1. **True or False (reason your answer if you think the statement is false) (10%):**

(a) Martensitic transformation always generates hard and brittle product phase. (2%)

(b) It is very common to find a twinning system in metal that both the twinning plane and twinning shear direction are rational. (2%)

(c) Compared to homogeneous nucleation, heterogeneous nucleation has a smaller critical free energy barrier (ΔG^*) and critical radius (r^*) both. (2%)

(d) We only need solid solution treatment and aging treatment for effective precipitation hardening. (2%)

(e) When a crystal is deformed in compression, the slip plane rotates so that it tends to become perpendicular to the stress axis. (2%)

2. **The structure of crystalline solids (10%):**

(a) Write down all seven crystal systems. Which two systems do not have any perpendicular interaxial angles (that is, $\alpha \neq 90°$, $\beta \neq 90°$, $\gamma \neq 90°$)? (3%)

(b) The interplanar spacing d_{hkl} is a function of the Miller indices and lattice parameters. For example, for crystal structures having cubic symmetry:

$$\frac{1}{d_{hkl}^2} = \frac{(h^2 + k^2 + l^2)}{a^2}$$

Derive the interplanar spacing d_{hkl} for crystal structures having tetragonal symmetry. (3%)

(c) A BCT unit cell in martensitic steel is simply a body-centered cube that has been elongated along the c-axis. Due to the reduced symmetry from BCC, the martensite (002) and (200) peaks split in X-ray diffraction pattern may be observed. Today a martensitic steel sample with unknown carbon concentration is detected to have $2\theta = 5.7°$ difference between (002) and (200) planes while using X-ray diffraction with Cr-Kα radiation (wavelength = 0.22897 nm). From a linear relationship between carbon content and c/a ratio: $\frac{c}{a} = 1 + 0.031$ wt% C, and lattice parameter a = 0.2868 nm, evaluate the carbon concentration of this martensitic steel. (4%)

3. **Fundamentals of dislocation slip (11%):**

(a) What is the definition of the Burgers vector? Also, write down the Burgers vector **b** for FCC, BCC, and HCP structures. (2%)

(b) Zinc has an HCP crystal structure, a c/a ratio of 1.856. In addition to slip on the basal plane, zinc has been observed to slip on a unique slip system $\{11\bar{2}2\} < \bar{1}\bar{1}23 >$. Draw one schematic HCP unit cell (such as the figure shown below) to illustrate basal slip **AND** another HCP unit cell to illustrate $\{11\bar{2}2\} < \bar{1}\bar{1}23 >$ slip system. (2%)

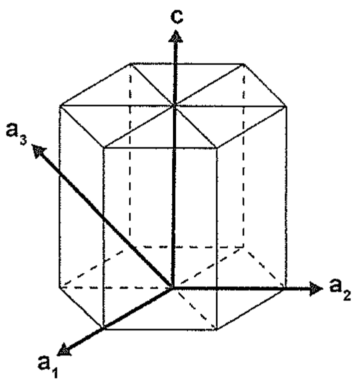

Figure 1 A standard hexagonal unit cell showing $\mathbf{a_1}, \mathbf{a_2}, \mathbf{a_3}$, and $\mathbf{c}$ axes.

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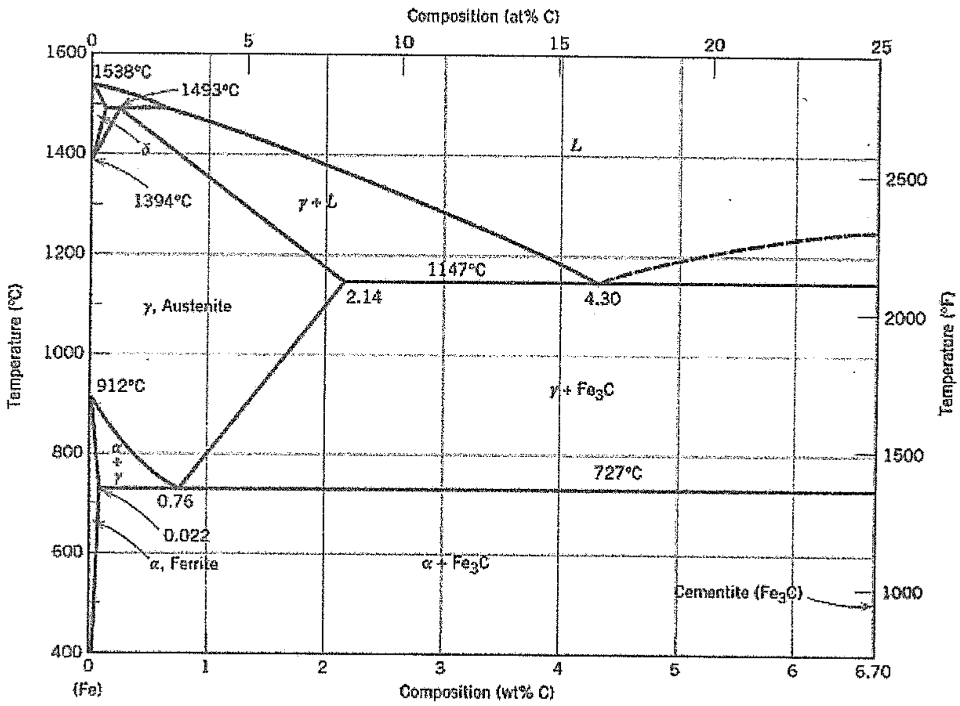
(c) Zirconium also has an HCP crystal structure, a c/a ratio of 1.593. It slips primarily on its prismatic plane $\{10\bar{1}0\}$ instead of basal plane. Again, draw one schematic HCP unit cell to illustrate slip on the prismatic plane. (2%)

(d) Discuss the possible influence of the c/a ratio on the difficulty of basal slip (Hint: your statement should include the ideal c/a ratio of HCP crystal structure). (3%)

(e) Some engineering alloys are extremely ductile at room temperature although they do not have closely-packed slip planes. Why? (2%)

4. Applications of ferrous alloys (9%):



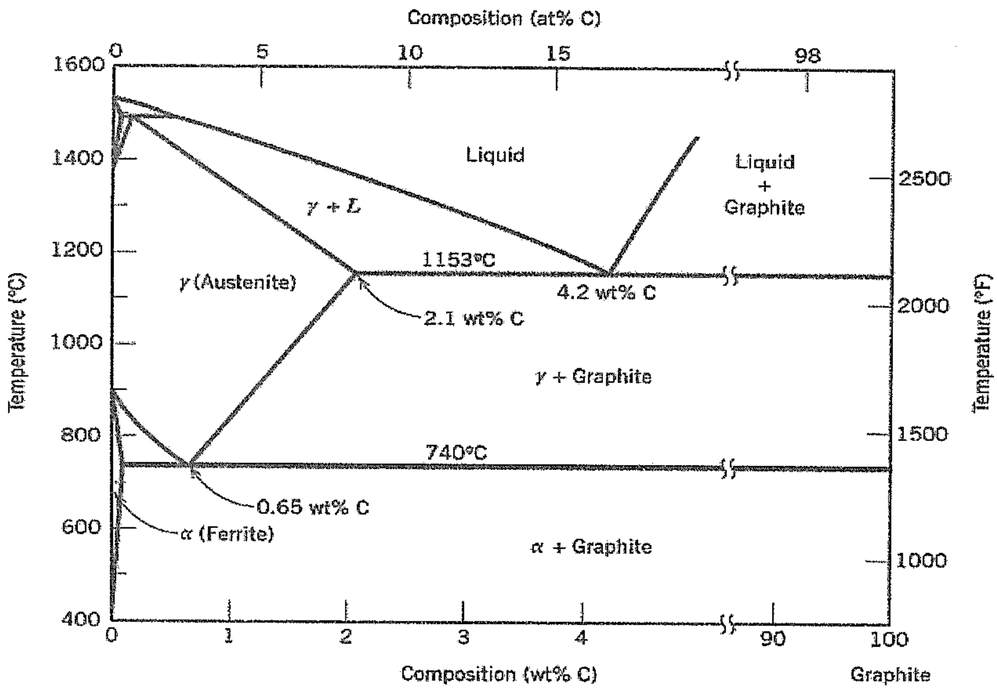


Figure 2 Fe-Fe$_3$C and Fe-Graphite phase diagrams

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With the aid of a stable phase diagram and a metastable phase diagram shown above, answer the following questions:

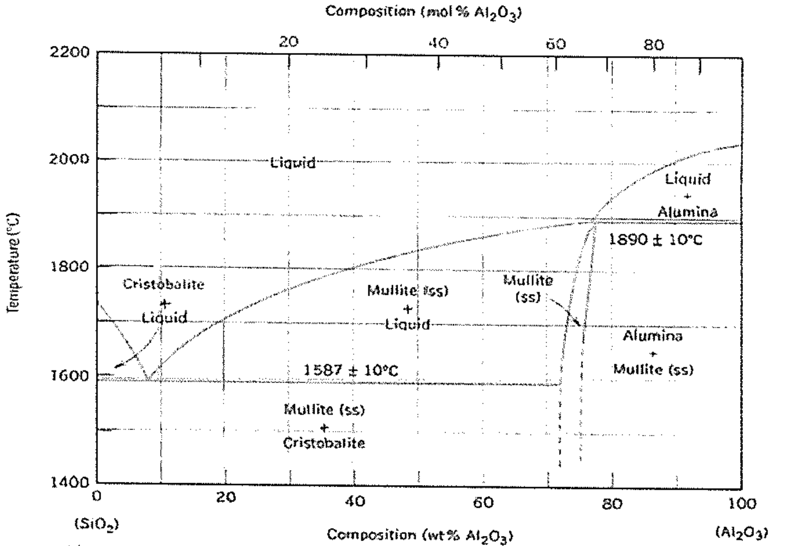
(a) Discuss the typical carbon concentration ranges (in wt%) for (i) steels, (ii) stainless steels, and (iii) cast iron. (3%)

(b) In spite of brittleness, cast iron is still widely used today. Cite three main advantages of cast iron in addition to its fair price. (2%)

(c) You are requested to make a cast iron with volume percent of graphite in 14%. Additionally, the cast iron should consist of a martensite matrix where graphite is embedded. Calculate the proper carbon concentration, and describe the treatment necessary to produce such this microstructure. Assume densities of 7.87 and 2.25 g cm^{-3} for α ferrite and graphite, respectively. (4%)

5. Suppose that $CaCl_2$ is added as an additive to NaCl, assuming that Ca^{+2} substitute for Na^+ and vacancy is formed. How many of this vacancy is created for every Ca^{+2} added (10%)?

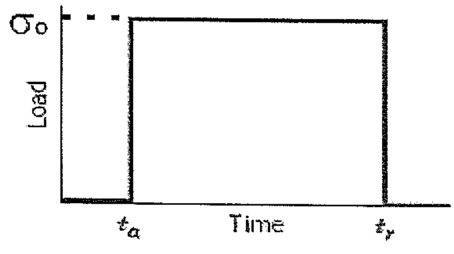
6. Both kaolinite and mullite are Al-Si-O compounds. The chemical formula of kaolinite is $Al_2(Si_2O_5)(OH)_4$, of mullite is $3Al_2O_3\ 2SiO_2$. Can we use kaolinite as the refractory for a 1600 °C furnace ? Explain briefly using the phase diagram for SiO_2-Al_2O_3 in the following (10%).
Note: the atomic weight of Al is 27, of Si is 14, of O is 8.



Adapted from F. J. Klug, S. Prochazka, and R. H. Doremus, "Alumina-Silica Phase Diagram in the Mullite Region," J. Am. Ceram. Soc., 70[10], 758 (1987). Reprinted by permission of the American Ceramic Society.

7. How the flexibility of polymer material affects its glass transition temperature and melting point? Why? (10%)

8. For the load-time cycle in figure (a), sketch schematic responses strain-versus-time for atactic poly(methyl methacrylate) at 0 °C and explain. (10%)



(a)

9. Please describe and compare the fundamental properties and the applications in devices for the following semiconductor materials (i) silicon (Si), (ii) gallium arsenide (GaAs), (iii) silicon carbide (SiC), and (iv) gallium nitride (GaN). Please explain the reasons. (12%)

10. What is the complex refractive index of materials? Please explain how the complex refractive index affects the surface reflection, transmission, and absorption of the materials with a thickness of **d**. (8%)

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