

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
**Thermodynamics of Materials**

3.00 Fall 2000

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77 Massachusetts Ave.

Cambridge, MA 02139

Final Exam: Friday December 22, 2000 (9AM-NOON) 4-237

**NAME:** \_\_\_\_\_

This exam is composed of three questions. Please read them carefully and thoughtfully before you answer.

Your answers should fit in the space provided in the exam. If you find that the provided space is insufficient, use the back of the previous page and clearly indicate that your answer continues.

You may wish to work your answer out on scratch paper before writing on the exam. Your answers will be graded on their accuracy, physical insight, and clarity. A concise clear answer will get a better score with a longer answer with the same content. You may supplement your answer with a figure, a plot, or equations. Your answers will be graded in their entirety—extraneous or irrelevant equations or remarks may reduce the clarity or accuracy of your answer.

The questions are not necessarily ordered according to their difficulty—it would be prudent to read them all before you start. Finally, each question is not weighted equally in the grading; the weights are given below.

Question 1: 72 points possible \_\_\_\_\_

Question 2: 14 points possible \_\_\_\_\_

Question 3: 14 points possible \_\_\_\_\_

Total: 100 points possible \_\_\_\_\_

## Exam Question 1

1-i What is the difference between heat and temperature?

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1-ii Two questions on implications of the laws of thermodynamics:

1-ii-a State one physical consequence of the the first law of thermodynamics and describe how it relates to the first law.

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1-ii-b State one physical consequence of the second law of thermodynamics and describe how it relates to the second law.

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1-iii What is the maximum number of phases that can be in equilibrium in an alloy with six possible components at 1 atmosphere pressure?

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1-iv Two questions on conditions for equilibrium:

1-iv-a What is a necessary condition of equilibrium for a closed system in thermal and mechanical equilibrium with a reservoir at fixed pressure and temperature?

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1-iv-b How would you distinguish between systems that are locally stable, globally stable and unstable?

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1-v Two questions on the common tangent construction:

1-v-a What is the common tangent construction?

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1-v-b What does the common tangent construction represent physically (e.g., from what physical principle does it derive) and how is it used?

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1-vi Suppose a gram of carbon graphite is placed in equilibrium with pure oxygen gas at one atmosphere pressure and at 300K. Demonstrate how you would predict the equilibrium composition of the gas. You may designate a  $\Delta\overline{G}$  for any reactions that you might require for your solution.

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1-vii Draw an example of a peritectic phase diagram for a two-component alloy and clearly describe what it represents.

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1-viii From the regular solution model an expression for the molar free energy of mixing can be derived in terms of the parameters:  $X_B$ ,  $z$ ,  $\omega_{AA}$ ,  $\omega_{BB}$ , and  $\omega_{AB}$  (the average composition, the number of bonds per atom, and,  $\omega_{ij}$ , the energy of a single  $i$ - $j$  bond respectively).

If a regular solution exhibits a miscibility gap at very low temperatures, what if anything can be inferred about the parameters of the model?

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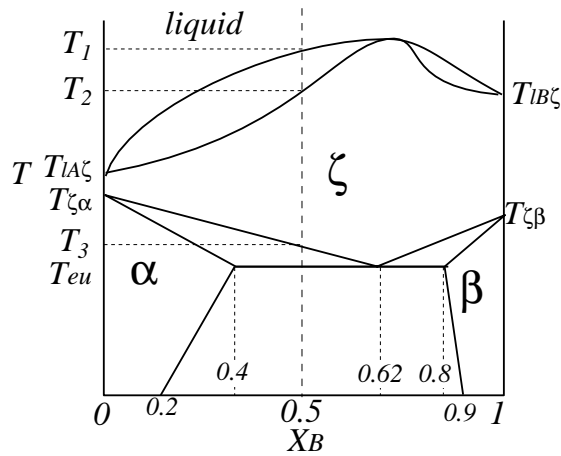
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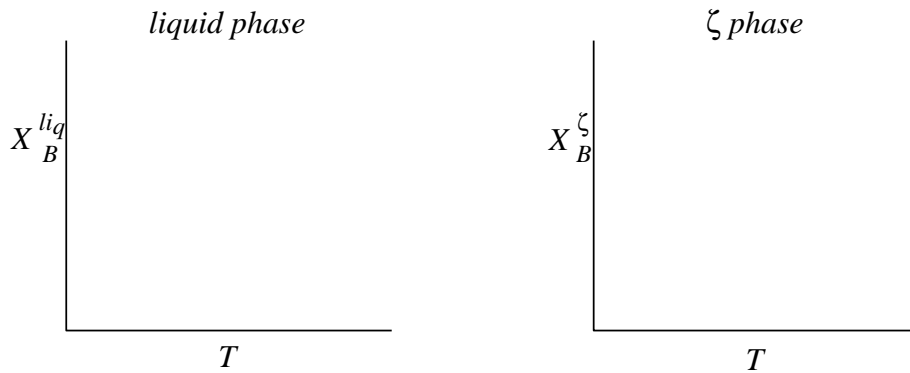
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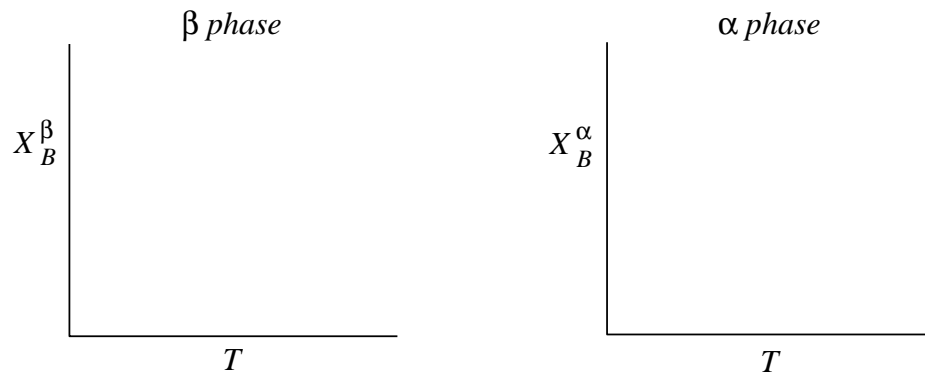
1-ix Plot the equilibrium compositions and phase fractions:



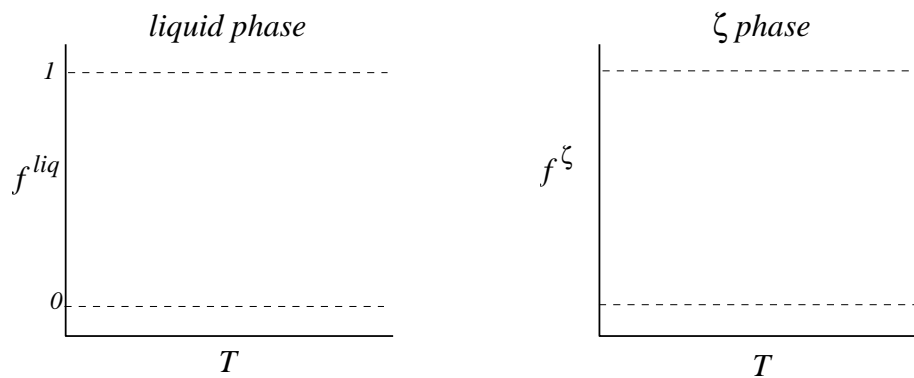
Use the above phase diagram to answer the following question. The average alloy composition illustrated by the dashed line ( $X_B = 1/2$ ) is indicated for your qualitative plots for the equilibrium concentrations of the existing equilibrium phases and their phase fractions as a function of temperature in the diagrams provided below and on the following page.



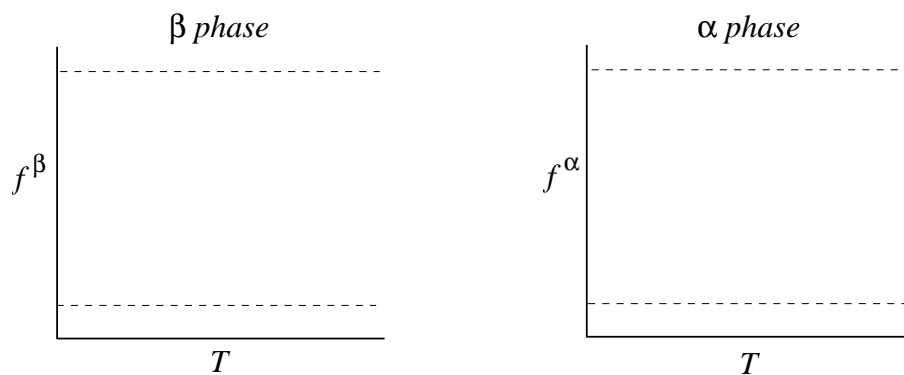
Plot the compositions as a function of temperature in the *liquid* and  $\zeta$  phases at every temperature that they exist at equilibrium for average alloy composition  $X_B = 0.5$ . Signify the compositions and temperatures by using the values indicated in the phase diagram. Your plot need only be qualitatively correct.



Plot the compositions as a function of temperature in the  $\beta$  and  $\alpha$  phases at every temperature that they exist at equilibrium for average alloy composition  $X_B = 0.5$ . Signify the compositions and temperatures by using the values indicated in the phase diagram. Your plot need only be qualitatively correct.



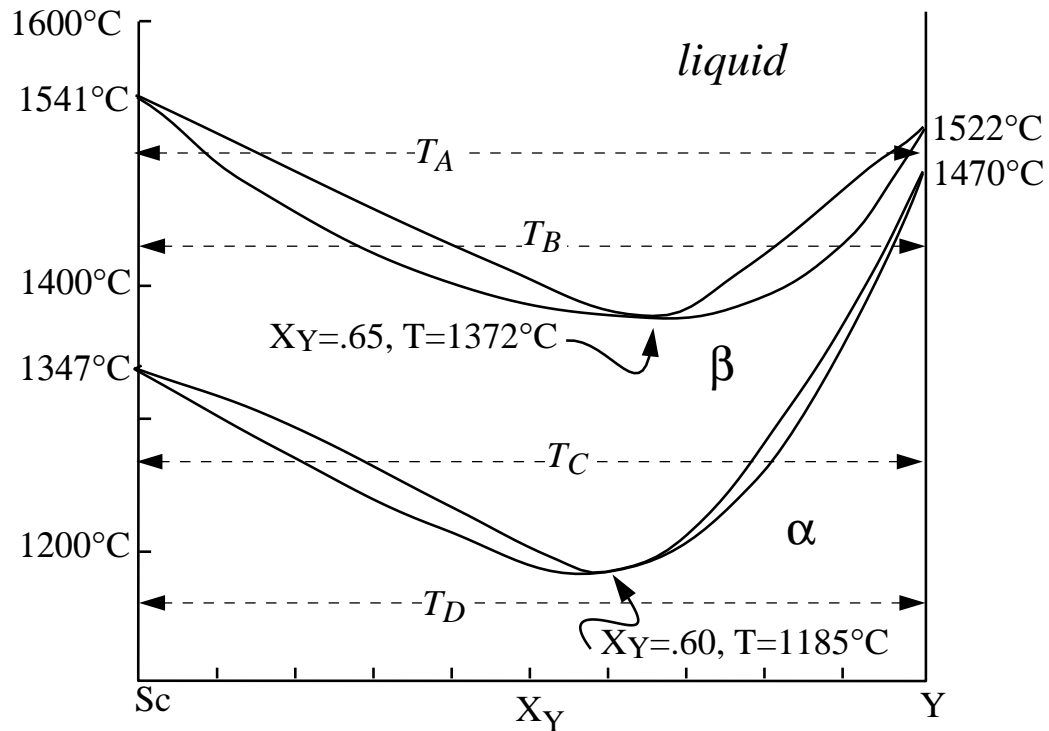
Plot the phase fractions of the *liquid* and  $\zeta$  phases as a function of temperature. Signify the temperatures by using the values indicated in the phase diagram. Your plot need only be qualitatively correct.



Plot the phase fractions of the  $\beta$  and  $\alpha$  phases as a function of temperature. Signify the temperatures by using the values indicated in the phase diagram. Your plot need only be qualitatively correct.

## Exam Question 2

An experimentally determined binary phase diagram for the Scandium-Yttrium system is shown below:



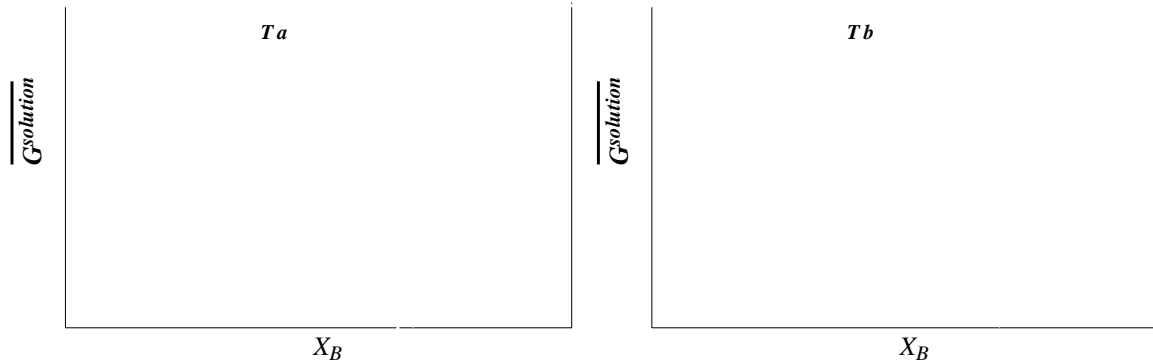
Experimentally determined binary phase diagram at atmospheric pressure. The scale at top is the atomic composition.

For each of the four temperatures ( $T_A$ ,  $T_B$ ,  $T_C$ , and  $T_D$ ) illustrated in the diagram, draw a plausible set of Molar Gibbs Free energy curves for solutions of any stable *and not-stable* phases corresponding to the phase diagram. *Please show your work on the axes provided on the following page.*

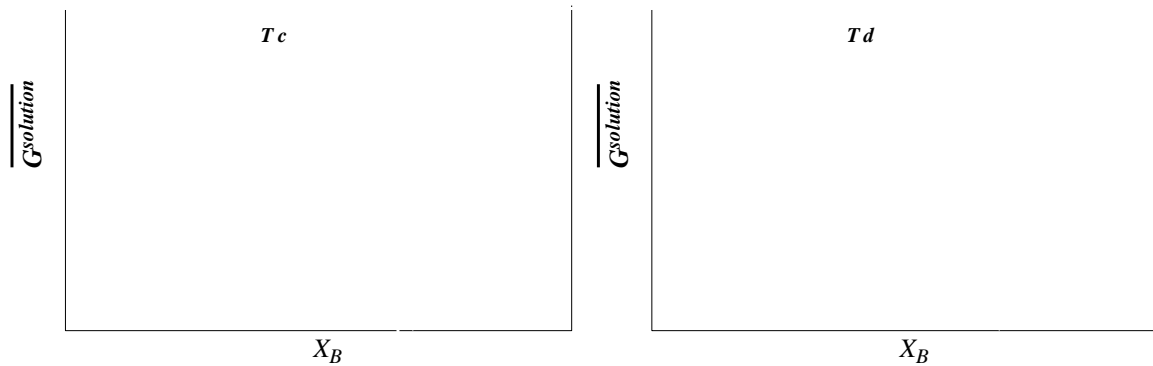
Clearly label any relevant points on your diagram; you may draw corresponding labels on the phase diagram if you find it to be useful.

Workspace provided on the next page.

Problem 2 workspace:

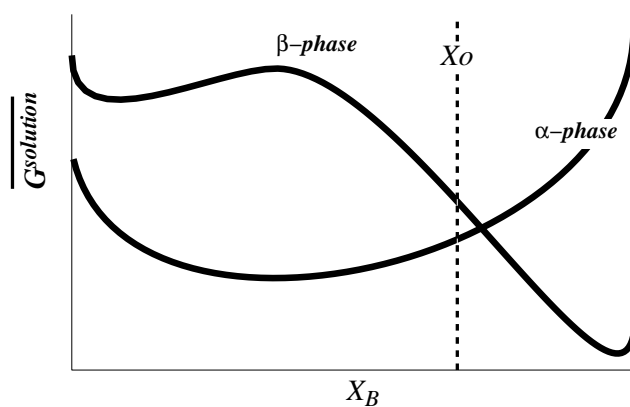


Draw a set of plausible molar free energy of solution curves for temperatures  $T_a$  and  $T_b$  for the Sc-Y system. Carefully identify any relevant points or curves.

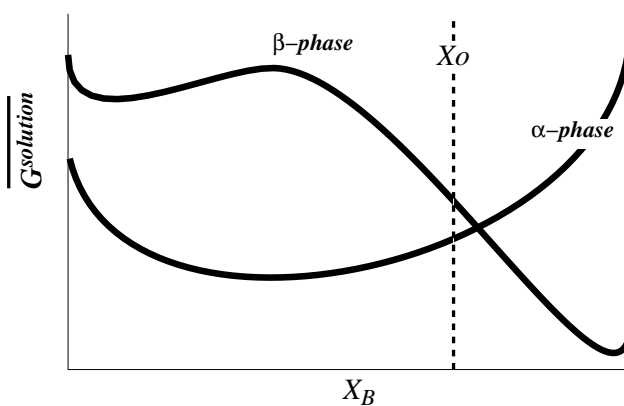


Draw a set of plausible molar free energy of solution curves for temperatures  $T_c$  and  $T_d$  for the Sc-Y system. Carefully identify any relevant points or curves.

### Exam Question 3

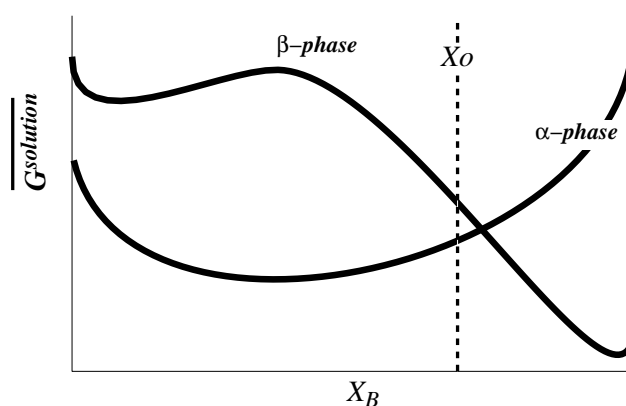


Molar Gibbs Free energy of solution, drawn at  $T$  and  $P$  constant, for an  $\alpha$ -phase and a  $\beta$ -phase.



3-i

What is the most stable state of the system at an average composition of  $X_o$ ? You may use the plotted curves to help illustrate your answer.



3-ii

Suppose the  $\alpha$ -phase was somehow prevented from forming (i.e., consider the equilibrium under the constraint that the  $\alpha$ -phase is absent). In this case, what would be the equilibrium state of the system with average composition  $X_o$ ? You may use the plotted curves to help illustrate your answer.

3-iii Using the molar free energy curves as guidance, rank the following systems with an average composition of  $X_o$ , from most stable to least stable (*A magnified version of the free energy curves are provided on the following page to help you*):

3-iii-a A combination of two  $\beta$ -phases, one with composition pure  $A$  and the other pure  $B$ .

3-iii-b The answer in part 1 above.

3-iii-c A combination of an  $\alpha$ -phase with composition pure  $A$  and  $\beta$ -phase with composition pure  $B$ .

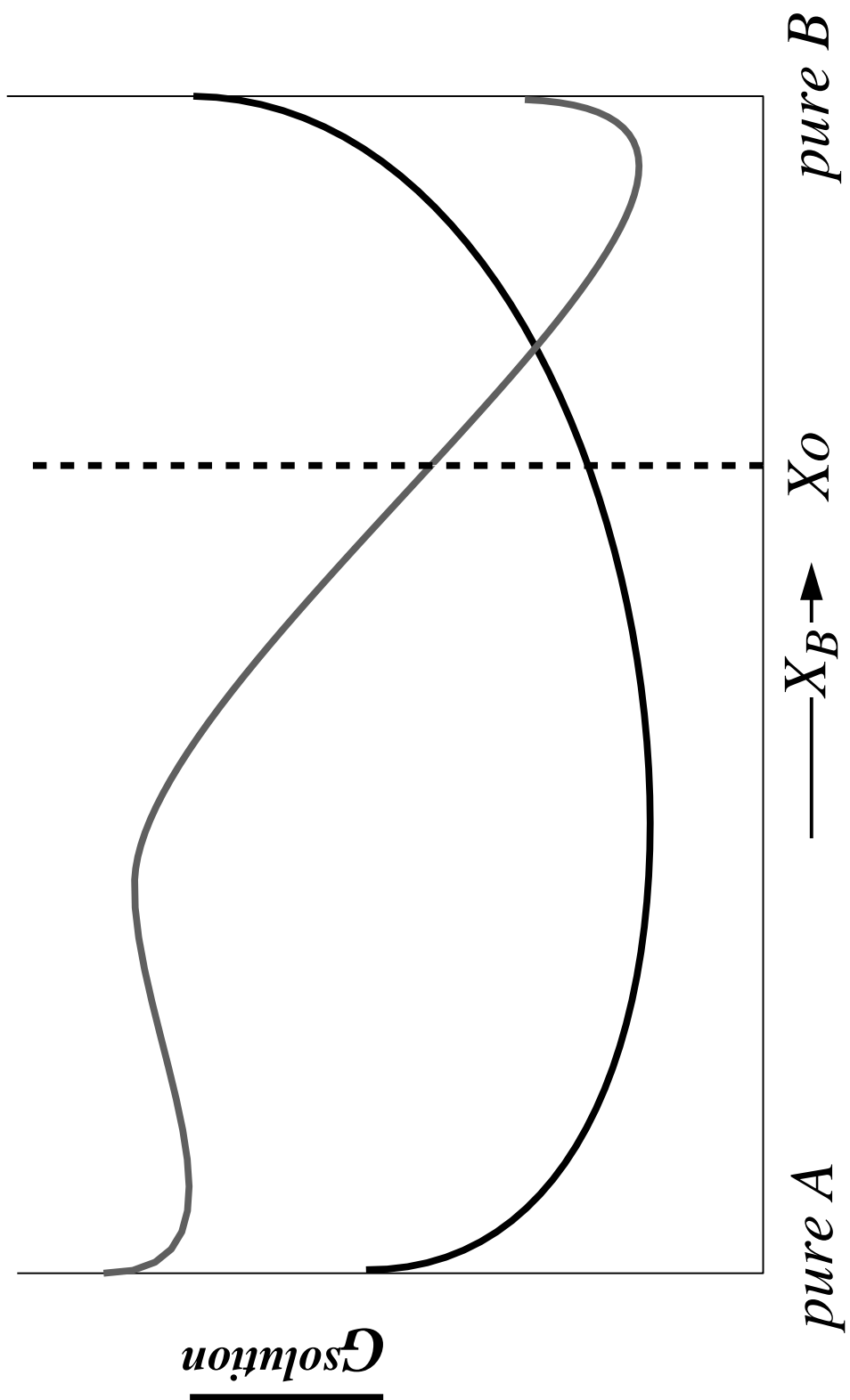
3-iii-d A combination of two  $\alpha$ -phases, one with composition pure  $A$  and the other pure  $B$ .

3-iii-e The answer in part 2 above.

3-iii-f A single  $\beta$ -phase at composition  $X_o$ .

3-iii-g A single  $\alpha$ -phase at composition  $X_o$ .

3-iii-h A combination of an  $\alpha$ -phase with composition pure  $B$  and  $\beta$ -phase with composition pure  $A$ .



Large version of the molar free energy curves.