Problem 1: This problem concerns the Pb-Sn system, the phase diagram for which is reproduced on pages 3 and 4.

(a) (10 points) On page 3, sketch Gibbs free energy curves as a function of composition for the Pb, Sn and liquid phases at a temperature of 250°C. Use the common tangent construction to identify the regions of single-phase and two-phase stability. Your sketch should be consistent with the phase boundary compositions given by the phase diagram.

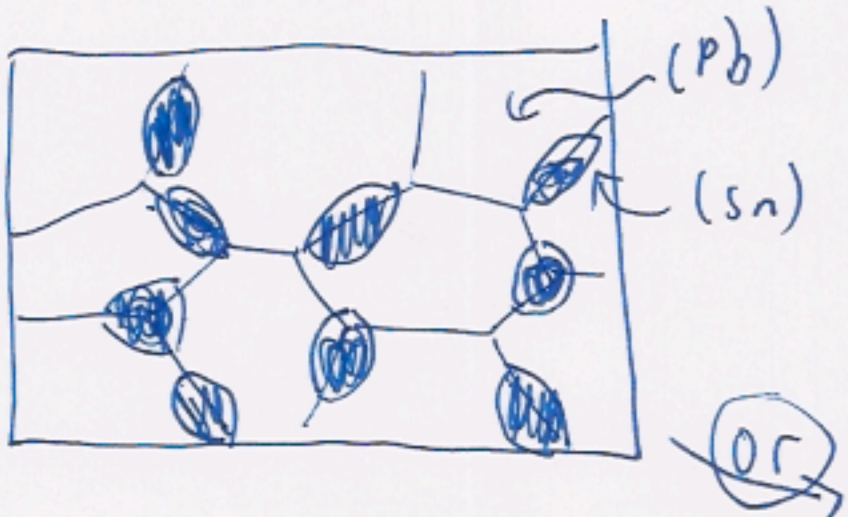
(b) (10 points) For an alloy with 80 at. % Sn, what is the composition of the first solid to form upon slow cooling from the melt? What is the composition of the last remaining liquid left during cooling? Give your answer on page 4 using the copy of the phase diagram included on that page to show your work.

(c) (10 points) Shown on page 5 is the microstructure of an alloy with 80 at. % Sn that formed through slow cooling to room temperature. On page 5, list which phases are present and which phase gives dark contrast and which gives light contrast. Explain your answer.

(d) (10 points) For the microstructure considered in part (c) what fraction of atoms are in the eutectic microconstituent of the microstructure? Use the space on page 5 to show your work and give your answer.

(e) (10 points) Using the space below on this page, sketch the microstructure of an alloy with 30 ~~28~~ at. % Sn resulting from slowly cooling from the melt to 30°C. On your sketch label the phases present and use the lever rule to determine the equilibrium atomic fraction of each of these phases.

30 ~~28~~ at. % Sn is ~~the~~ approximately the ~~eutectic~~ composition of (Pb) at the eutectic temperature

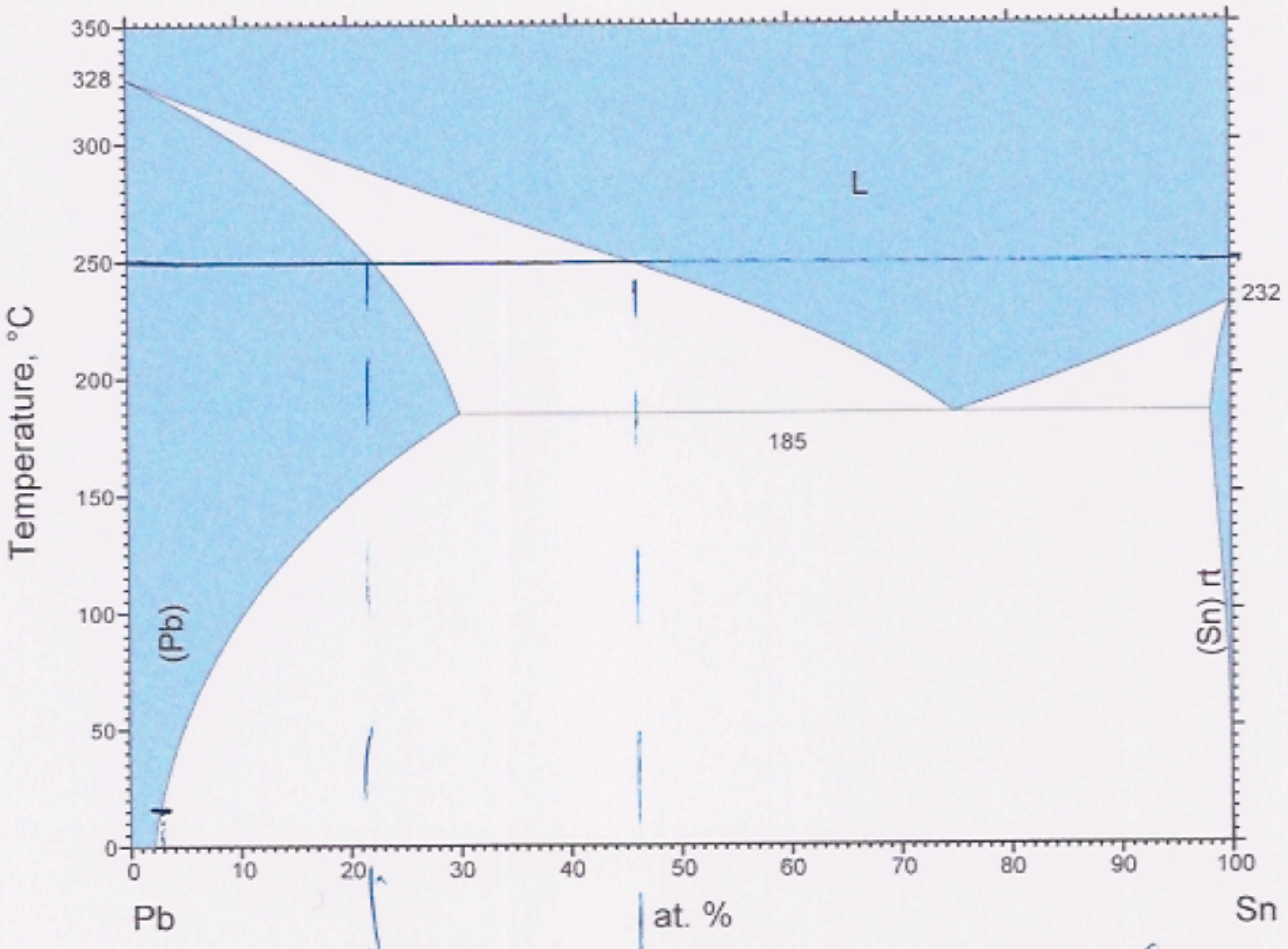


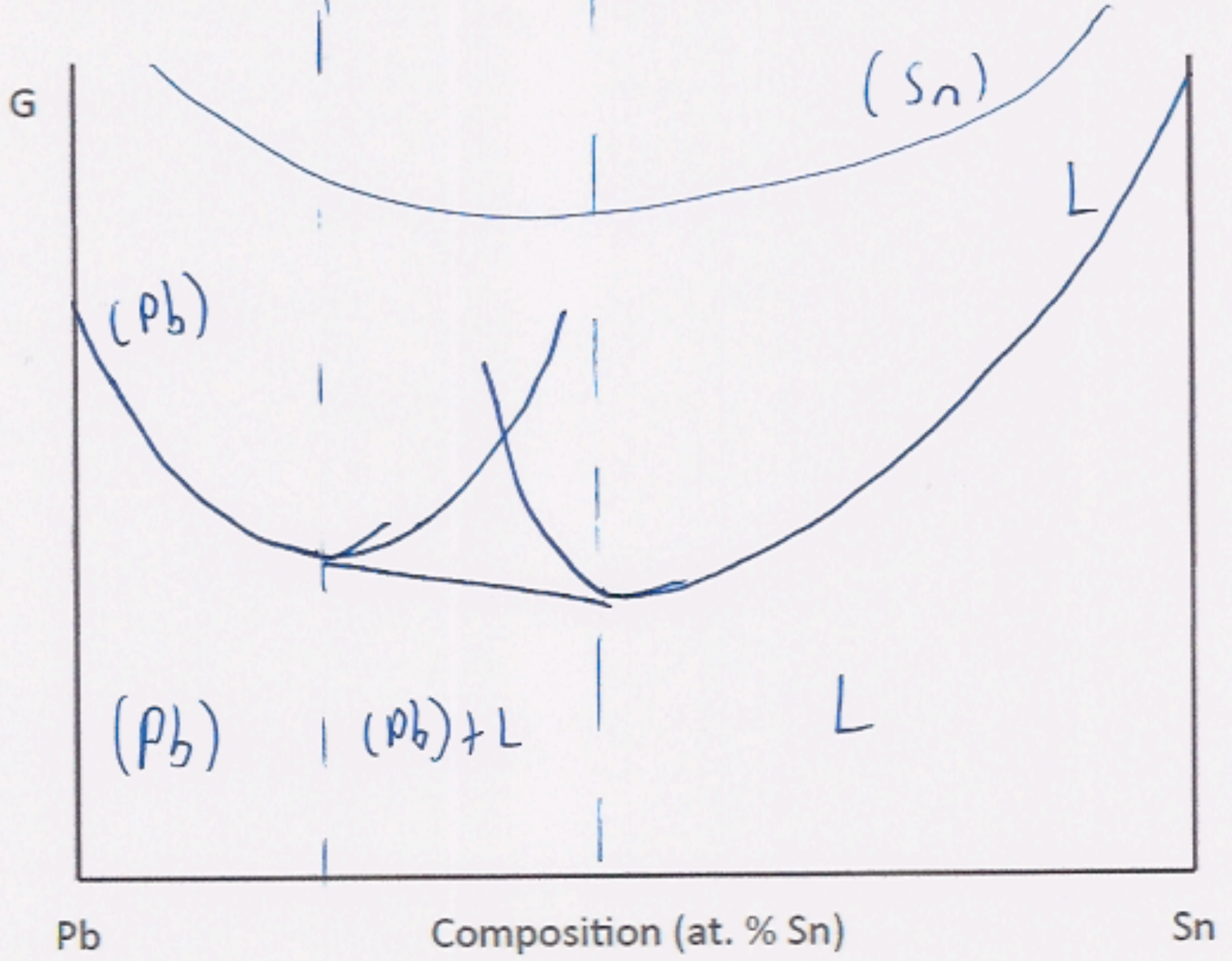
$f_{(Pb)} \approx \frac{1-0.3}{1-0.03} \doteq 0.72$

$f_{(Sn)} = 0.28$

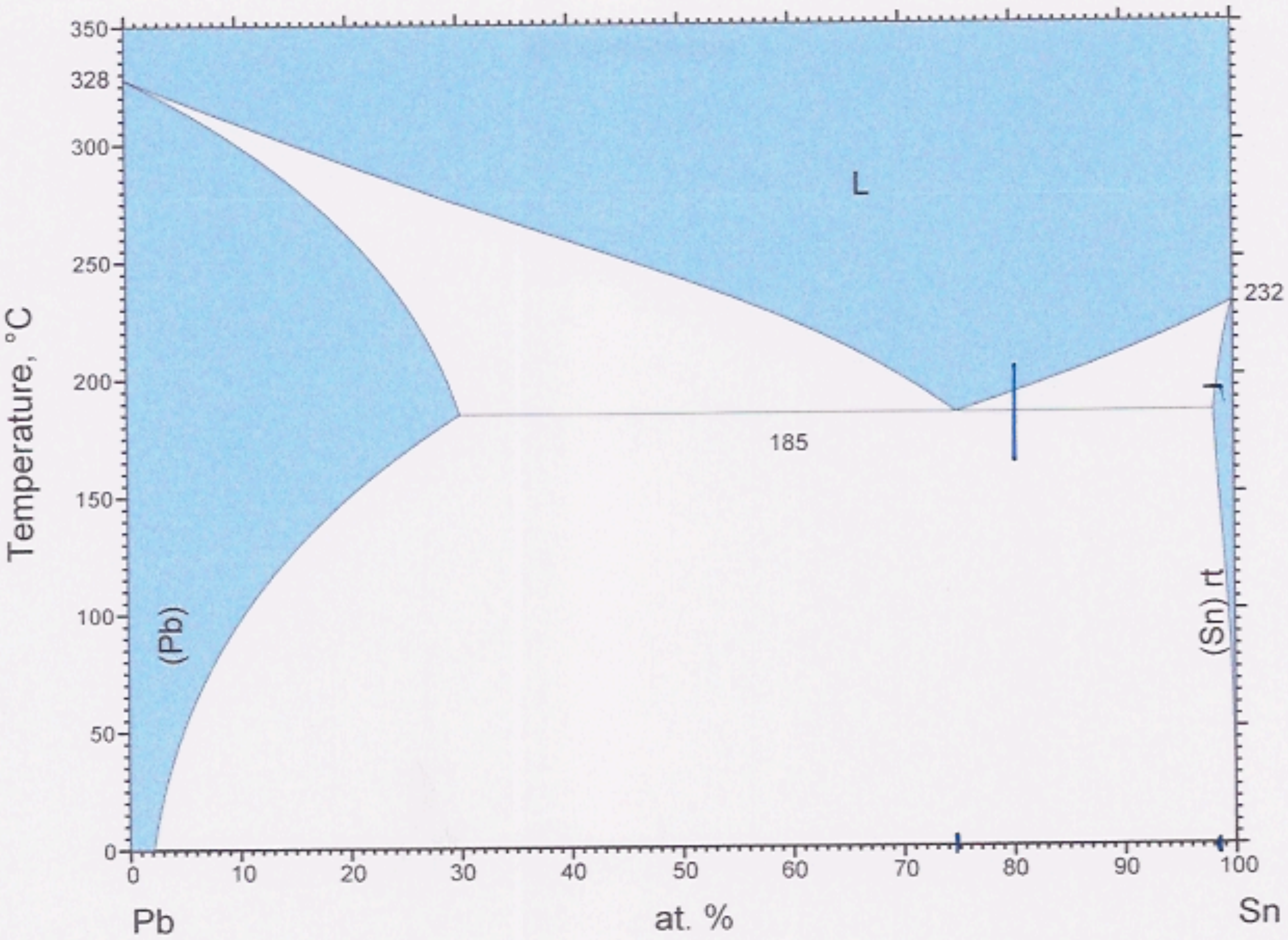
or

For problem 1 (a)





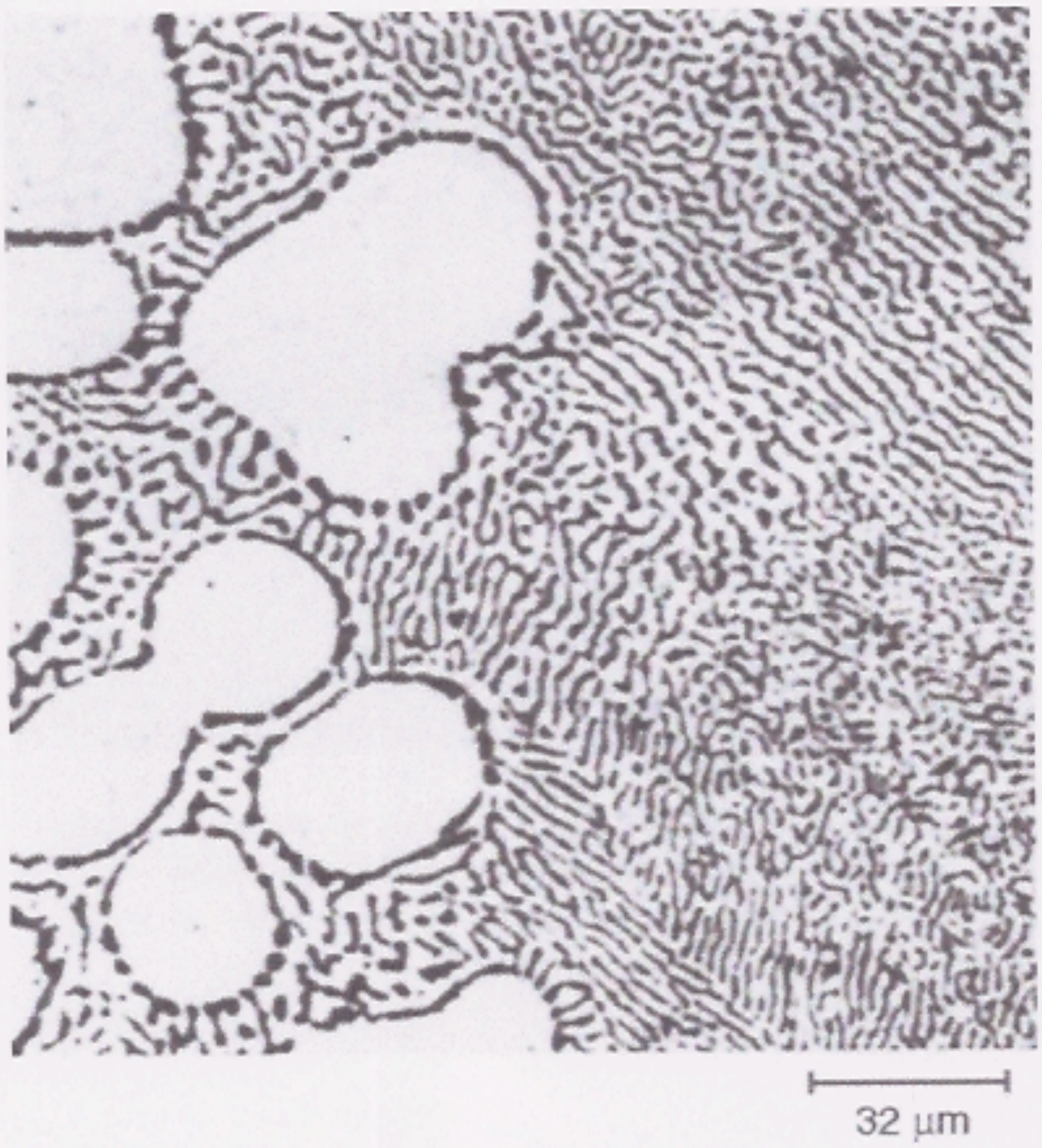
For problem 1(b)



First solid: (Sn) with ≈ 98.5 at. % Sn

Last liquid: Eutectic composition ≈ 75 at. % Sn

For problems 1 (c) and 1 (d):



Microstructure of a solidified Pb-Sn alloy containing 80 at. % Sn.

(d)

$$f_{eutectic} = \frac{C_{(Sn)}(T_E) - C_0}{C_{(Sn)}(T_E) - C_E} = \frac{0.985 - 0.8}{0.985 - 0.75} = 0.787$$

(c) Phases present: (Sn) and (Pb)

Bright contrast: (Sn) since it is the first phase to form on cooling and is the primary phase in the micrograph, which is bright.

Dark contrast: (Pb)

Problem 2: Shown on page 7 is the time-temperature-transformation (TTT) diagram for an Fe-C alloy, with three time-temperature paths indicated. In the TTT diagram A, F, P, B and M stand for Austenite, Ferrite, Peralite, Bainite and Martensite, respectively.

(a) (10 points) Relation to phase diagram.

  i. (5 points) Is the composition of this steel hypoeuctoid, eutectoid or hypereutectoid? Explain.

Hypo eutectoid because of presence of hypo eutectoid F

  ii. (5 points) On the TTT diagram indicate the eutectoid temperature.

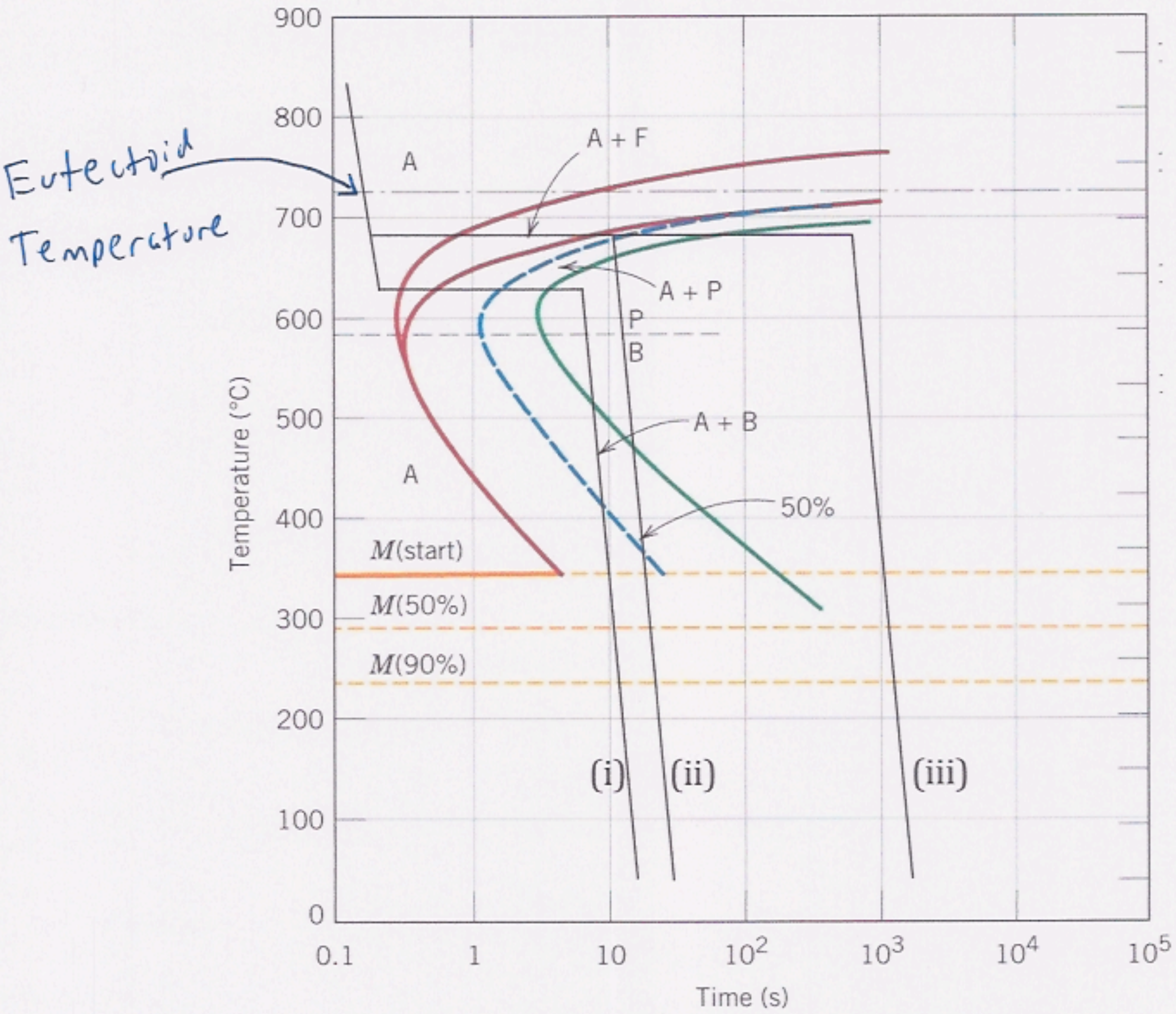
See diagram

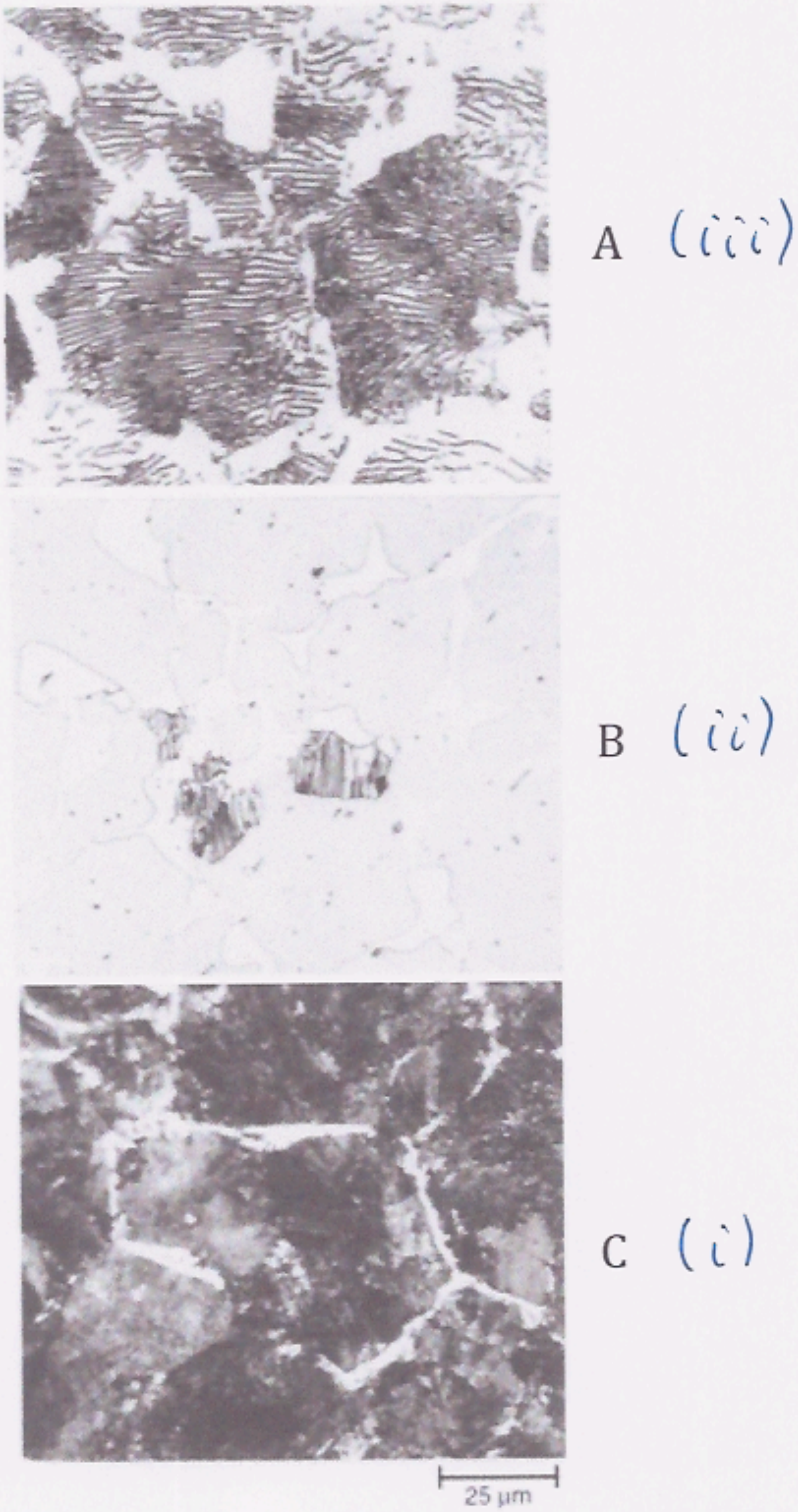
(b) (10 points) On page 8 are shown three micrographs: A, B and C. Next to each micrograph indicate which corresponds to path (i), which to path (ii) and which to path (iii) in the TTT diagram below. Explain your answers.

A ⇔ (iii) because it shows hypoeutectoid ferrite and relatively coarse pearlite

B ⇔ (ii) because it shows martensite, ferrite and pearlite

C ⇔ (i) because it shows fine pearlite and hypoeutectoid ferrite in smaller fraction than A


Eutectoid Temperature
900
800
700
600
500
400
300
200
100
0
Temperature (°C)
A
A + F
A + P
P
B
A + B
A
50%
M(start)
M(50%)
M(90%)
(i)
(ii)
(iii)
0.1
1
10
10^2
10^3
10^4
10^5
Time (s)



In the three micrographs above the white regions (brightest) are ferrite, the dark are cementite and the intermediate (grey) is martensite.

Problem 3: In a certain metal the self-diffusion constant (D) at a temperature of $T_1 = 900$ K is measured to be $D(T_1) = 5.25 \times 10^{-7}$ cm^2/s. The vacancy formation energy for this metal is $Q_v = 0.7$ eV and the vacancy migration energy is $Q_m = 0.6$ eV.

(a) (10 points) What is the value of D at a temperature of $T_2 = 600$ K.

$$D(T_2) = D(T_1) \times \frac{\exp\left[-\frac{Q_d}{kT_2}\right]}{\exp\left[-\frac{Q_d}{kT_1}\right]}$$

$$Q_d = Q_m + Q_v = 1.3\,eV$$

$$D(T_2) = 1.20 \times 10^{-10}\ cm^2/s$$

(b) (20 points) Suppose that when the metal is quenched from $T_1 = 900$ K to $T_2 = 600$ K it maintains a vacancy concentration equal to the equilibrium value at T_1 for a few minutes before it equilibrates to its equilibrium value at T_2.

i. (10 points) What is the value of D at T_2 during this initial period of time?

$$D(T_2) = D(T_1) \times \frac{\exp\left[-\frac{Q_m}{kT_2}\right]}{\exp\left[-\frac{Q_m}{kT_1}\right]} = 1.09 \times 10^{-8}\ cm^2/s$$

(see next page)

ii. If the electrical conductivity of the metal is measured during this initial period of time at T_2, would it be larger or smaller than the value obtained much later, after the vacancy concentration equilibrates at T_2? Explain your answer.

Lower because more vacancy scattering means lower mean free path means lower mobility.

$$D(T) = \frac{1}{6} a^2 \nu \, [C_v] \exp\left[-\frac{Q_m}{kT}\right]$$

<u>In this case:</u>

$$D(T_2) = \frac{1}{6} a^2 \nu \left[C_v(T_1)\right] \exp\left[-\frac{Q_m}{kT_2}\right]$$

$$D(T_1) = \frac{1}{6} a^2 \nu \left[C_v(T_1)\right] \exp\left[-\frac{Q_m}{kT_1}\right]$$

$$\Downarrow$$

$$\frac{D(T_2)}{D(T_1)} = \frac{\exp\left[-\frac{Q_m}{kT_1}\right]}{\exp\left[-\frac{Q_m}{kT_2}\right]}$$