Ph.D. Qualification Exam
Materials Science & Engineering

Example Problems
(Closed-book Exam)

Name: ____________________

Part I: Multiple-choice questions. Please circle the best answer.

1. **Ionic bonding in solids is caused by:**
   a. Interactions between the inner electrons in the neighboring atoms
   b. Sharing of valence electrons among the nearest neighbor atoms
   c. Interaction between oppositely charged nearest neighbor ions
   d. Interaction between the positive ion cores and the valence electron charge cloud

2. **The net force between a pair of bonded atoms:**
   a. Becomes zero when the two atoms are at equilibrium
   b. Becomes positive when the two atoms are equilibrium
   c. Reaches its maximum value when the two atoms are at equilibrium
   d. Reaches its minimum value when the two atoms are at equilibrium

3. **The crystal system classification that groups all crystals into seven systems is based on**
   a. The coordinates of the lattice points in the unit cell
   b. The coordinates of the atoms in the unit cell
   c. The dimensions (a, b, c & α, β, γ values) of the unit cell
   d. The atomic packing factor for the unit cell

4. **The body diagonal of a cubic unit cell have the indices belongs to the family of directions:**
   a. <001>
   b. <111>
   c. <112>
   d. <100>

5. **Two kinds of line defect that occurs in crystals are**
   a. Vacancies & twin faults
   b. Edge & screw dislocations
   c. Interstitials & substitutionals
   d. Deformation & twin faults

6. **Imperfections most likely to be present in an alloy *single crystal* include all of the following except for:**
   a. Dislocations
   b. Solute atoms
   c. Grain boundaries
   d. Vacancies

7. **During inter-diffusion in a Cu-Ni diffusion couple, the predominant atomic mechanism of diffusion is :**
   a. Steady state mechanism
   b. Self-diffusion mechanism
   c. Interstitial mechanism
   d. Vacancy mechanism

8. **A screw dislocation in a crystal:**
   a. Has an extra half plane normal to the dislocation line
   b. can be created due to a displacement normal to the dislocation line
   c. has a b-vector parallel to the dislocation line
   d. is equivalent to a chain of vacancies parallel to the b-vector

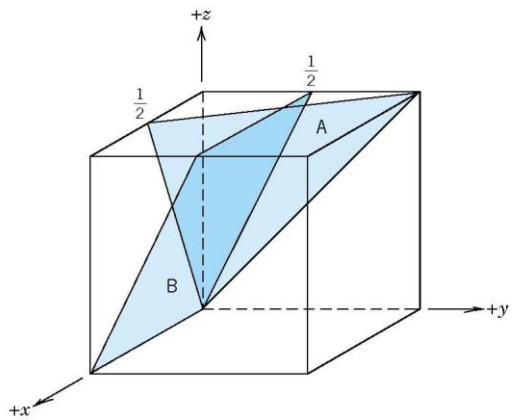
9. **A crystalline materials may lack all attributes listed below *except* for**
   a. An atomic structure based on one of the three cubic lattices
   b. A microstructure consists of grains and grain boundaries
   c. An atomic structure characterized by periodically repeating atoms or molecules in 3 dimension
   d. An external topography characterized by flat surfaces, sharp edges and corners.

10. **Plastic deformation of a metal requires:**
    a. atomic bond breaking & fracture
    b. atomic bond stretching & relaxation
    c. atomic diffusion & mass flow
    d. dislocation motion & slip

11. **" Modulus of elasticity" of a materials is a measure of:**
    a. Its resistance to elastic deformation under shear
    b. Its resistance to plastic deformation under uniaxial loading
    c. Its resistance to elastic deformation by indentation
    d. The strength of the bonding forces between atoms.

<u>Part II:</u> Short questions and concept problems. Please show detail procedures.

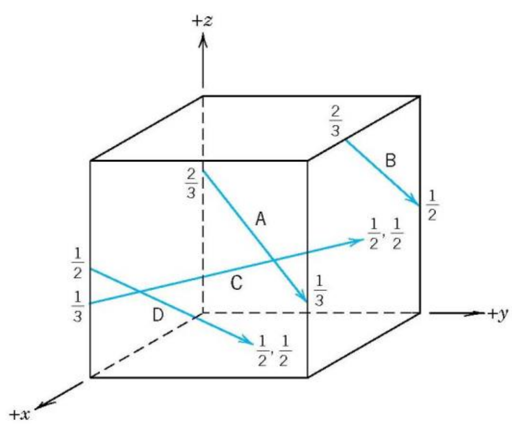
12. Determine the Miller indices for planes shown in the following unit cell.



Plane A ________________________

Plane B ________________________

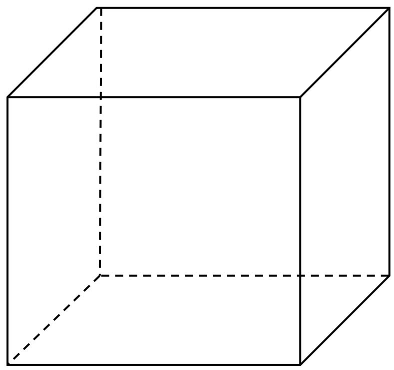
13. Determine the indices for the direction A and B shown in the following cubic unit cell.

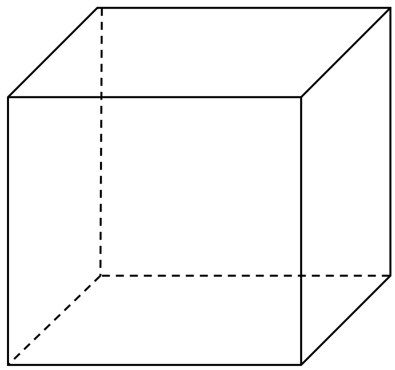


Direction A ________________________

Direction B ________________________

14. Within cubic unit cells, sketch the $[2\bar{1}0]$ direction and the $(21\bar{1})$ plane, respectively. <u>Please indicate the coordination systems you are using</u>.





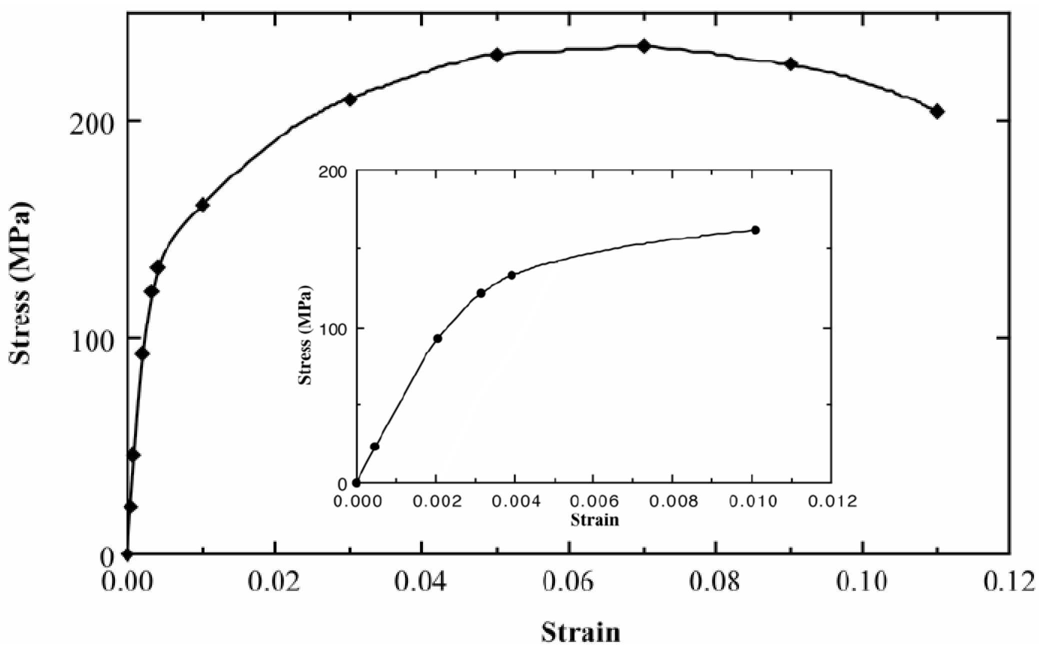
15. In the diffraction pattern of a polycrystalline sample of BCC metal recorded with x-rays of λ=0.154nm, the beam diffracted from the (211) planes occur at 2θ = 60°. Based on this information, determine

(a) d-spacing $d_{(211)}$ = ______________________________

(b) Lattice constant a_0 = ______________________________

(c) Atomic Radius r = ______________________________

16. From the tensile stress-strain behavior for a magnesium specimen shown in the figure below, determine the following. <u>For full credits, must show steps and equations, and indicate necessary procedures on the plot.</u>



a. The modulus of elasticity.

b. The yield strength determined by strain offset method.

c. If the specimen is originally 250 mm long, determine (1) its total length when it is subjected to a tensile stress of 200 MPa, and (2) its total length after the stress is released.

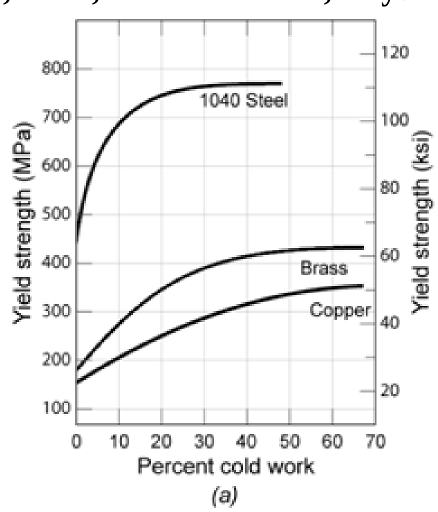
17. Surface for some steel specimens that have failed by fatigue have a bright crystalline or grainy appearance. Laymen may explain the failure by saying that the metal crystallized while in service. Offer a criticism for this explanation.

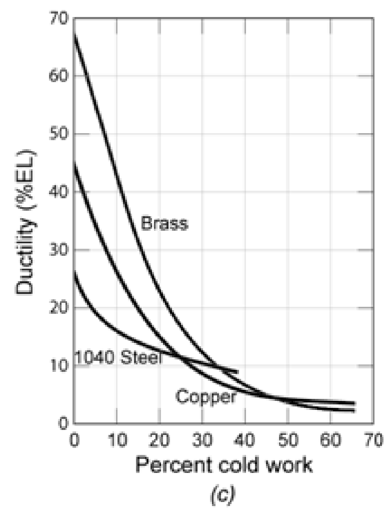
18. **For some metals and alloys, the true stress and the true strain follow the power law relation of $\sigma_T = k(\varepsilon_T)^n$. Explain for a given alloy, how you will determine the parameter *K* and *n* experimentally.**

19. **A relatively large plate of a glass is subjected to a tensile stress of 80 MPa. If the specific surface energy and modulus of elasticity for this glass are 0.3 J/m^2 and 50 GPa, respectively. What is the maximum length of a surface flaw that is possible without fracture?**

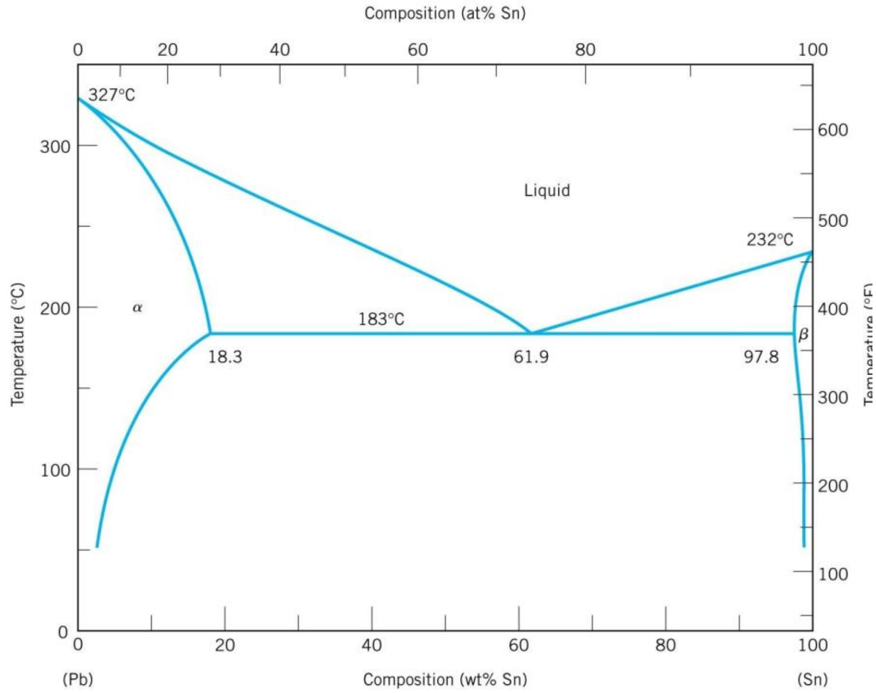
<u>Part III:</u> Comprehensive questions. For full point, please write down the equations and procedures needed to solve the problems.

20. **It is necessary to select a metal alloy for an application that requires a yield strength of at least 345 MPa (50,000 psi) while maintaining a minimum ductility (%EL) of 20%. If the metal can only be cold worked once, decide which of the following are candidates: copper, brass, and a 1040 steel, why?**





21. **Referring to the phase diagram below, pls. answer**
    a. label all two-phase regions in the phase diagram
    b. Name any isothermal reaction occurring in the system and write out reaction equation as completely as possible.
    c. A Pb-30% Sn sample is cooled slowly from 300C to room temperature. At what temperature, solidification begins and what is the composition of the first bit of solid phase to form?
    d. At what temperature solidification is complete for this alloy and what is the composition of the last portion of the liquid to solidify?
    e. For an 100gm sample of the above alloy, calculate the total amount of α, total amount of β and the amount of the eutectic product (α+β) (lamellar portion) present in the microstructure just below 183°C.



Pb-Sn phase diagram

22. The surface of a 0.1% C steel gear is to be hardened by carburizing. In gas carburizing, the steel gears are placed in an atmosphere that provides 1.2% C at the surface of the steel at a high temperature. Carbon then diffuses from the surface into the steel. For optimum properties, the steel must contain 0.45% C at a depth of 0.2 cm below the surface. Using the data in Table 5.2, design a carburizing heat treatment that will produce these optimum properties. Assume that the temperature is high enough (at least 900 °C) so that the iron has the FCC structure.

Table 5.2 A Tabulation of Diffusion Data

Diffusing Species	*Host Metal*	*$D_0(m^2/s)$*	*Activation Energy Q_d* kJ/mol	*eV/atom*	*Calculated Value* $T(°C)$	*$D(m^2/s)$*
Fe	α-Fe (BCC)	2.8×10^{-4}	251	2.60	500 900	3.0×10^{-21} 1.8×10^{-15}
Fe	γ-Fe (FCC)	5.0×10^{-5}	284	2.94	900 1100	1.1×10^{-17} 7.8×10^{-16}
C	α-Fe	6.2×10^{-7}	80	0.83	500 900	2.4×10^{-12} 1.7×10^{-10}
C	γ-Fe	2.3×10^{-5}	148	1.53	900 1100	5.9×10^{-12} 5.3×10^{-11}
Cu	Cu	7.8×10^{-5}	211	2.19	500	4.2×10^{-19}
Zn	Cu	2.4×10^{-5}	189	1.96	500	4.0×10^{-18}
Al	Al	2.3×10^{-4}	144	1.49	500	4.2×10^{-14}
Cu	Al	6.5×10^{-5}	136	1.41	500	4.1×10^{-14}
Mg	Al	1.2×10^{-4}	131	1.35	500	1.9×10^{-13}
Cu	Ni	2.7×10^{-5}	256	2.65	500	1.3×10^{-22}

List of Equations

1. Bragg's law

$$2d_{hkl}\sin\theta = \lambda$$

2. For cubic system with lattice parameter *a*,

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

3. Grain Size Determination

$$N = 2^{n-1}$$

where N is the average number of grains per square inch at a magnification of 100 ×, n is the ASTM grain size number.

$$N = N_M\left(\frac{M}{100}\right)^2$$

where M is the magnification, N_M is the average number of grains per square inch at a magnification of M.

4. Fick's first law

$$J = -D\frac{dC}{dx}$$

where J is the diffusion flux, D is the diffusion coefficient, dC/dx is the concentration gradient.

5. Fick's second law

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right)$$

6. Solution to Fick's second law for vapor-solid diffusion problem

$$\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

- C_x: the concentration at depth x after time t.
- erf( ): Gaussian error function, values can be found from the table on backside of this page.
- C_0: concentration of the diffusing solute atoms in the solids before the diffusion
- C_s: the constant surface concentration at x=0
- x: distance from the solid surface (x=0) to the inside of solid
- D: diffusion coefficient
- t: time

7. Dependence of the diffusion coefficient on temperature

$$D = D_0 \exp(-\frac{Q_d}{RT})$$

- D: diffusion coefficient (diffusivity)
- D_0: a temperature-independent preexponential
- Q_d : the activation energy for diffusion
- R : the gas constant, 8.31 J/mol-K
- T : absolute temperature (K)

8. Tabulation of error function values

5.1 Tabulation of Error Function Values

z	$erf(z)$	z	$erf(z)$	z	$erf(z)$
0	0	0.55	0.5633	1.3	0.9340
0.025	0.0282	0.60	0.6039	1.4	0.9523
0.05	0.0564	0.65	0.6420	1.5	0.9661
0.10	0.1125	0.70	0.6778	1.6	0.9763
0.15	0.1680	0.75	0.7112	1.7	0.9838
0.20	0.2227	0.80	0.7421	1.8	0.9891
0.25	0.2763	0.85	0.7707	1.9	0.9928
0.30	0.3286	0.90	0.7970	2.0	0.9953
0.35	0.3794	0.95	0.8209	2.2	0.9981
0.40	0.4284	1.0	0.8427	2.4	0.9993
0.45	0.4755	1.1	0.8802	2.6	0.9998
0.50	0.5205	1.2	0.9103	2.8	0.9999

9. Engineering stress: $\sigma = \frac{F}{A_0}$ **,** where F is the applied load, and A_0 is the original area of the cross section of the sample.

Engineering strain: $\varepsilon = \frac{l_i - l_0}{l_0} = \frac{\Delta l}{l_0}$ **,** where l_0 is the original sample length, and l_i is the deformed length.

Young's modulus *E*: $\sigma = E\varepsilon$

10. **Hall-Petch equation**: $\sigma_y = \sigma_0 + k_y d^{-\frac{1}{2}}$, where σ_y is the yield strength, d is the average grain diameter, and σ_0 and k_y are constants for a particular material.

11. **Power law of true stress and true strain**: $\sigma_T = k(\varepsilon_T)^n$

True stress: $\sigma_T = \dfrac{F}{A_i}$ True strain: $\varepsilon_T = \ln\left(\dfrac{l_i}{l_0}\right)$

12. **Critical stress for crack propagation in brittle materials**: $\sigma_c = \left(\dfrac{2E\gamma_s}{\pi a}\right)^{1/2}$, where E is the modulus of elasticity, γ_s is the specific surface energy, and a is the crack size (length of a surface crack or one half length of an internal crack).

13. **Stress intensity factor:** $K = Y\sigma\sqrt{\pi a}$, where Y is a constant, σ is the applied stress, and a is the crack size (length of a surface crack or one half length of an internal crack).