Engineering 45
Properties of Materials
Second Midterm Exam
April 25, 2015

Name: Solutions

Instructions: Answer all questions and show your work. You will not receive partial credit unless you show your work. Good luck!

1a: 15 points	
1b: 15 points	
2a: 10 points	
2b: 10 points	
3a: 5 points	
3b: 10 points	
4a: 10 points	
4b: 10 points	
5a: 10 points	
5b: 5 points	
Total: 100 points	

1. The figure below is the composition-temperature phase diagram for Cu-Ag. The eutectic temperatures and compositions, and the single and two-phase regions are labeled.

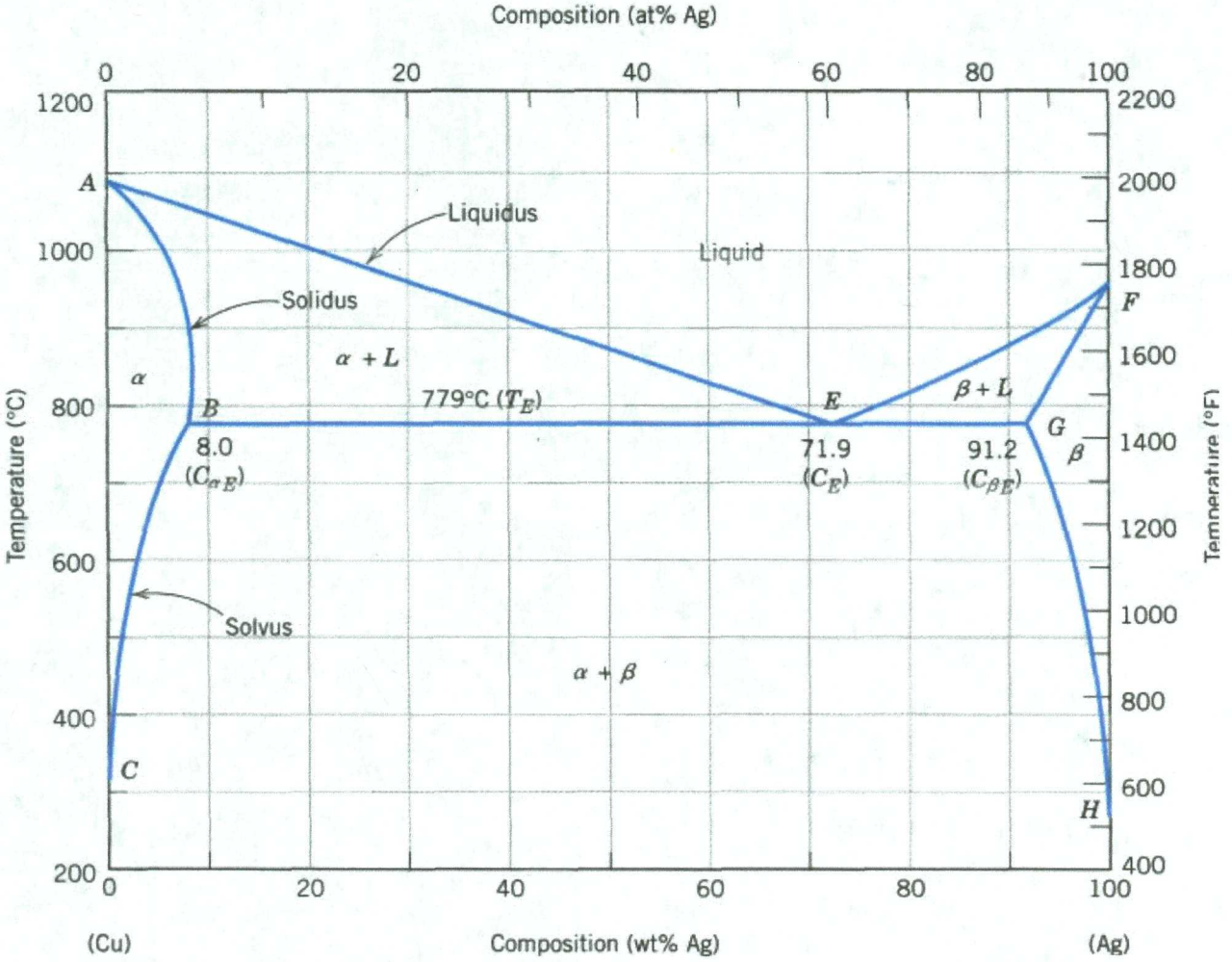
   a. On the next page, in the circles drawn, sketch the microstructure that results from slow cooling from the liquid to T=778°C, for the following alloy compositions: (i) 5 wt. % Ag, (ii) 20 wt. % Ag, and (iii) 71.9 wt. % Ag.

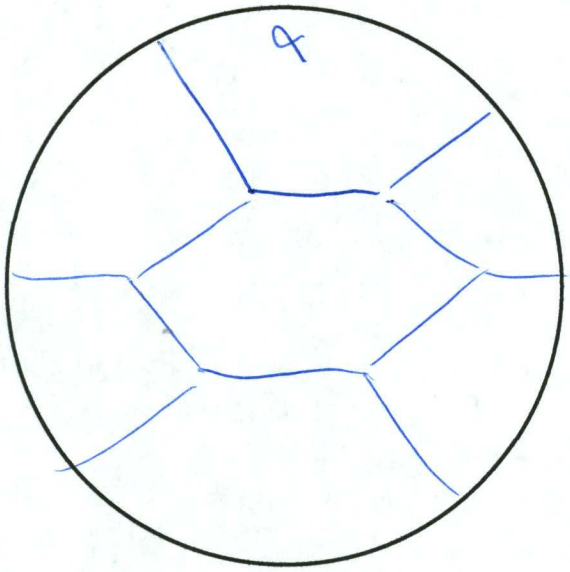
   b. For each composition given in part (a) list the phases that are present and the weight fraction of each phase resulting from a slow cool from the liquid to T=778°C.

(i) α wt. fraction = 1

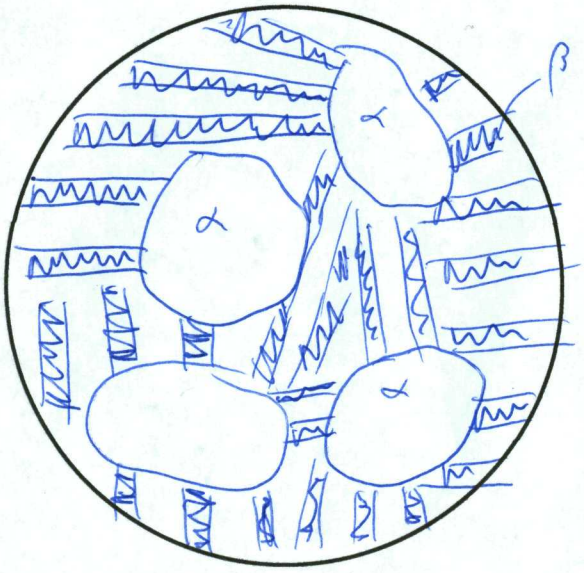
(ii) $\alpha+\beta$ $W_\alpha = \frac{91.2-20}{91.2-8} = \frac{71.2}{83.2} = 0.86$ $W_\beta = 0.14$

(iii) $\alpha+\beta$ $W_\alpha = \frac{91.2-71.9}{91.2-8} = 0.23$ $W_\beta = 0.77$

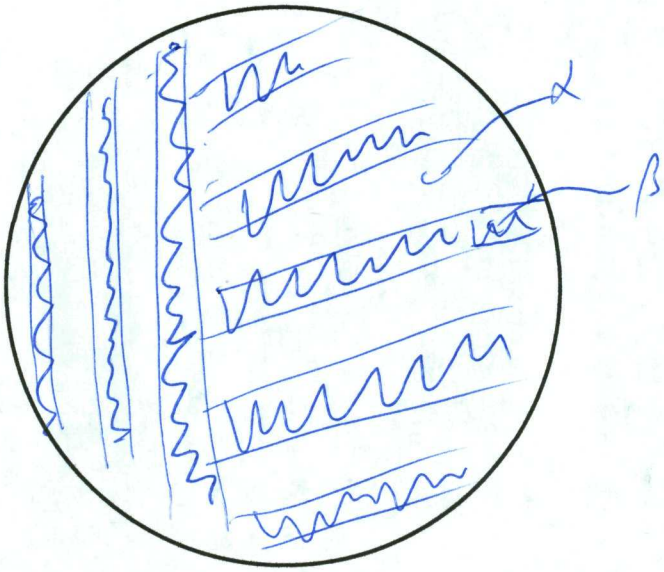




5 w. % Ag



20 wt. % Ag



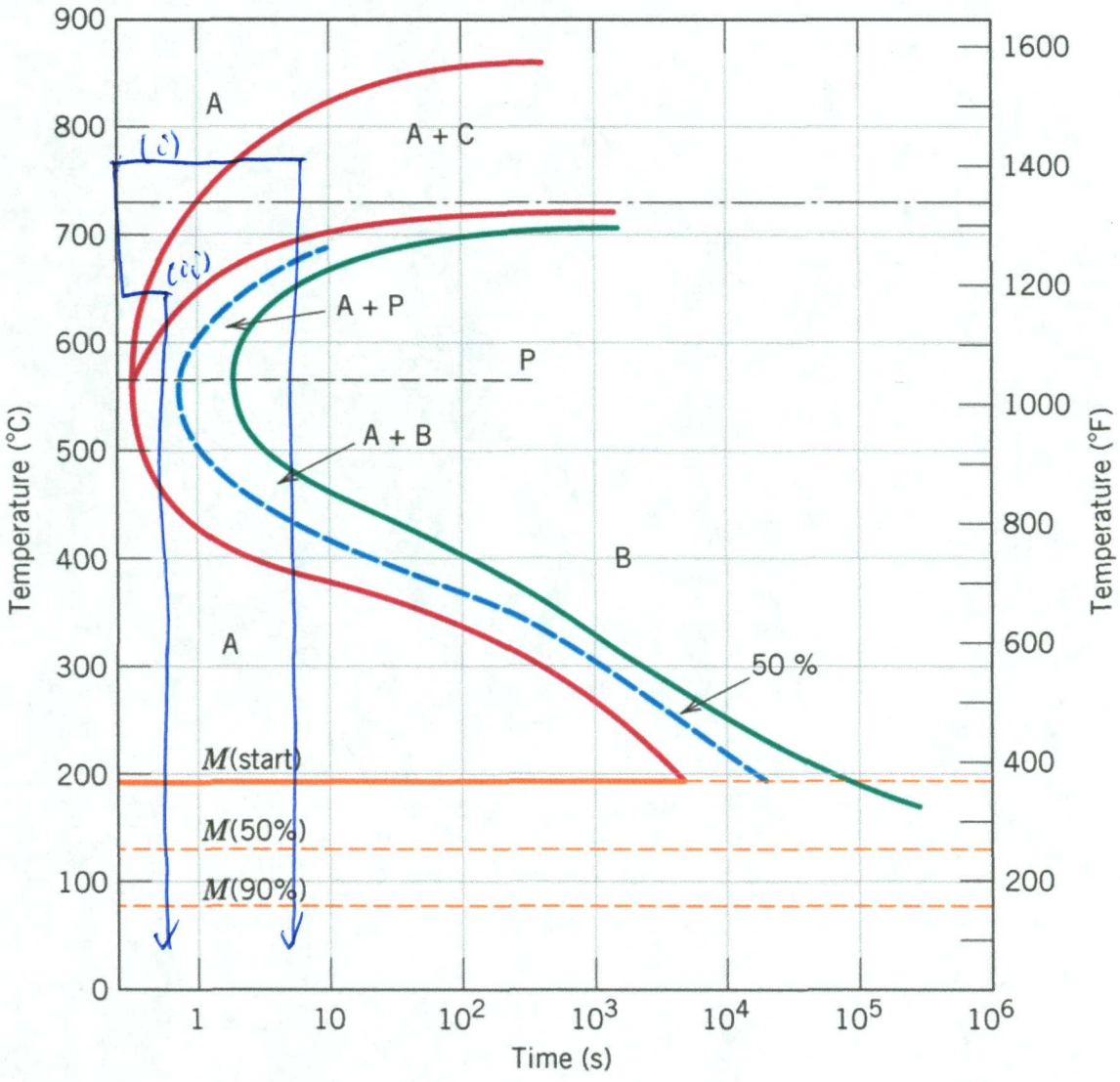
71.9 wt. % Ag

2. Shown below is a time-temperature-transformation (TTT) diagram for a steel with a hypereutectoid composition.

   a. Draw a path on the TTT diagram that leads to formation of a microstructure with only cementite and martensite microconstitutents. Either (i) or (ii) works

   b. List the microconstituents that would result from a rapid quench to 500°C, followed by an isothermal age for 1 second and then a rapid quench to room temperature. Give the fraction of each of these microconstituents and briefly (a couple of sentences) explain your answer. 50% Bainite, 50% Martensite

Age at 500°C leads to transformation of 50% of A to B. Subsequent quench leads to transformation of remaining A to Martensite



3. This problem relates to the diffusion of elements in a crystalline solid.

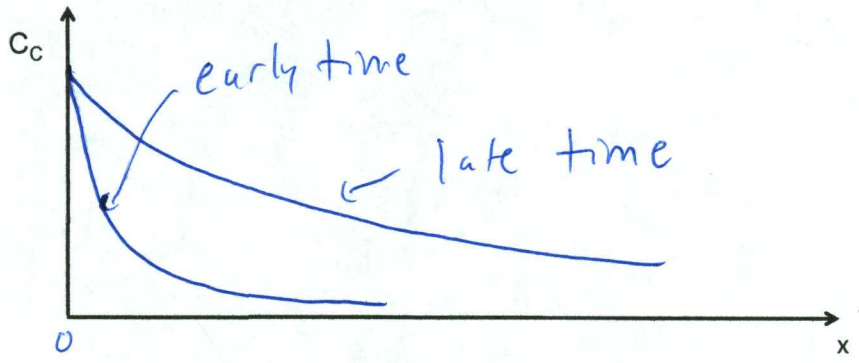
   a. Give an expression for the activation energy for diffusion in the case of interstitial and substitutional diffusion. Based on your expressions, explain why the diffusion coefficient for an element undergoing interstitial diffusion is typically much larger than that for an element undergoing substitutional diffusion.

substitutional: $Q = Q_v + Q_m$ (Q_v: vacancy formation, Q_m: vacancy migration)

interstitial: $Q = Q_m$ (migration)

Due to contribution of Q_v the value of Q is typically larger for substitutional diffusion. Since $D = D_0 \exp[-Q/kT]$, larger Q implies smaller D

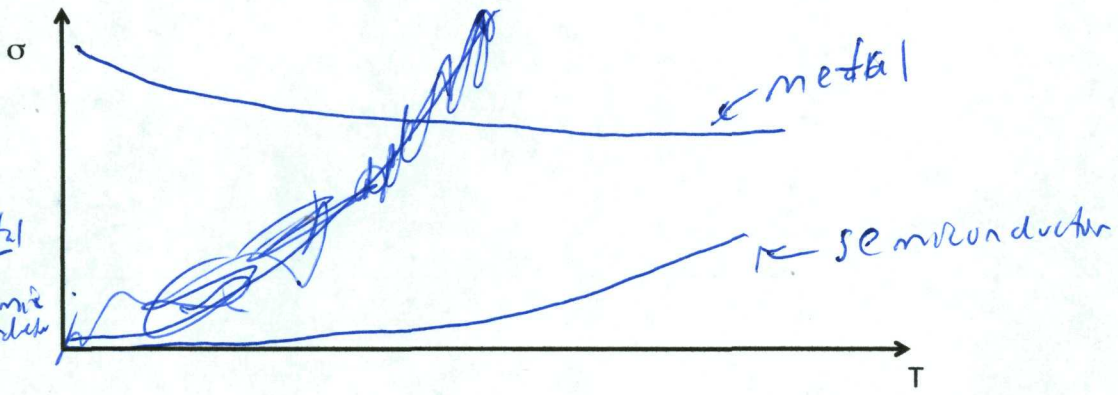
   b. When a steel sample is exposed to an atmosphere rich in carbon, the hardness of the region near the surface increases over time, through a process known as carburization. On the plot below, sketch the expected profile of the carbon concentration (C_C) as a function of distance from the surface (x) at an early and later time. Explain using your sketch why the hardness of the surface region is higher at the later time. In the sketch let x=0 be the surface of the steel.



As time increases, more carbon diffuses into steel, leading to an increase in carbon content and thus increase in hardness in near surface region

4. This problem relates to electrical conductivity.

a. On the plots below make a sketch of the conductivity versus temperature for (i) a metal, (ii) an intrinsic semiconductor, and briefly explain the differences.

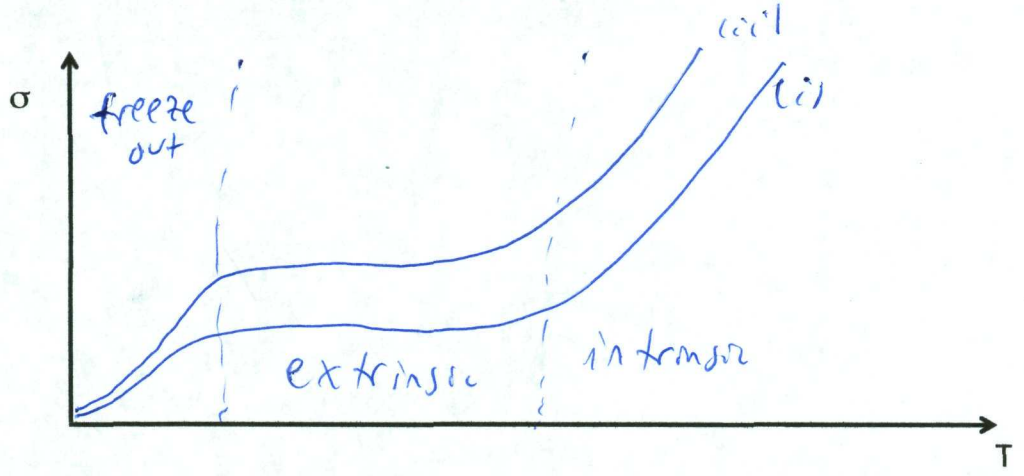


$\sigma = ne\mu$ metal

$\sigma = ne(\mu_e + \mu_h)$ semiconductor

For metal the conductivity decreases with increasing T because mobility decreases. For semiconductor the conductivity increases with T due to strong increase in carrier concentrations (electrons and holes)

b. On the plot below make a sketch of the conductivity versus temperature for (i) an extrinsic n-type semiconductor with a donor dopant concentration of N_D, and (ii) an extrinsic p-type semiconductor with an acceptor dopant concentration of $N_A = 2N_D$. Label the regions of freeze-out, extrinsic conduction and intrinsic conduction.



If $\mu_e \simeq \mu_h$ then σ should be larger for (ii) since doping level is higher

5. Consider two materials A and B used for window glass applications. It is found that it is possible for a person to be sunburned through windows made of A, but not for B.

   a. Given that sunburn is caused by ultraviolet light, which material has a larger bandgap? Briefly explain your answer.

A has higher band gap, because it transmits ultraviolet light while B does not. B thus absorbs UV light due to smaller bandgap.

   b. What is a possible value for the bandgap of material B in eV? Note: both A and B are transparent to visible light, as required for window glass applications. The energy of light in visible and ultraviolet regions is given below.

B transmits visible light for $E_{gap} \geq 3.1$ eV

B absorbs UV so bandgap must be right around 3.1 eV

COLOR	WAVELENGTH	ENERGY
Red	700 nm	1.771 eV
Reddish orange	650 nm	1.909 eV
Orange	600 nm	2.067 eV
Yellow	580 nm	2.138 eV
Yellowish green	550 nm	2.254 eV
Green	500 nm	2.480 eV
Blue	450 nm	2.765 eV
Violet	400 nm	3.100 eV

Wavelengths and energy of visible light (from K.Nassau, "Experimenting with Color")