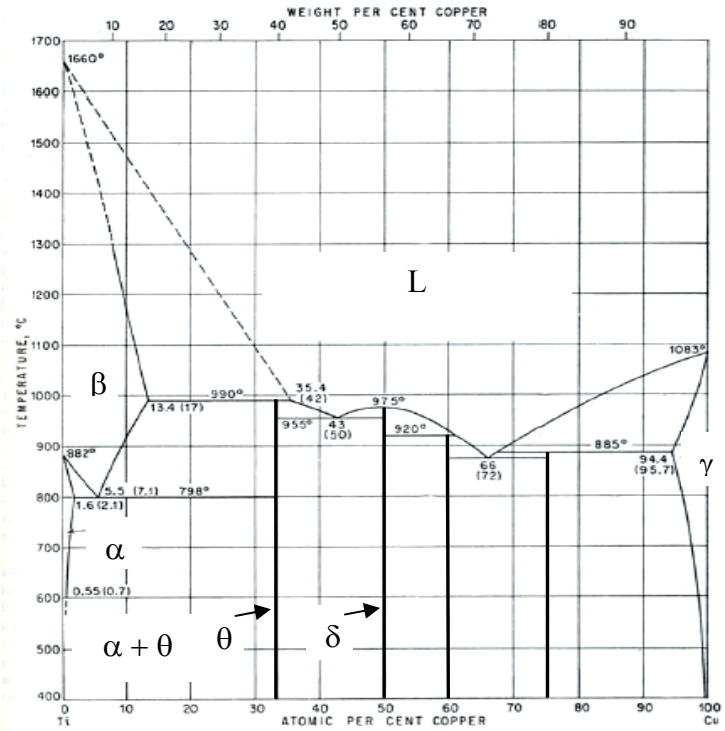
# Sample Ph.D. Qualifying Exam in Materials
## Work All Problems

(1) The titanium-copper binary phase diagram is provided below.




(a) Describe the differences between the α and θ phases of this alloy. Which phase do you expect to be more ductile?

(b) Identify the <u>eutectoid</u> reaction. Write the equation of this reaction and the composition of each phase involved.

(c) A titanium-copper alloy with 10 at.%Cu is cooled slowly from 1000 $^{o}$C to room temperature; what are the composition and amounts of each phase at room temperature?

(d) If this alloy is cooled in equilibrium, draw a picture of the alloy microstructure at 850 $^{o}$C.

(e) If this alloy is cooled in equilibrium, draw a picture of the alloy microstructure at room temperature.

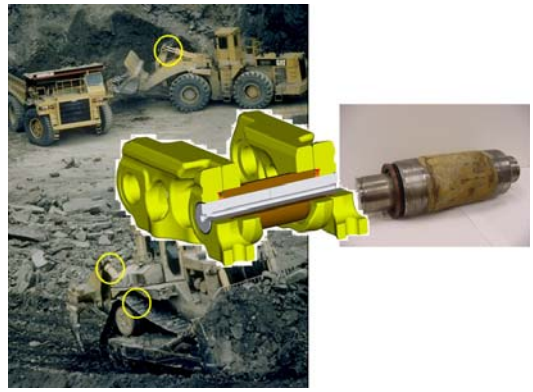
(2) The stress-strain relationship during plastic deformation of Cu is described by the equation $\sigma=310\varepsilon^{0.5}$ and for steel it is $\sigma=450\varepsilon^{0.3}$. Stress is expressed in MPa.

(a) Explain the significance of the exponent in the above relationships. In which material will strain-hardening be more effective? Explain.

(b) Calculate the energy required to deform a block of these materials that is 10 cm x 10 cm in cross-section and 100 cm long while applying a force in the axial direction.

(c) Calculate the force capacity of a machine that will be needed to plastically deform blocks of each material.

(3) Earth movers manufactured by Caterpillar, Komatzu and others use various joints when assembling these systems. One key joint is a pin-joint. This equipment operates in harsh environment, including heavy impacts, wear and friction, temperature variations (from Siberia and Alaska to middle-east and African continent). Durability of pin-joints is vital not only for efficient operation, but also for saving energy by reducing friction and wear losses as well as reducing down time, when catastrophic or gradual failure occurs.

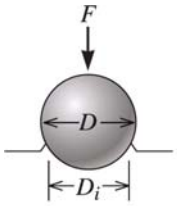


(a) Discuss materials used in the pin joint. What materials/properties are desired for the pin bulk, the pin surface and the spacing between mating surfaces in the joint. When discussing materials and related fabrication processes, identify why certain material is used, how it will be processed, what properties are desired to enable this application.

(b) One of the key properties for the application above is hardness of the material. Discuss two different techniques (not including the one discussed below) for testing hardness of a material, one for macro hardness and one for micro hardness.

(c) What material is the indenter ball made of in a Brinell hardness measurement? What three key factors related to indentation process one needs to calibrate, before testing? Derive the following formula for Brinell hardness measurement. (F is the applied force)

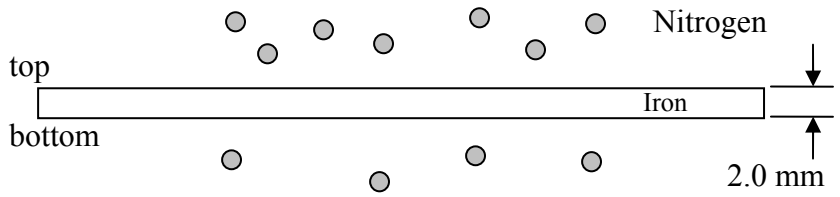
$$\text{Hardness} = \frac{F}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - D_i^2}\right]}$$




Brinell test

(d) List four applications each, in addition to the above, where the macro and micro hardness techniques could be applied as a quality control process.

(4) A sheet of BCC iron 2.0 mm thick has nitrogen atmosphere on both sides at 900 $^{o}$C. The system is allowed to reach steady-state equilibrium. The diffusion constant of N in BCC Fe is 0.0047 $cm^2/s$ and the activation energy for diffusion is 18,300 cal/mol.




(a) Explain the difference between steady-state and transient diffusion. What does the composition profile of the diffusing species look like in each case?

(b) For the above example, if the diffusion flux is $1.0 * 10^{-7}$ $kg/m^2$-s and the concentration of nitrogen in the iron at the top surface is 2 $kg/m^3$, how far into the iron from the top surface will the concentration of nitrogen be 1.5 $kg/m^3$?

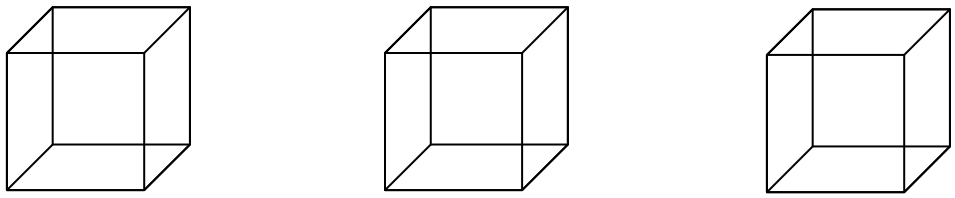
R = 1.987 cal/mol-K.

(5) Crystallography and Miller indices.

(a) Explain the concept of "slip" in metallic materials. How are Miller indices important in the definition of slip?

(b) Sketch the following directions or planes <u>within</u> the unit cell provided. Be sure to indicate your coordinate system on each cube.

(a) [212] (b) (101) (c) (320)



(a) (b) (c)

(c) Determine the Miller indices for the shaded crystal planes in units cells A and B.