\%; X_{MgCu2} = 65\%$

$$f_L = \frac{0.65-0.55}{0.65-0.48} = 0.59; f_{\mathrm{MgCu2}} = 0.41. \quad m_L = 250 \times 0.59 = 147\text{ g}; \ m_{\mathrm{MgCu2}} = 103\text{ g}.$$

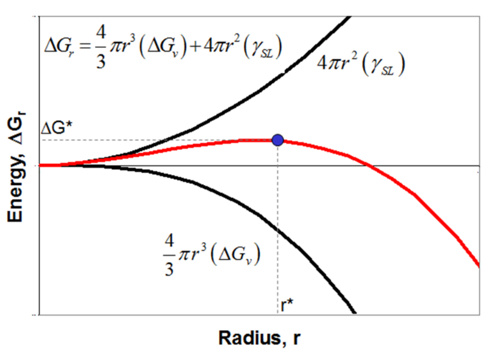
(c) Sketch the equilibrium cooling curve for this alloy (X_0 = 55 at% Cu) (6pt)



5. For homogeneous nucleation, the change in free energy to create a nucleus of size r is given by the equation (10 pts),

$$\Delta \boldsymbol{G}(\boldsymbol{r}) = \frac{\mathbf{4}}{\mathbf{3}}\boldsymbol{\pi r}^{\mathbf{3}}(\Delta \boldsymbol{G}_{\boldsymbol{v}}) + \mathbf{4}\boldsymbol{\pi r}^{\mathbf{2}}\boldsymbol{\gamma}_{\boldsymbol{s/l}}$$

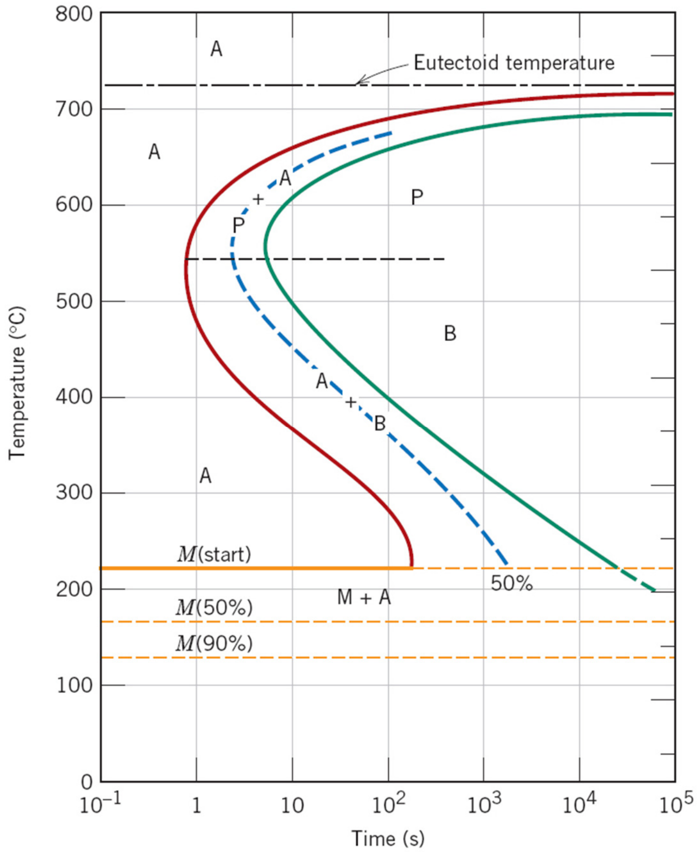
(a) Schematically plot ΔG(r) as a function of radius for a homogeneous nucleation process. On the same plot, sketch and label the two free energy terms that determine ΔG(r), the energy barrier for nucleation ΔG* and the critical radius, r*. (6 pts)



(b) How do the energy barrier for nucleation ΔG* and the critical radius r* change with increased undercooling ΔT? (4 pts)

Both ΔG* and r* decrease with increased undercooling ΔT.

6. Based on the isothermal transformation diagram for a eutectoid steel, answer the following questions (10 pts),



A: Austenite

B: Bainite

M: Martensite

P: Pearlite

(a) Describe the phases present and the microstructures that would occur when a piece of eutectoid steel is held at 800°C for long, and then processed using the following quench path:

Instantaneous quench at 360°C → hold for 100 seconds → rapid quench to room temperature

<u>50% bainite and 50% martensite</u>

(b) Describe a heat treatment that would result in the following microstructure for a plain carbon eutectoid steel:

A 50-50 mixture of coarse pearlite and martensite

<u>For example, hold at 800°C to form austenite, then instantaneously quench to 650°C and hold for 30s (now 50% austenite is transformed to coarse pearlite and 50% austenite left), then instantaneously quench to room temperature.</u>

(Please feel free to tear out this page)

Mg-Cu phase diagram