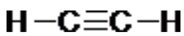
Example Exam Questions

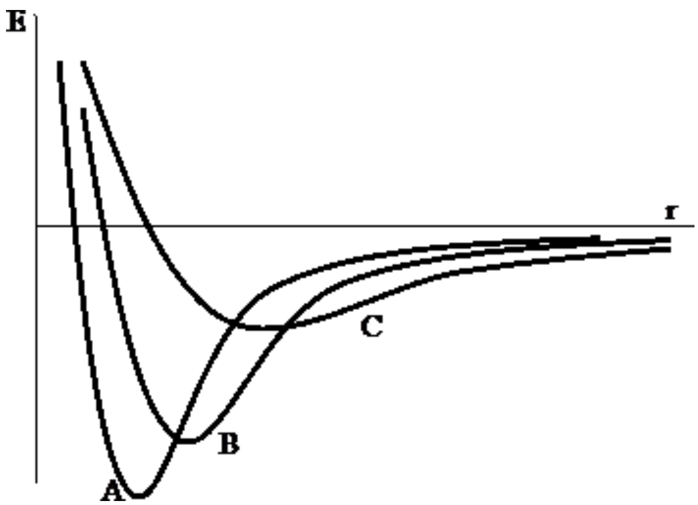
Note: You must show all work to receive full credit.
The number of questions here does not reflect the actual length of the exam.
Periodic table will be provided for all exams.

- **Introduction**
  - Describe one example where the structure of the material directly determines its property. One sentence description with a specific property must be given.
  - Site one technological need which may require developing new materials.

- **Atomic Structure and Bonding**
  1. Write the electron configuration for Ti^{4+}.
  2. List the following materials in the order of DECREASING ionicity: KBr, GaAs, CdSe. Justify your answer.
  3. What is the hybridization of the carbon atoms in the molecule shown below (acetylene)?



  4. The energy (E) vs. inter-atomic spacing (r) curves are shown below for three solids A, B and C.



  i. Which solid do you expect to have the largest elastic modulus? Explain.
  ii. Which curve might be representative of C-C bond in diamond and which to hydrogen bonding in water? Explain.

- **Crystal Structure**
  1. Draw an FCC and a BCC unit cell.
  2. What is the ratio of atomic packing factors for FCC and BCC unit cells (assuming they are made of same atoms)? Show work.
  3. Calculate the ratio of linear densities along [110] direction of FCC and BCC unit cells.
  4. Draw the unit cell and the [110] direction for a face-centered tetragonal unit cell.
  5. List all the crystallographic directions in the <110> family of a face-centered tetragonal

unit cell.

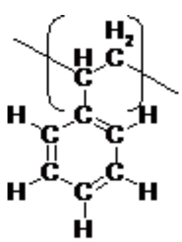
6. Draw the atomic arrangement on the (110) plane of a face-centered tetragonal unit cell.
7. Iron has BCC structure at room temperature. At temperatures between 912^{o}C and 1394^{o}C, the crystal structure changes to FCC. Calculate the percent change in density from BCC to FCC. Show your work.
8. Galena is a naturally occurring semiconductor. For simplicity we will consider it as an ionic crystal composed of lead and sulfur. The ionic radii of Pb^{2+} and S^{2-} are 0.133 nm and 0.184 nm, respectively.
    a) What is the empirical formula for lead sulfide?
    b) If the sulfur anions can be considered to form a cubic close packed crystal, which type(s) of interstitial sites and what percentage of these sites do the lead cations occupy?
    c) What is the name of this crystal structure?

9. Describe in one sentence what molar lattice energy is.

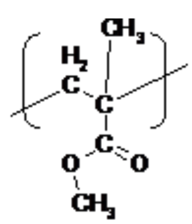
10. Can a vacancy diffuse more easily in an elemental metal or in an ionic crystal? Explain in one or two sentences.

- **Polymer structure**

1. Molecular weight (MW) distribution of a polymer sample was found to be:
    30% with MW = 5,400 g/mol
    40% with MW = 50,000 g/mol
    30% with MW = 100,000 g/mol
    a) Calculate number average and weight average MWs.
    b) If the polymer is found to be a copolymer of styrene and methyl methacrylate with number average degree of polymerization of 501, calculate the fraction of each type of monomer.

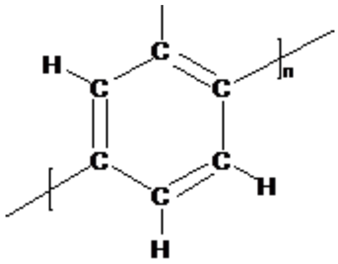


polystyrene

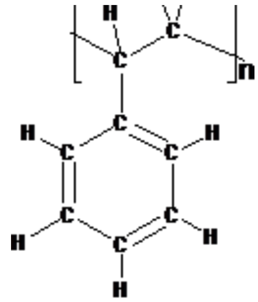


Poly(methyl methacrylate)

2. One of the main goals of molecular electronics is developing electronic components where one molecule is the active element in a device (e.g. as the semiconducting element in a transistor). We would like to design a system where electrically conducting polymers are used to “wire up” single molecule transistors. Below are two candidate polymers.



poly(para-phenylene)



polystyrene

a. Label the hybridization of all carbon atoms on each of the polymers.
b. Which one do you expect to be more electrically conducting? Explain in one sentence.
c. Describe in one sentence how the conductivity of the polymer you have chosen in part b can be increased.

(note: 2b and c are part of additional topics which may be covered near the end of the semester – if time permitting).

- **Imperfections**
  1. Will there be more vacancies or self-interstitials in a pure elemental metal at room temperature? Explain in one or two sentences.

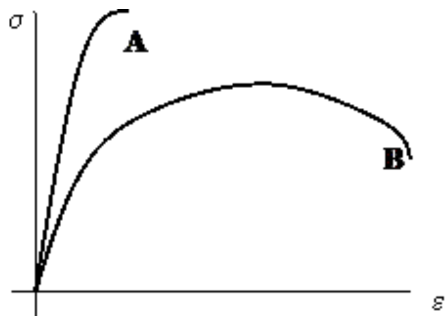
	Ni	Mo	C	Au	Si	Ti	Pd
Atomic radius (nm)	0.125	0.136	0.07	0.144	0.118	0.145	0.138
Crystal structure	FCC	BCC	hex. (not HCP)	FCC	Diamond cubic	HCP	FCC
Valence	2+	4+	4+	1+	4+	4+	2+
Atomic Weight	58.69	95.94	12.01	196.97	28.09	47.88	106.42
Density (g/cm^3)	8.90	10.22	2.25	19.32	2.33	4.51	12.02

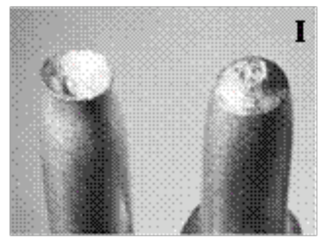
  2. Which element in the above table would have the highest solubility in Ni as substitutional solution? Explain.
  3. Calculate how much of the element (in at%) you have chosen needs to be added to increase or decrease the density of Ni by 1%.
  4. In order for Li^+ ions to be placed in galena (see problem 8 in Crystal structure section) as interstitial impurity, what other imperfection(s) and how many of these imperfections must be created for each Li^+ impurity. Give the most likely case.

- **Diffusion**
  1. Briefly describe two factors that contribute to the activation energy needed for an interstitial impurity to diffuse.
  2. In carburizing an iron-carbon alloy that has an initial C concentration of 0.15wt%C, you are asked to achieve 0.3wt%C at a position 3mm into the alloy in less than 20 hours.

The surface concentration can be maintained at 1.3wt%C. The pre-exponential and the activation energy for carbon diffusion in Fe are 2.3 x 10^{-5} m^2/s and 148kJ/mol, respectively. What is the minimum temperature at which you should run the carburization process?

- **Mechanical Properties**
  1. Fill in the blank: Cold work _____________ strength and _____________ ductility.
  2. Match the pictures with the corresponding stress-strain behavior.
  3.





  4. Label on the graph above the yield strength (s_y) and tensile strength (TS) for specimen **B**.
  5. A square rod specimen with stress-strain characteristic **A** is placed under tensile stress. The initial length and cross-sectional area are 60 mm and 100 mm^2, respectively. For a given load, a completely elastic elongation of 2 mm along the load direction is observed to occur without change in volume. Calculate the Poisson ratio of this specimen.
  6. Explain in one or two sentences why the neck propagates in semicrystalline polymers (unlike metals where deformation is confined to small neck) in stress-strain tests.

- **Deformation and Strengthening**
  1. Determine the slip system(s) and calculate the yield strength of an FCC crystal if the applied load is in the [101] direction and the critical resolved shear stress is 70 MPa.
  2. Fine grained materials are usually harder and stronger than coarse grained materials. Explain briefly.
  3. For each polymer pair, determine which will have **larger tensile modulus**. *Briefly explain your choices (one sentence answers).* If you cannot determine which will have larger modulus based on the given information, state so and explain why not.

     a) atactic polypropylene isotactic polypropylene -Assume same average molecular weights here.

     b) polystyrene with M_n = 10,000 g/mol polystyrene with M_n = 50,000 g/mol

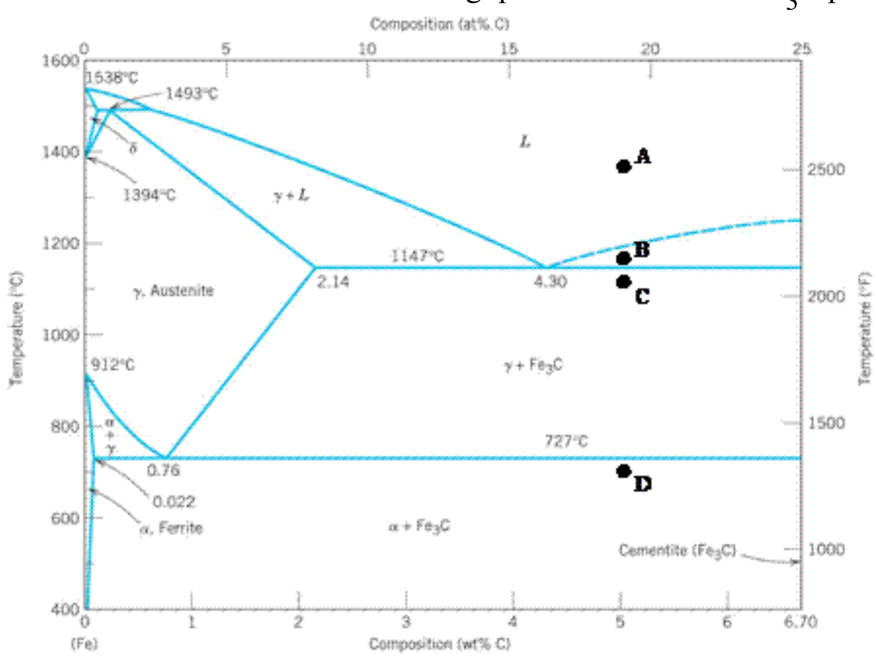
· **Failure**
  1. Describe one possible way to minimize the effects of creep in materials.
  2. Describe one possible way to minimize fatigue in materials.

3. About 500 years ago, DaVinci observed that a long wire fails at smaller tensile load than a short wire although the two wires were made of the same material with same cross sectional area. Explain why this happens in one sentence.
4. You are to design a thin-walled spherical tank for storage of high pressure gas. Safety design requires that the gas tank plastically deforms before detrimental breakdown (i.e. crack propagation). This condition will be met when the yield strength is equal or less than the critical stress for crack propagation. For the 3 alloys listed below, determine which one(s) can be used for the gas tank. Critical crack size for all three alloys are 4 mm. Assume plane strain conditions and that the parameter *Y* for all alloys is 1.

Material	**Yield strength (MPa)**	**K_{Ic} (MPa $\sqrt{m}$)**
1040 steel	260	54
Ti alloy	910	55
Al alloy	495	24

- **Phase Diagrams**

1. Answer the following questions for the Fe-Fe_3C phase diagram shown below.

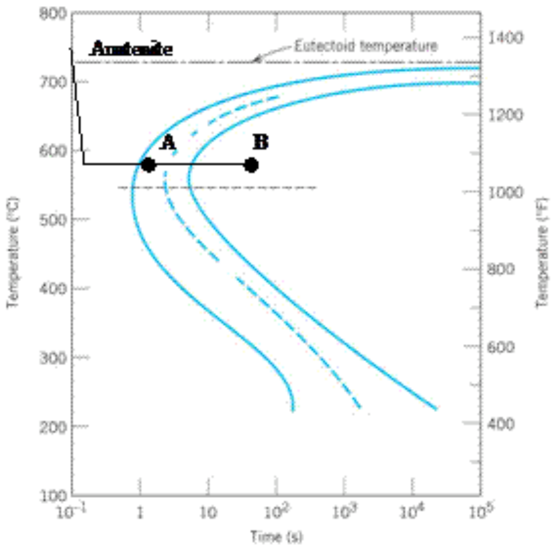


a) Draw the microstructures formed at points A, B, C, and D upon cooling from A to D. Label all phases and give the compositions. If there is more than one microstructure of the same phase (e.g. phases in eutectic or eutectoid structures as opposed to proeutectic or proeutectoid structures), label them so and indicate compositions as well.

b) Calculate the mass fractions (W_j) of each of the phases present at point C. If there is more than one microstructure of the same phase present calculate mass fractions for each one.

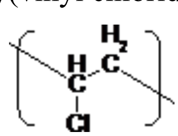
- **Phase Transformation**

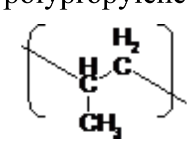
1. Answer the following questions for the Fe-C system isothermal transformation diagram of *eutectoid composition* shown below. You may need to refer to the Fe-Fe_3C phase diagram in the previous problem for appropriate information.



2. What is the composition (in wt% carbon) of the Austenite phase?
3. The alloy is cooled rapidly from T = 750°C to 580°C then held at 580°C. Draw the microstructures that arise at points A and B.
4. What is the rate of this reaction?
5. Draw the microstructure of the resulting alloy if it were heated at 580°C for an extended period of time. Explain why the structure changes upon extended heating.
6. Draw a cooling path that will lead to 100% martensite.
7. Draw a cooling path that will lead to 50% coarse pearlite and 50% bainite.
8. For each polymer pair, determine which will have **higher melting point**. Assume comparable average chain lengths/molecular weights for each case. <u>Explain your choices (one sentence answers)</u>. If you cannot determine which will have higher melting point based on the given information, state so and explain why not.

a) poly(vinyl chloride) polypropylene





b) polystyrene polypropylene

- **Composites**

1. Which will have higher elastic modulus assuming same types of fiber and matrix materials, same volume fractions, and same fiber-matrix bond strengths:

discontinuous-random or **discontinuous-aligned**? For the aligned fiber composite, use longitudinal elastic modulus.

2. Calculate the longitudinal tensile strength of an aligned carbon fiber reinforced composite with fiber volume fraction of 0.5, average fiber diameter of 1 mm and average length of 0.5 mm. The tensile strength of carbon fiber is 2 GPa, the stress in the matrix at fracture is 5 MPa, fiber-matrix bond strength is 60 MPa and the matrix shear yield strength is 50 MPa.

3. An employee at a composites manufacturing plant has made a mistake of using glass fibers where another type of fibers was supposed to be used. You are brought in as an expert in composite materials to figure out a way to salvage the composites by adding in another fiber material. The manufacturer says that the glass fibers are continuous and aligned and that the additional fibers can be placed homogeneously to the current composite (also continuous-aligned).
   a. Assuming a homogeneous distribution of the both fibers, derive the relation for the <u>*longitudinal*</u> *elastic modulus* of the 2-fiber composite. Useful equations: s = Ee; e = DL/L.
   b. Below are the properties of candidate materials to be used as the additional fiber, along with glass fiber and epoxy matrix. Initially, the glass fibers take up 20% volume fraction (therefore, 80% volume fraction for the matrix). Calculate the longitudinal elastic modulus of the composite for each additional fiber if 20% volume fraction of the total (i.e. up to 20% vol. fraction of the new fiber in the final product that contains 2 types of fibers). Determine which fiber you would recommend to use as the second additional fiber. No additional matrix material is added. Justify your answer.

	Elastic modulus (GPa)	Density (g/cm^3)	Cost ($/kg)
Glass fiber	72.5	2.58	2.50
C-fiber	400	1.80	175.00
Aramid fiber	131	1.44	31.00
Epoxy	2.41	1.14	9.00

Also refer to HW problems and examples from lecture…