Name: ____**Solutions**______ GTID: _________________________

# MSE 2001 B: Principles and Applications of Engineering Materials

Midterm exam 3, July 15, 2014, 10am – 11am

**Please read this cover sheet carefully before continuing with the exam.**

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

All pages are numbered at the bottom of the page. Make sure that you have all 9 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 two pages (p.8 & p.9).

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: ____________________________________

1. Circle the correct answer (15 points)

(1) At high altitudes the boiling point of water is

(a) above 100 °C (b) below 100 °C

(2) A copper-aluminum alloy contains 10% weight percentage of copper. The atomic mass of Cu is larger than that of Al. The atomic percentage of copper in this alloy is

(a) above 10% (b) below 10%;

(3) When there is a clustering tendency in the solid phase of a two-component system, the solidus boundary will bend

(a) downward (b) upward

(4) The general formula for a peritectoid reaction is

(a) $\gamma + \beta \leftrightarrow \alpha$ (b) $\gamma \leftrightarrow \alpha + \beta$

(5) The lower the temperature is, the faster the rate of solidification will be.

(a) True (b) False

(6) When the amount of undercooling $\Delta T$ is increased, the critical radius r* for homogeneous nucleation will

(a) increase (b) decrease

(7) In cloud seeding, silver iodide is added to trigger

(a) homogeneous nucleation (b) heterogeneous nucleation

(8) When you dip your finger into a soda drink, small carbon dioxide bubbles will emerge around your finger. This is because your skin provides ___ for the evaporation of $CO_2$:

(a) preferred nucleation sites (b) heat as activation energy

(9) The most important phase transformation in a 0.77% (wt% of C) steel is a

(a) eutectic reaction (b) eutectoid reaction

(10) Which of the following mixtures of ferrite + cementite has a layered texture?

(a) pearlite (b) bainite

(11) Pearlite formed at higher temperature is coarser than that formed at lower temperature. This results from the temperature dependence of

(a) diffusion of carbon atoms (b) thermal expansion of the alloy

(12) As the carbon content in steal increases, ___ undercooling is required to induce the martensitic phase transformation.

(a) less (b) more

(13) For a eutectoid steel, the transformation from austenite (γ) to ______ is a diffusionless process.

(a) martensite (b) spheroidite

(14) The process to transform martensite into spheroidite is called

(a) temping; (b) quenching

(15) "Coring" usually occurs during

(a) equilibrium solidification (b) non-equilibrium solidification

2. (10 points)

The figure shows the Ag-Cu phase diagram.

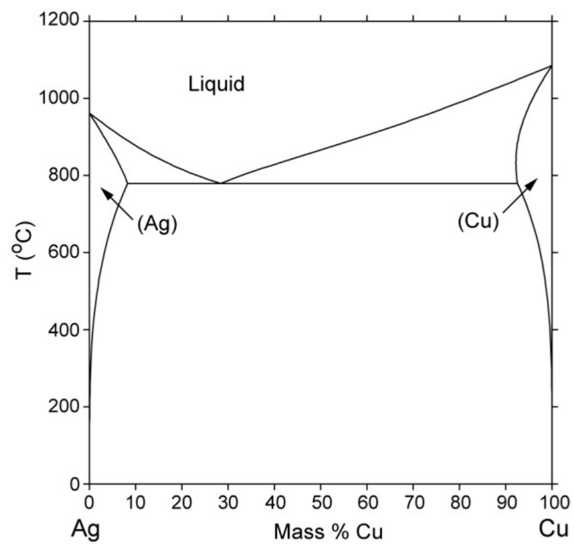
(a) Write down the type and equation for the invariant reaction in the diagram. (1 pt)

(b-d) Sketch the cooling curve for an Ag-Cu alloy with

(b) 0% Cu (pure Ag)

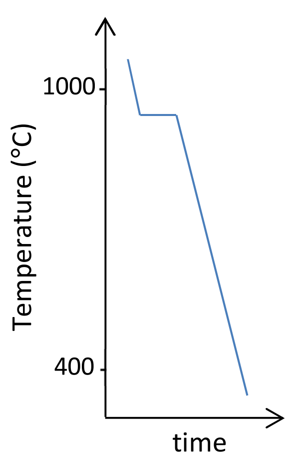
(c) 29% Cu

(d) 50% Cu

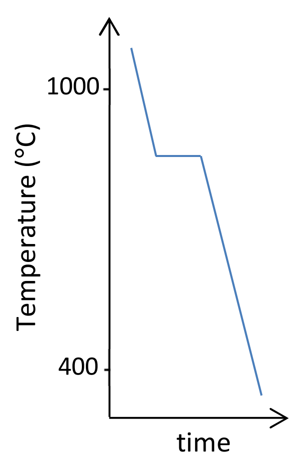



(a) The invariant reaction is ______________________________________ [L→Ag+Cu, eutectic]

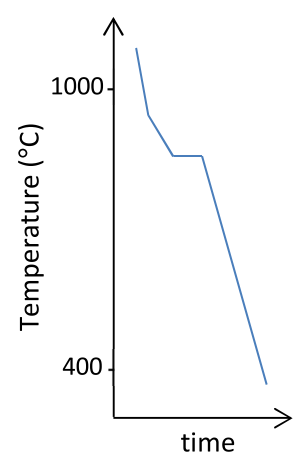
(b)




(c)




(d)



3. (25 points)

Answer the following questions based on the Nb-Ge phase diagram on page 8.

(a, 10 pt) Find five invariant reactions. Express each reaction in the following format (a fake example): Eutectic at 1234 °C with composition 56% Ge, $L \rightarrow \alpha + Nb_7Ge_8$

____eutectic___________ at _1865_°C with composition _27_%Ge, ___$L \rightarrow \beta + Nb_5Ge_3$_______

____eutectic___________ at _1580_°C with composition _59_%Ge, ___$L \rightarrow Nb_5Ge_3 + NbGe_2$___

____peritectic__________ at _1900_°C with composition _18_%Ge, ___$L + Nb \rightarrow \beta$____________

____congruent melting_ at __2180_°C with composition _37_%Ge, ___$L \rightarrow Nb_5Ge_3$___________

____congruent melting_ at __1680_°C with composition _66_%Ge, ___ $L \rightarrow NbGe_2$____________

(b, 5 pt)

Calculate the Gibbs degrees of freedom for the following state points:

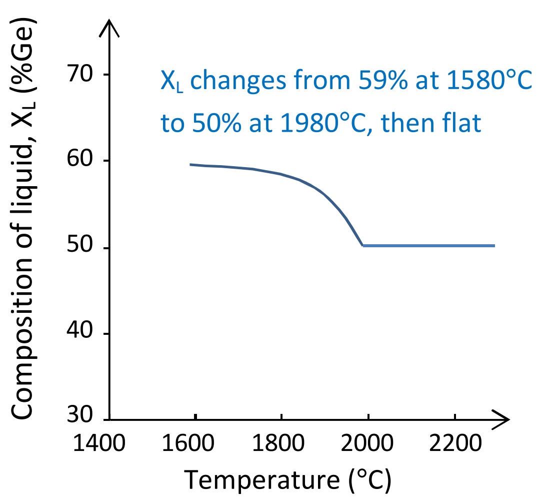
Point 1: $X_0$ = 18%Ge at 1900 °C, F = ____0_____; Point 2: $X_0$ = 90%Ge at 1000 °C, F = __1______

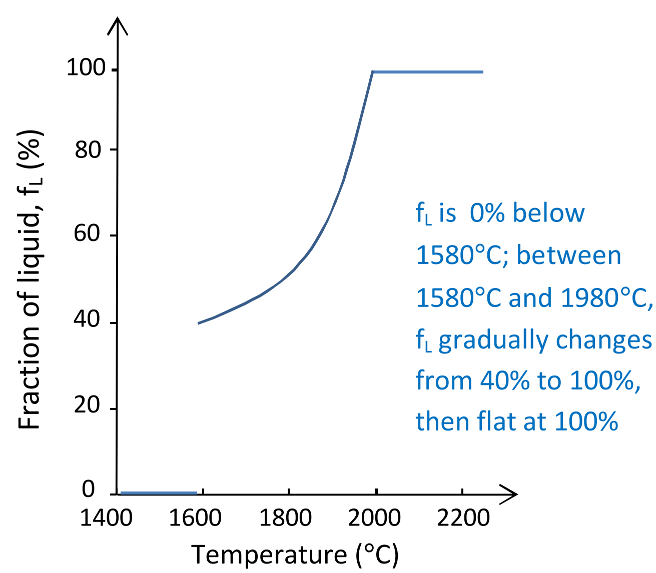
Point 3: $X_0$ = 40%Ge at 1600 °C, F = ____2_____; Point 4: $X_0$ = 30%Ge at 2000 °C, F = __1______

Point 5: $X_0$ = 60%Ge at 2000 °C, F = ____2____

(c, 10 pt)

An Nb-Ge alloy with $X_0$ = 50%Ge is slowly heated from 1400°C to 2200°C. Sketch (1) The composition of the liquid phase ($X_L$) as a function of temperature; (2) The fraction of the liquid phase ($f_L$) as a function of temperature.



4. (20 points)

The phase diagram for the Cu-Ag binary system is shown on p.9.

(a) For an alloy of composition 40 wt%Ag cooled slowly from the melt, what is the mass fraction of <u>pro-eutectic</u> $\alpha$-phase at the room temperature?
(note: pro-eutectic $\alpha$ means the $\alpha$-phase formed before the eutectic isotherm)

Using the lever at a temperature just above the eutectic temperature will give us the mass fractions of the pro-eutectic phase:

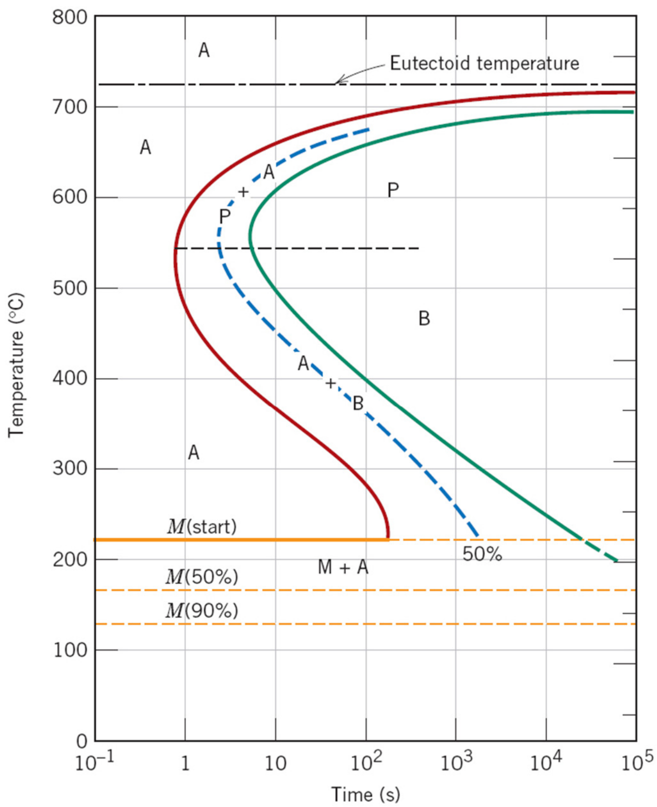
$$\boxed{M_{PRO-\alpha} = \frac{C_{EUT} - C_0}{C_{EUT} - C_\alpha} = \frac{71.9 - 40.0}{71.9 - 8.0} = 50\%.}$$

(b) An alloy of composition 20 wt%Ag is heated to a temperature within the ($\alpha$ + Liquid) phase region. If the composition of the liquid phase is 50 wt%Ag, determine (1) the temperature of the alloy; (2) the mass fraction of the liquid phase ($f_L$) at this temperature.

Draw a vertical line at 50% wt%Ag, and it intersects with the liquidus boundary of the ($\alpha$+L) zone at the temperature of 875 °C

Draw a tie line at this temperature, and we find $f_L$ = (20-8)/(50-8) = 0.286

5. (15 points)




The figure shows the isothermal transformation diagram for a eutectoid steel.

A: Austenite

B: Bainite

M: Martensite

P: Pearlite

(a) Describe the phases present and the microstructures that would occur with quench path:

Instantaneously quench to 450°C → hold for 10 seconds → quench to room temperature.

450°C for 10s: ~50% of austenite is transformed to bainite and ~50% remaining austenite. After quenched to room temperature, 50% bainite and 50% martensite.

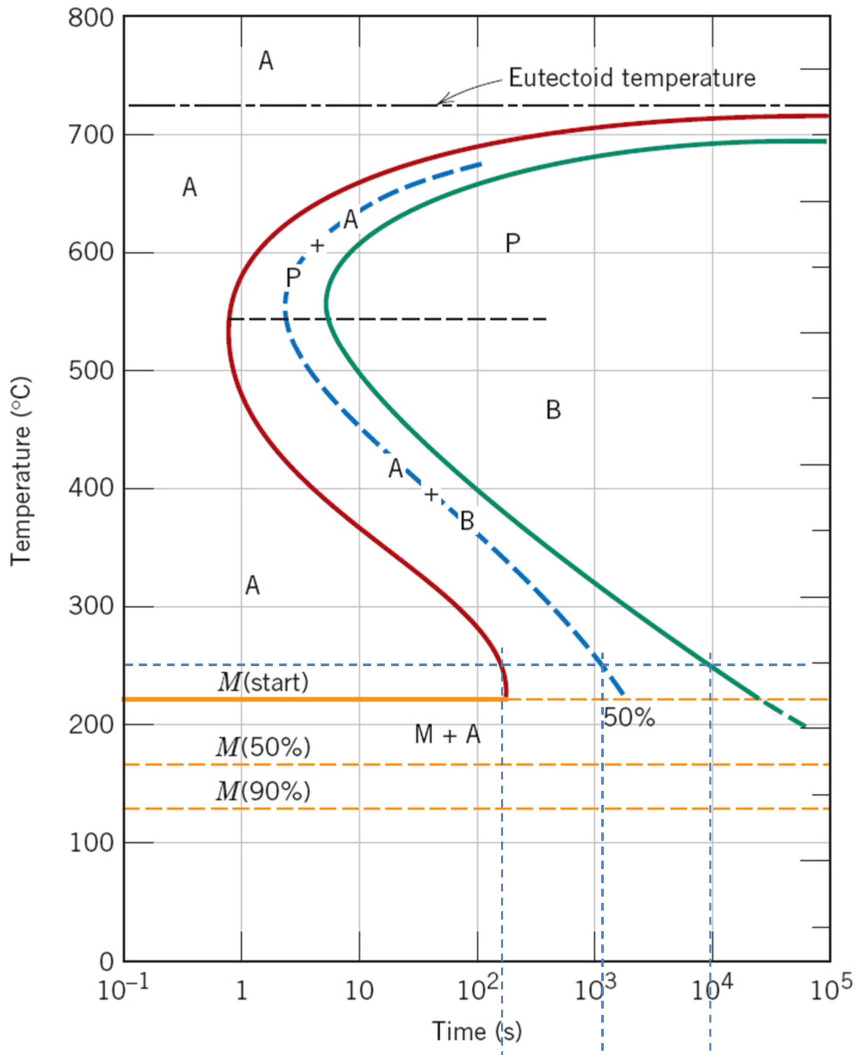
(b) A piece of carbon steel (unknown microstructure) with the eutectoid composition (0.77% C) is to be recycled. Describe a heat treatment that would result in 100% fine pearlite.

Above 727°C hold to form 100% austenite (γ), then instantaneously quench to 550°C (or up until 600°C). Hold for at least 8 seconds.

(c) A piece of eutectoid carbon steel is held at 800°C for sufficiently long. The steel is then to be quenched at a constant cooling rate. Estimate the slowest possible cooling rate (unit: °C/second) that would result in 100% martensite.

To avoid the starting C curve for (γ → α+$Fe_3C$) transformation, the minimum rate is approximately (800 °C – 500 °C)/1 sec = 300°C/s

6. (15 points)




We see again the isothermal transformation diagram for a eutectoid steel.

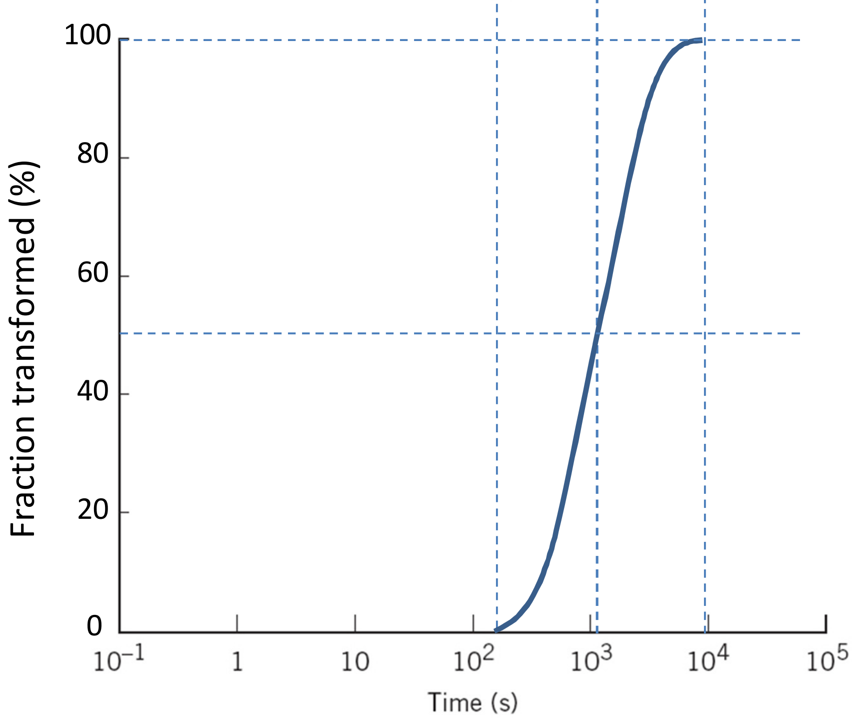
(a, 10 pt) Based on the C curves, sketch the fraction transformed as a function of time for the Austenite → Bainite transformation at the temperature of 250°C

(b, 5 pt) The fraction of transformed material can be described by the JMA equation:

$$X = 1 - \exp[-(kt)^n]$$

In this reaction, $n \approx 2$.

Estimate the constant $k$.




Look at the 50% point:

n = 2

X = 0.5

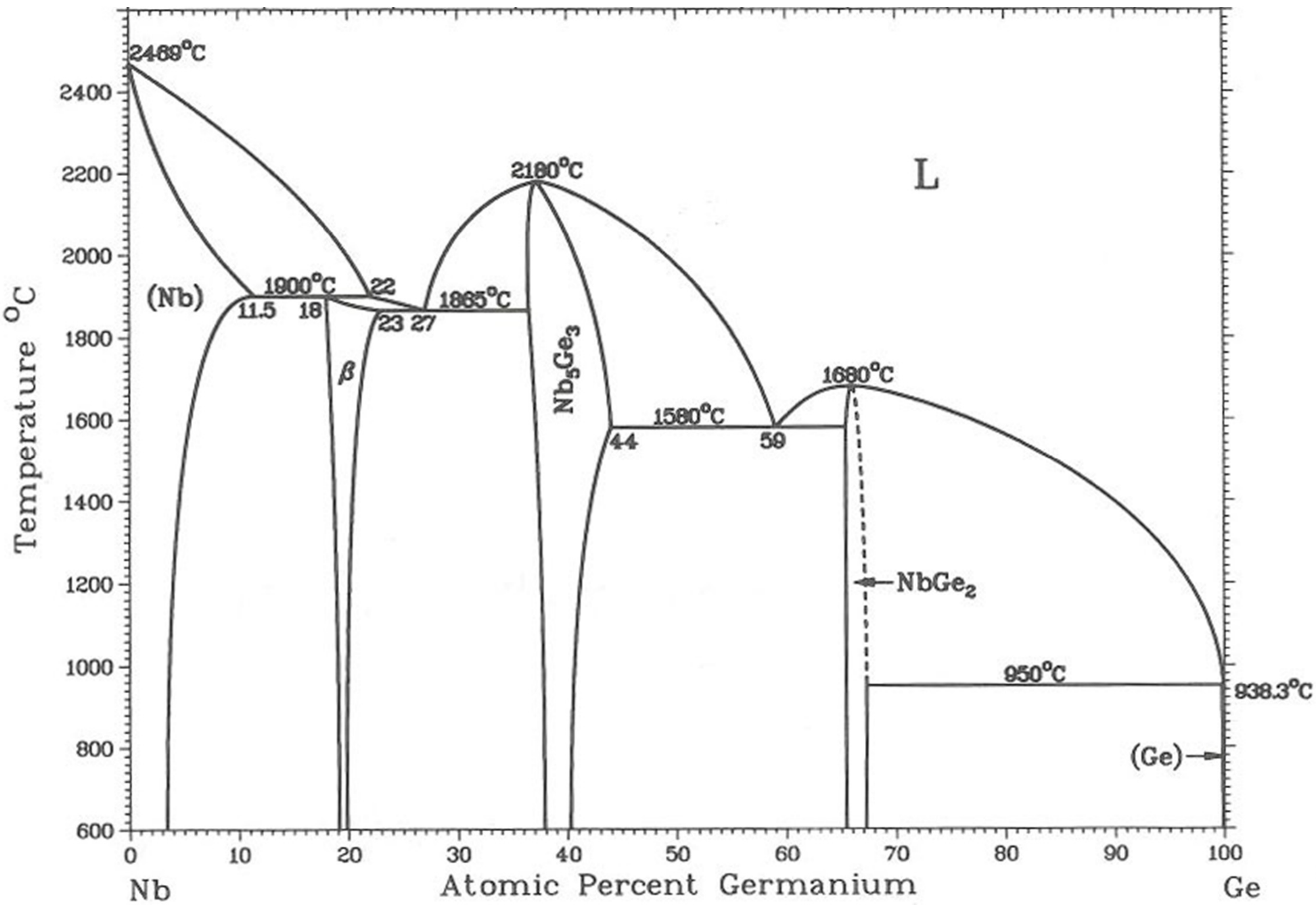
t ≈ 1000 sec

Solve for k,

we get k = 0.00083/sec

(Please feel free to tear out this page)

**Nb-Ge phase diagram for problem #3**



(Please feel free to tear out this page)

**Cu-Ag phase diagram for problem #4**