Department of Materials Science and Engineering

DOCTORAL WRITTEN EXAM
May 21, 2015

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. **You must submit 2 questions from each core area you are taking for grading**. 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 all 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 all other exam pages in the other side of your folder, and return everything to Renee if you finish before your time is up.

Please be sure to complete the information required on each page.

Name_____ **CODE NUMBER** _____

CHECK THE QUESTIONS YOU WISH TO HAVE GRADED:

Materials Physics And Chemistry:	Advanced Mechanical Behavior:
1. _____	4. _____
2. _____	5. _____
3. _____	6. _____

Advanced Thermodynamics Of Materials	Kinetics and Phase Transformations	Structure of Materials
7. _____	10._____	13._____
8. _____	11._____	14._____
9. _____	12._____	15._____

Materials Physics and Chemistry **Code_____**

1.

Scanning Tunneling Microscopy

An electron tunnels from a scanning tunneling microscope (STM) tip to the surface of a sample which is 3 nm away from the STM tip. Assume that the tunneling electron is the highest energy electron in the tip, but has very little kinetic energy. The tip has a work function of 4 eV and the sample has a work function of 5 eV.

a) Draw the potential energy curve for an electron in the case where there is NO VOLTAGE difference between the tip and the surface. Your curve should show potential energy in the tip, the gap between tip and surface, and the sample's surface (LABEL EACH). Explain the shape, and label and explain all the quantities you know.

b) You hook up a 5 V battery between the tip and the sample's surface, with the positive side of the battery hooked to the sample. Draw a new curve and explain what has changed, what has not changed, and indicate energy of the tunneling electron and the direction the electron will tunnel.

c) Does an electron lose energy when it tunnels? Explain your answer in terms of conservation of energy.

2.

2014 Nobel Prize in Physics was awarded to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes [LEDs] which has enabled bright and energy-saving white light sources."

a) Discuss the principles of operation of (i) incandescent and (ii) fluorescent light bulbs. Which equations and results from quantum mechanics do you need to apply to quantify the wavelength of light emission in each case?

b) Describe the structure of a blue LED. What are the layers that the device consists of and what are the materials and their composition used for each layer? What dopants are used for the doped semiconductor layers?

Materials Physics and Chemistry **Code_____**

3.

Thermal properties: Consider 4 materials for cookware: copper, cast iron, aluminum, and stainless steel.

a) Rank the 4 materials in order of increasing thermal conductivity
b) Rank the 4 materials in order of increasing electrical conductivity
c) Use a phonon dispersion curve to explain your answer in Part (a)
d) Use a band diagram to explain your answer in Part (b)
e) Which material would you choose for a pan to cook steak? Why?

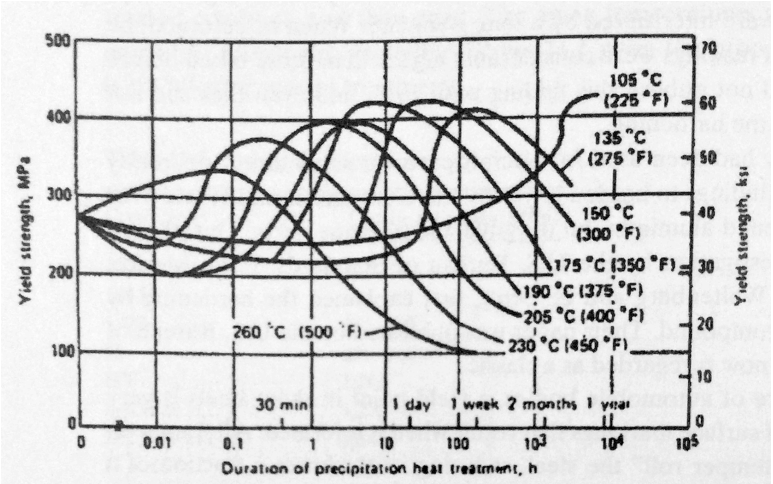
Advanced Mechanical Behavior **Code_____**

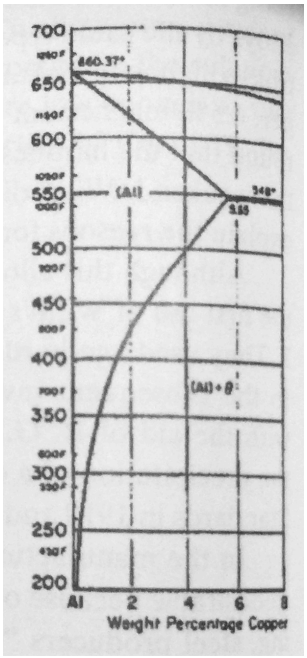
4.

A - During aging of an aluminum alloy, second precipitates nucleate, grow, and coarsen. Plot (qualitatively) the strengthening contributions of the particles and of the solid solution as a function of aging time. Make sure to explain the shape of the curves by providing all controlling equations for the microstructure and strengthening mechanisms.

B - The variations in yield strength of Al alloy 2014 when aged at different temperatures after solution treatment at 500C and quenching are shown below. The alloy has about 4.5%Cu. The Al-Cu phase diagram is shown on the right hand side.

(a) Estimate is the strengthening effect of Cu in solid solution. State all the assumptions you make.
(b) Estimate the increase in yield strength attributable to precipitation at 150C. Assume complete precipitation once the curve reaches a maximum. State all assumptions.
(c) Estimate the distance between precipitates.





Figures from ASM International 1993 and ASM 1973.

Advanced Mechanical Behavior **Code_____**

5.

Discuss with great detail the role of particle strengthening and low and high temperatures. Make sure to organize your essay to highlight differences and similarities.

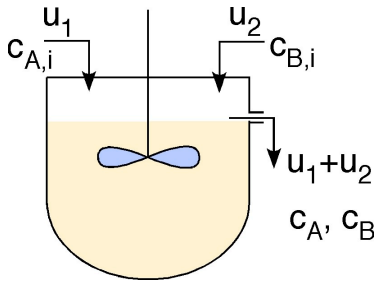
6.

The philosophies behind the testing methods for fatigue and creep are similar. Justify this statement by explaining what the main approaches for testing creep behavior and the available for fatigue behavior are, and by comparing the data and properties extracted from the mechanical tests.

Kinetics and Phase Transformations **Code _____**

10.

Consider two chemicals A and B that react with each other according to a second order reaction to form product AB. The process is designed to take place in a continuously stirred tank reactor (CSTR) with a capacity of 100 liters. The two reactants enter the CSTR in separate streams, each at a volume flow rate of 1 l/s. The concentration of A in the incoming stream is 15 mol/l and that of B is 25 mol/l, respectively. Calculate how many moles of A and B have been converted to product after flowing through the reactor. The reaction rate coefficient is 0.02 s^{-1}l/mol.



Kinetics and Phase Transformations **Code _____**

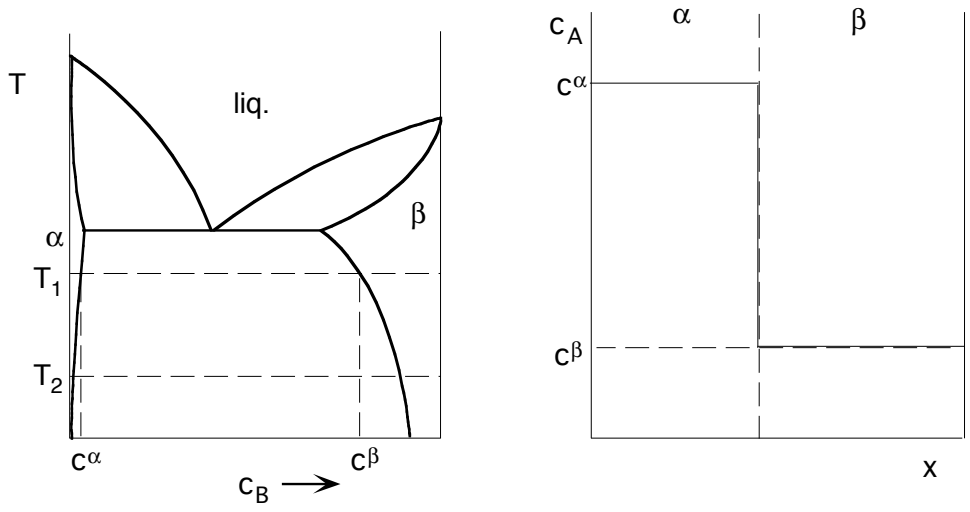
11.

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.

c)



Kinetics and Phase Transformations **Code_____**

12.

Methane gas flows over the surface of gadolinium-doped cerium oxide (GDC) at 700°C. GDC is an oxygen conductor (just like calcium-doped zirconia). The gadolinium doping level is at 10 mol-%. Assume that the lattice constant of the oxide is 0.5 nm. Furthermore, assume that the surface is predominantly formed by the (100) plane of the material, and there are 4 oxygen sites (arranged in a square pattern) on that face of the unit cell. The adsorption rate of CH_4 molecules onto the surface of membrane can be modeled using collision rate theory assuming an activation energy for physisorption of 18 kJ/mol. The steady-state coverage fraction of available surface sites, assuming monolayer coverage, is 30%.

a) Calculate the average residence time of the methane molecules on the surface.
b) During this time each adsorbed molecule is able to diffuse on the surface. The surface diffusion coefficient is $9.4 \cdot 10^{-7}$ cm^2/s at 700°C. Calculate the mean squared displacement reached by adsorbed CH_4 molecules on average.
c) While migrating on the surface, the CH_4 molecule only visits oxygen sites, as they form the terminal layer. Estimate the number of oxygen sites a CH_4 molecule visits on average while adsorbed? (No need to concern yourself with trying to correct for the fact that sites may have been visited multiple time in a random walk.)