Department of Materials Science and Engineering

DOCTORAL WRITTEN EXAM
May 22, 2014

Please follow these instructions:

Your exam packet contains 3 questions from each core area for which you signed up, along with several answer sheets. A copy of the Table of Constants is included for your reference. **<u>You must submit 2 questions from each core area you are taking for grading</u>**. You will have 1 1/2 hours to complete each section. You can obtain extra answer sheets from the proctor, if needed. Please use the following procedure:

1. Write a four (4) digit code of your choice, and your name on the page provided. Use this code in place of your name to identify <u>all</u> answer sheets you submit for both days of the exam. Renee will keep the code information, sealed in an envelope, until after the exams are graded.

2. For each answer, use the question sheet as the first page of your answer. If additional pages are required, use the blank answer sheets provided. **At the end of the examination, staple each question sheet and corresponding answer sheets for each question separately,** put this instruction sheet on top of the questions you are turning in, and place them in one side of your exam folder. Place <u>all</u> other exam pages in the other side of your folder, and return <u>everything</u> to Renee if you finish before your time is up.

<u>Please be sure to complete the information required on each page</u>.

Name________________________________ **CODE NUMBER** _____________

<u>CHECK THE QUESTIONS YOU WISH TO HAVE GRADED:</u>

Materials Physics <u>And Chemistry:</u>

1. _____
2. _____
3. _____

Advanced Mechanical <u>Behavior:</u>

4. _____
5. _____
6. _____

Advanced Thermodynamics <u>Of Materials</u>

7. _____
8. _____
9. _____

Kinetics and Phase <u>Transformations</u>

10. ______
11. ______
12. ______

<u>Structure of Materials</u>

13. ______
14. ______
15. ______

10.

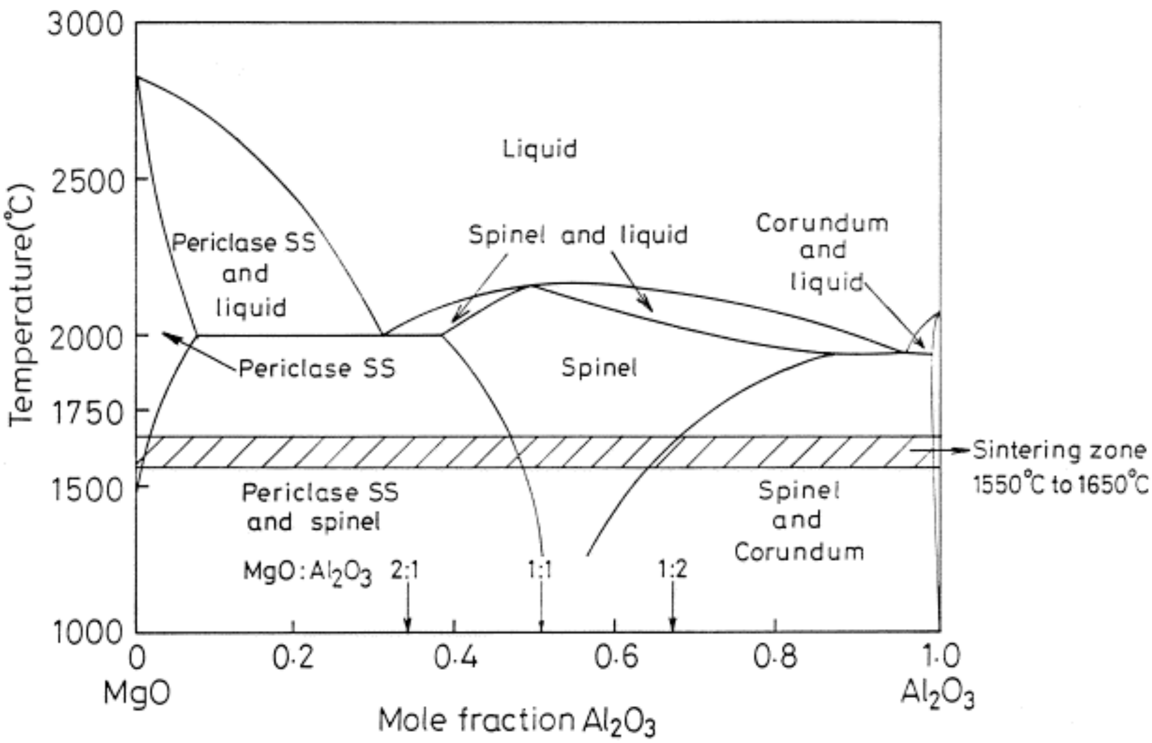
Magnesium oxide (MgO) and aluminum oxide (Al_2O_3) form spinel ($MgAl_2O_4$) via solid-state reaction:

$$MgO + Al_2O_3 \xrightarrow{k} MgAl_2O_4$$

a) Assuming that the rate-limiting mechanism in spinel growth consists of the diffusion of Al and Mg cations across the spinel layer in opposite directions, while maintaining charge neutrality, devise a simple kinetic rate equation that yields the thickness of the spinel layer as a function of time. Assume planar interfaces and one-dimensional fluxes.

b) Given the densities of MgO, Al_2O_3, and $MgAl_2O_4$ as 3.58 g/cc, 3.95 g/cc, and 3.6 g/cc, respectively (you may not need all these densities to solve the problem), and assuming effective diffusion coefficients of 10^{-9} cm2/s and $6 \cdot 10^{-9}$ cm^2/s for Al and Mg, respectively, at 1600˚C, calculate the time it takes for the spinel layer to reach a thickness of 50 μm.

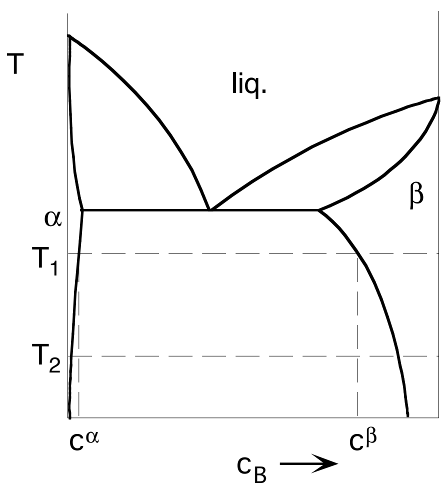
The MgO-Al_2O_3 phase diagram is given below. For simplicity assume that the in spinel compositions that are at equilibrium with MgO and Al_2O_3 are described by MgO:Al_2O_3 ratios of 1:1 and 1:2, respectively. Also given, the atomic weights of Mg, Al, and O are 24, 27, and 16 g/mol, respectively.

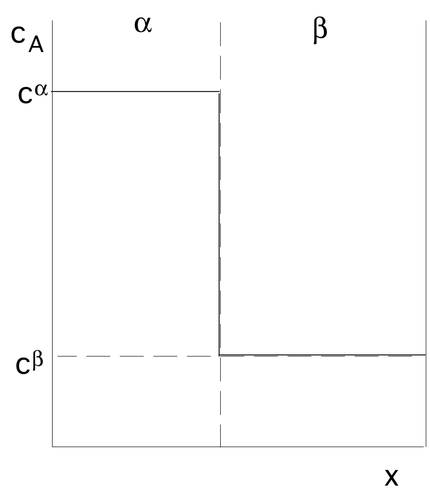


11.

Consider the geometric configuration of two phases *a* and *b* given in the diagram below (right hand side). This configuration corresponds to a situation in equilibrium at T_1 of the adjacent phase diagram. The system is cooled abruptly to T_2.

a) Superimpose the concentration profile after some time (sufficient for the effects to be visible, but still far from equilibrium). Make sure the direction of migration of the interface is obvious from your sketch.
b) Develop an expression for the velocity of migration of the interface based on the diffusivity of A in *b*. Assume that the change in solubility of B in *a* is negligible.





12.

The inert gas contained in a spherical bubble that is submersed in a liquid slowly resorbs into the surrounding liquid. The rate process involves two steps: adsorption of the gas onto the wall and diffusion of the gas molecules into the liquid. The latter occurs across a boundary layer of thickness *d* = 0.5 mm that is governed by the convective flow around the bubble and that is independent of the bubble radius. The system is maintained at ambient conditions, i.e., room temperature and 10^5 Pa. The diffusion coefficient of the gas molecule in the liquid is $D = 10^{-5}$ cm^2/s and the molecular weight of the gas is 40g/mol. The adsorption rate is governed by the collision rate of the gas with the bubble wall, and the desorption rate is 20% of the adsorption rate. The maximum solubility of the gas in the liquid is 0.01 mol/cm^3 and beyond the boundary layer the convection dilutes the gas to zero concentration.

Fick's second law for spherical coordinates is $\frac{\partial c}{\partial t} = D\frac{1}{r^2}\left(r^2\frac{\partial^2 c}{\partial r^2} + 2r\frac{\partial c}{\partial r}\right)$. Initially, the gas bubble is 10 mm in diameter

a) determine which of the two steps is rate limiting in the resorption of the gas.
b) Develop the rate equation describing the change in radius of the gas bubble with time, assuming steady-state conditions where applicable. (symbolic solutions suffice, no need to provide numerical answers.)