Exam-2: Chapters 3 (from linear densities) ~ Chapter 5

Name: _____Answer____

Part	Points	Maximum	Grader
A		**20**	
B		**30**	
C		**20**	
D		**30**	
Total		**100**	

Part A. (20 points, 2 point each) Choose the right answer.

1. The requirements for the formation of a substitutional solid solution are defined by Hume-Rothery's rules. (*true*, *false*)
2. According to Fick's (*first*, *second*) law, the time dependent change in composition is related to the sign of the curvature of the composition versus distance.
3. An ion-vacancy pair formed in ionic solids is referred to as *(Schottky*, *Frenkel)* defect.
4. Carbon dissolved in Fe is an example of a(n) *(substitutional*, *interstitial*) solid solution.
5. Fick's first law defines diffusion that is time (independent, dependent).
6. The activation energy for bulk diffusion is (lower, higher) than the activation energy for grain boundary diffusion.
7. Increasing temperature (*increases*, *decreases*) the concentration of vacancies.
8. Increasing grain size (*increases*, *decreases*) strength
9. Slip is the process by which a dislocation motion produces a permanent deformation. (*true*, *false*)
10. Which of the following is the most likely slip plane in an FCC structure?
    (a) (1 0 0) (b) (0 1 0) (c) (1 1 0) (d) (1 1 1)

Part B. (30 points, 2 point each) Choose the right answer.

1. The movement of atoms in a pure material is termed__________.
   (a) expansion diffusion
   (b) inter-diffusion
   (c) intra-diffusion
   (d) self-diffusion

2. Which of the following statements is **INCORRECT**?
   (a) In an FCC material, slip tends to occur along <110> directions.
   (b) Increasing the dislocation density decreases the strength of a metal or alloy.
   (c) Increasing the grain size decreases the strength of a metal or alloy.
   (d) The probability of dislocation climb increases as temperature increases.

3. Which statement about diffusion is **INCORRECT**?
   (a) Diffusion is faster at higher temperature.
   (b) Diffusion is faster along the dislocation than in the crystal lattice.
   (c) Diffusion is faster at the grain boundary than in the crystal lattice.
   (d) Diffusion is faster in FCC structure than in BCC structure.

4. Which statement is *mostly* **INCORRECT** about the effect of raising temperature?
   (a) The concentration of free charges in ionic crystals increases.
   (b) The concentration of Frenkel defects increases.
   (c) The concentration of interstitials increases.
   (d) The concentration of vacancies increases.

5. Which of the following statements is *mostly* **INCORRECT**?
   (a) Grain boundaries can be utilized to strengthen materials.
   (b) Impurities may be utilized to strengthen materials.
   (c) Macroscopic defects can be utilized to strengthen materials.
   (d) Point defects can be utilized to strengthen materials

6. The purpose of x-ray diffraction is to gain more information on
   (a) Interplanar spacing
   (b) Atomic positions
   (c) Both A and B
   (d) Neither A and B

7. For Schottky defects, what determines the ease of ion migration?
   (a) The distance of the jump
   (b) The activation energy of the jump
   (c) The charge of the ion
   (d) Ion migration occurs spontaneously

8. Why are point defects formed?
   (a) To decrease entropy in the system
   (b) To favor a lower Gibbs Free Energy
   (c) To decrease number of vacancies
   (d) None of the Above

9. Which condition would lead to an increase in the number of defects present?
   (a) Increase of Gibbs free energy (b) Increase in temperature
   (c) Decrease of Gibbs free energy (d) both b & c

10. Which of the following is NOT a factor that affects atomic transport?
   (a) concentration gradient (b) atomic radii (c) jump distance, Δx (d) temperature

11. Which of the following is not a factor in atomic transport for Fick's first law?
   (a) Concentration Gradient (b) Jump Distance (c) Temperature (d) Time

12. Grain boundary defines the boundary between two grains of
   (a) Two different phases
   (b) Two different compositions
   (c) Two different orientations

13. Work Hardening is the process of strengthening through:
   (a) Increase in dislocation density
   (b) Precipitation
   (c) Increasing the number of solute atoms.

14. Which of the following is not a method of strengthening a metal?
   (a) Heat the metal up and hold at a high temperature then cool rapidly.
   (b) Heat the metal up and hold at a high temperature, then allow to cool slowly.
   (c) Hammer or draw the metal while it is cool.
   (d) Add alloying substances to the metal.

15. An x-ray diffraction experiment with a wavelength of 1.2 Å on a crystal sample displays a peak at 30 deg. What is the interplanar spacing, given first order diffraction?

   a. $\frac{1.2\ \text{Å}}{\sin(30^\circ)}$ b. $\frac{2.4\ \text{Å}}{\sin(30^\circ)}$ c. $\frac{2.4\ \text{Å}}{\sin(60^\circ)}$ **d.** $\frac{1.2\ \text{Å}}{2\sin(30^\circ)}$

PART C. PROBLEMS (20 points, as marked) A question from your textbook.

1. (8 points) A candidate material for a turbine blade application oxidizes by diffusion of metal atoms through the oxide to the metal surface, where metal and oxygen react to form the oxide. After 10 hours at 550 ^{o}C, an oxide layer 8 μm thick has formed in the cylindrical metal. What will the thickness be after 100 hours? The effective penetration distance is given as $x_{eff} = \gamma (Dt)^{1/2}$.

   For cylinders, γ = 2, hence $x_{eff} \approx 2(Dt)^{1/2}$.

   Since the diffusion occurs at the same temperature,

$$\frac{x_{eff,1}}{x_{eff,2}} = \sqrt{\frac{D_1 t_1}{D_2 t_2}} = \sqrt{\frac{t_1}{t_2}}$$

$$\frac{8\ \mu m}{x_{eff,2}} = \sqrt{\frac{10\ hr}{100\ hr}}$$

$$x_{eff,2} = \underline{25.3\ \mu m}$$

2. (4 points) The coefficient of diffusion for Cu in Ag for a given temperature is 0.8 cm^2/s. Two planes in an Ag crystal are 2 mm apart. The concentration of Cu is 7.4 × 10 $^{-18}$ atoms/cm^3 on the first plane and 5.2 × 10 $^{-20}$ atoms/cm^3 on the second plane. What is the flux of Cu atoms between the two planes? Assume that the concentrations are constant.

   (a) $(0.8\ \text{cm}^2/\text{s}) \left(\dfrac{(7.4 \times 10^{-18} - 5.2 \times 10^{-20})\ \text{atoms/cm}^3}{0.2\ \text{cm}} \right)$

   (b) $(5.2\ \text{cm}^2/\text{s}) \left(\dfrac{(7.4 \times 10^{-18} - 0.8 \times 10^{-20})\ \text{atoms/cm}^3}{0.2\ \text{cm}} \right)$

   (c) $(0.8\ \text{cm}^2/\text{s}) \left(\dfrac{(5.2 \times 10^{-20} - 7.4 \times 10^{-18})\ \text{atoms/cm}^3}{0.2\ \text{cm}} \right)$

   (d) $(0.8\ \text{cm}^2/\text{s}) \left(\dfrac{7.4 \times 10^{-18}\ \text{atoms/cm}^3}{0.2\ \text{cm}} \right)$

3. (4 points) Calculate the planar density for the (111) closest packed plane in FCC structure.

   (a) $2\sqrt{3}/\boldsymbol{r}^2$ (b) $1/(2\sqrt{3}\boldsymbol{r}^2)$ (c) $2/(\sqrt{3}\boldsymbol{r}^2)$

4. (4 points) Calculate the interplanar spacing for BCC (110) with an atomic radius of r.

   (a) $\frac{4r}{\sqrt{3}}$ (b) $\frac{4r}{\sqrt{6}}$ (c) 2r (d) r

PART D. PROBLEMS (30 points, as marked)

1. (4 points) It is known that it takes time t_1 for a Cu atom to diffuse a distance x_1 through a Cu/Ni alloy sheet. Determine the time required for a Cu atom to diffuse a distance of $2x_1$ through the same Cu/Ni alloy. Write your answer in terms t_1 and x_1.

   Using $x \sim \sqrt{Dt}$ and constant diffusion coefficient,

   For case 1: $x_1 \sim \sqrt{Dt_1}$

   For case 2: $2x_1 \sim \sqrt{Dt_2}$

   Comparing these two equations,

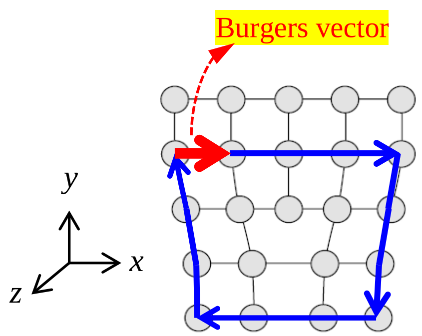
   $2x_1/x_1 = 2 = (t_2/t_1)^{1/2}$

   $t_2/t_1 = 4$

   $t_2 = 4\, t_1$

2. (20 points, as marked) A dislocation in an FCC structure is shown in the figure below. The lattice parameter is known to be a_0. The unit tangent vector is given in Miller indices as $[00\bar{1}]$.

   (1) (6 points) Draw a Burgers circuit in the figure and identify the Burgers vector in the circuit.



   (2) (4 points) Write the magnitude of the Burgers vector in terms of a_0.

   The magnitude of the Burgers vector is $a_0/2$.

   (3) (4 points) Given the *xyz* coordinates, find the Miller indices of the direction of the Burgers vector.

   The direction of the Burgers vector in Miller indices is [1 0 0].

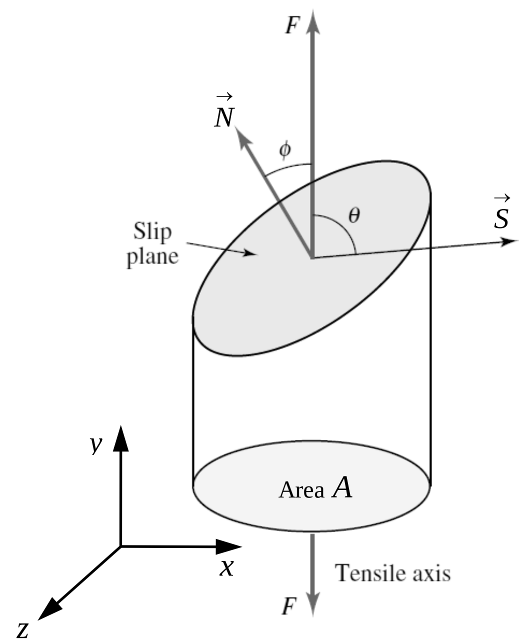
   (4) (6 points) Write in Miller indices of the normal vector to the slip plane.

The normal direction $\vec{n}$ is determined by the cross vector of the Burgers vector and the tangent vector:

$$\vec{n} = \boxed{\vec{b} \times \vec{t} = \frac{a_0}{2}[100] \times [00\bar{1}]} = \boxed{\frac{a_0}{2}\begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{vmatrix}} = \boxed{\frac{a_0}{2}\vec{j}}$$

Therefore, the normal vector to the slip plane in Miller indices is [0 1 0].

3. (6 points) The geometrical relation between the direction of an applied force F, a slip direction ($\vec{S}$), and the normal vector ($\vec{N}$) to the slip plane is shown in the following figure. The slip plane is $(\bar{1}11)$, and the slip direction is [1 1 0]. The force F for slip is known to be 10 kN (applied along the y direction), and the area A is known to be 1 cm^2. Determine the critical resolved shear stress.



$$\cos\theta = \boxed{\frac{[010]\cdot[110]}{\sqrt{0+1^2+0}\sqrt{1^2+1^2+0}}} = \boxed{\frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{2}}$$

$$\cos\phi = \boxed{\frac{[010]\cdot[\bar{1}11]}{\sqrt{0+1^2+0}\sqrt{(-1)^2+1^2+1^2}}} = \boxed{\frac{1}{\sqrt{3}} = \frac{\sqrt{3}}{3}}$$

$$\boxed{\sigma = \frac{F}{A}} = \frac{10\text{ kN}}{1\text{ cm}^2} = \boxed{10^8\text{ Pa} = 100\text{ MPa} = 10^9\ \text{dyne/cm}^2}$$

$$\tau_{CR} = \sigma\cos\theta\cos\phi = \boxed{100\frac{\sqrt{2}}{2}\frac{\sqrt{3}}{3}MPa = \frac{50\sqrt{6}}{3}MPa = \frac{50\sqrt{6}}{3}x\,10^7\ dyne/cm^2}$$

Useful equations

Chapter 3:

Packing factor = (Number of spheres x vol. of sphere) / vol. of unit cell

$$\rho_L = \frac{\text{Number of atoms centered along direction within one unit cell}}{\text{Length of the line contained within one unit cell}}$$

$$\rho_P = \frac{\text{Number of atoms centered on a plane within one unit cell}}{\text{Area of the plane contained within one unit cell}}$$

$$\text{APF} = \frac{(\text{Number of atoms in cell}) \times (\text{Volume of an atom})}{\text{Volume of the unit cell}}$$

Bragg's law: $m\,\lambda = 2\, d_{hkl} \sin\theta$

Spacing between the planes: $d_{(hkl)} = \dfrac{a_o}{(h^2 + k^2 + l^2)^{\frac{1}{2}}}$

Angle between two directions: $\theta = \cos^{-1}\left[\dfrac{uu' + vv' + ww'}{\left(u^2 + v^2 + w^2\right)^{1/2}\left(u'^2 + v'^2 + w'^2\right)^{1/2}}\right]$

Chapter 4:

$$J = -D\left(\frac{dC}{dx}\right), \qquad D = D_0 \exp\left(-\frac{Q}{RT}\right), \qquad \ln D = \ln D_0 + \left(-\frac{Q}{R}\right)\left(\frac{1}{T}\right)$$

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2}\right)$$

Gas constant R = 8.314 J/mol.^{o}K

$$x_{eff} = \gamma\sqrt{Dt}$$

Chapter 5:

$$\sigma = \frac{F}{A}, \qquad \tau = \sigma\cos\theta\cos\phi, \qquad \sigma_c = \frac{\tau_{CR}}{\cos\theta\cos\phi}$$

$$\mathbf{n} = \mathbf{b} \times \mathbf{t}$$

$$\mathbf{u} \cdot \mathbf{v} = |\mathbf{u}||\mathbf{v}|\cos\theta$$

$$\mathbf{u} \times \mathbf{v} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ u_1 & u_2 & u_3 \\ v_1 & v_2 & v_3 \end{vmatrix}$$

$$E_{dislocation} \propto |\mathbf{b}|^2$$