1. **(10%)** (a) (5%) Prove that the ideal c/a value for the hexagonal close-packed (hcp) structure is **1.633**. (b) (5%) The unit-cell volume of hcp titanium at 20°C is **0.106** nm^3 and the c/a ratio is **1.59**. What are the values of c and a ? What is the radius of the Ti in a direction that lies in the base of the unit cell?

2. **(15%)** (a) (6%) Calculate the atomic packing factors for the FCC and BCC crystals, respectively. (b) (5%) Indicate the possible slip planes for the FCC and BCC crystals, respectively. (c) (4%) Explain why HCP metals are typically more brittle than FCC and BCC metals.

3. **(10%)** (a) (5%) The density of polyethylene crystal is 998 kg/m^3, and the unit cell has dimensions $a = 0.741$ nm, $b = 0.494$ nm, and $c = 0.255$ nm. How many "monomer" units are there in a unit cell? (b) (5%) If the density of amorphous polyethylene is approximately 810 kg/m^3, please estimate the crystallinity of the low-density polyethylene with density of 920 kg/m^3.

4. **(15%)**(a) (5%) What is the difference between the steady-state and nonsteady-state diffusion processes? Which equation can be used to describe the nonsteady-state diffusion process? (b) (10%) The diffusivity of aluminum in copper is 2.6×10^{-17} m^2/s at 500°C and 1.6×10^{-12} m^2/s at 1000°C. Determine the values of D$_o$ and activation energy E$_a$ (in eV) for this diffusion couple and the diffusivity at 750°C. The Boltzmann's constant is 8.62×10^{-5} eV/atom-K.

5. **(10%)** Figure 1 shows the microstructure of wustite (solid FeO) plus an FeO-SiO$_2$ liquid. The overall composition is 90FeO-10SiO$_2$. (a) (2%) What is the liquidus temperature for this material? (b) (2%) What is the eutectic reaction? (c) (3%) What is the composition of fayalite (wt% FeO)? (d) (3%) What phases in the FeO-SiO$_2$ system undergo a polymorphic change? Indicate their transition temperature. (The atomic mass of Fe, O, and Si are 55.85, 16, and 28.01, respectively)
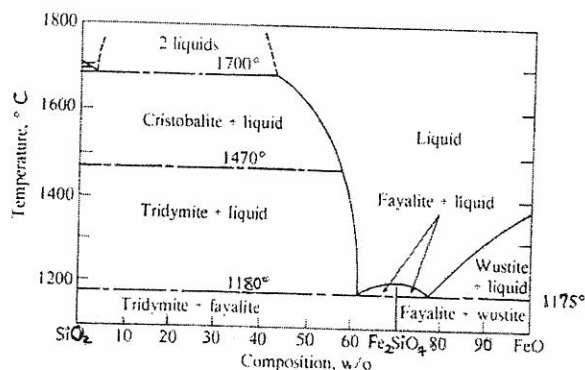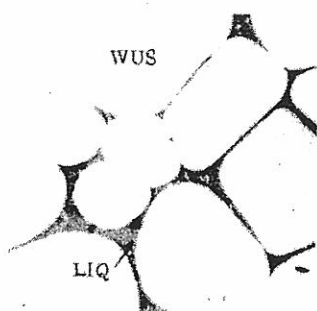

Figure 1

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6. **(10%)** (a) (5%) A copper wire has a nominal breaking strength of 300 MPa and its ductility is 77% reduction of area. Calculate the true stress σ_f for fracture. (b) (5%) The mechanical strength of SiO_2 is usually measured by its Younng's modulus. However, it was recently reported that the fracture strength of SiO_2 can be enhanced by incorporate the organic fragments (e.g. $-CH_2-$ or $-CH_2-CH_2-$) into the bond network while reducing its modulus of elasticity.   Can you provide a simple physical reason to explain this experimental result?

7. **(10%)** The soda-silicate glass of composition $20\%Na_2O-80\%SiO_2$ and density of approximately 2.4 g/cm^3 has a conductivity of $8.25\times10^{-6}\Omega^{-1}m^{-1}$ at $150^{\circ}C$. If conduction occurs by the diffusion of Na^+ ions, what is their drift mobility?   The atomic masses of Na is 23 and $1\ e = 1.6\times10^{-19}C$.

8. **(10%)** (a) (5%) Some metal oxides such as TiO_2 and $SrTiO_3$ have band gaps greater than 3.0 eV but are generally considered as n-type semiconductors. Please provide the physical origin of their semiconducting properties. (b) (5%) To increase the electron conductivity of ZnO, which would you add, Al_2O_3 or Li_2O? Explain.

9. **(10%)** (a) (5%) Please describe three different types of polarization found in materials. Which one has the highest relaxation frequency upon an alternating electric field?   (b) (5%) Both silica glass and quartz are composed of SiO_2 tetrahedra and neither material possesses a center of symmetry. Why is silica glass not a piezoelectric, whereas quartz is?