Concordia
UNIVERSITY

**FACULTY OF ENGINEERING AND COMPUTER SCIENCE**
**DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING**

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|---|---|---|---|
| **COURSE:** MATERIALS SCIENCE | | **NUMBER:** MECH221 | **SECTION:** X |
| **EXAMINATION:** Mock Exam | **DATE:** April 26, 2011 | **TIME:** 08:00-11:00<br>**ROOM:** | **# OF PAGES:** 14 |
| **PROFESSOR**<br>J. Peach | | **LAB INSTRUCTOR** | |
| **MATERIALS ALLOWED YES**<br>**CALCULATORS ALLOWED YES** | | ENCS approved calculators<br>1 page formula sheet (no notes or sample problems just formulae) | |

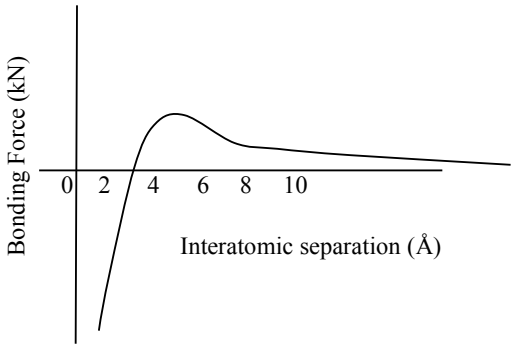
**SPECIAL INSTRUCTIONS:**
**Duration:** 3.0 hours

Answer questions 1-83 on the bubble sheet provided using a pencil **do not use a pen**. Include your name and student ID number on the bubble sheet and all other papers.

Questions 1 to 42 are worth 2 points each. Choose the SINGLE BEST answer.
Questions 43 to 83 are worth 1 point each
Questions 84 to 99 are to be answered in the booklet provided. The value of each question is noted in the question itself. If calculations are not provided your answer will not be marked. You *MUST* show *all* your steps in solving all problems!

**Name:** _____ **I.D.:** _____
**Surname, Given names**

1. The accompanying figure represents the net bonding force between two atoms. What is the equilibrium spacing between the two atoms?
   (a) 2 Å
   (b) 3 Å
   (c) 5 Å
   (d) 8 Å
   (e) Not enough information




2. By definition, a material that is considered "hard" will:
   (a) not be flexible.
   (b) be able to absorb energy during elastic loading and return it during unloading.
   (c) be resistant to fracturing when stressed.
   (d) have a low tensile strength.
   (e) be resistant to localized plastic deformation.

3. Which of the following electron configurations form an inert gas?
   (a) $1s^2 2s^2 2p^6 3s^2 3p^5$
   (b) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^2$
   (c) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$
   (d) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$
   (e) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^5 5s^2$

4. The Pauli exclusion principle states that:
   (a) each electron state can hold no more than two electrons, which must have the same spin.
   (b) each electron state can hold no more than two electrons, which must have opposite spins.
   (c) each electron state can hold no more than two electrons, which can have any spin.
   (d) each electron state must hold more than two electrons, which must have the same spin.
   (e) each electron state must an even number of electrons, which can have any spin.

5. Which of the following statements regarding atomic bonding is correct?
   (a) intermolecular bonds are usually stronger than atomic bonds.
   (b) the three atomic primary bonds are ionic, metallic and van der Waals.
   (c) metallic bonds are the result of attraction of ions of opposite charge.
   (d) atoms are subjected to attraction and repulsion forces between them and the lowest potential energy occurs when these forces cancel each other.
   (e) for ionic bonding, the coordination number depends on the number of valence electrons.

6. In what type of atomic bonding does the outer most valance electron loose its association with a specific atom?
   (a) Metallic bonding
   (b) Covalent bonding
   (c) Hydrogen bonding
   (d) Ionic bonding
   (e) This does not occur as the electrons must stay with the atoms to maintain charge balance.

7. Which of the following factors do not strongly effect the substitutional imperfections in metals
   (a) atomic size
   (b) crystal structure
   (c) electronegativity
   (d) valences
   (e) atomic mass

8. An edge dislocation can be described as:
   (a) a perfect crystal that has been sliced halfway through along its length and then sheared to produce a helix.
   (b) a perfect crystal that has had a line of atoms removed from the centre causing a zone of tension and compression.
   (c) a perfect crystal that has been sliced halfway through along its length and an extra half plane of atoms inserted into the slice.
   (d) a collection of vacancies that are ordered together forming a “defect line” in the centre of the crystal.
   (e) when the atoms at the edge of a material are removed or dislocated from the surface.

9. If a smooth block of copper is pressed against a smooth block of nickel and both are heated to a high temperature (but below their melting points), and held for a long time:
   (a) copper atoms will diffuse into nickel because copper has the lower melting point.
   (b) copper atoms will diffuse into the nickel and nickel atoms will diffuse into the copper.
   (c) no diffusion will occur between these metals because they have no solid solubility in each other.
   (d) nickel atoms will diffuse into copper because copper has the lower melting point.
   (e) nickel will diffuse into copper because copper is BCC and therefore has a lower packing factor and more empty space available for the nickel atoms.

10. According to Fick's first law, the flux will:
   (a) estimate the vacancies in a material.
   (b) change with the second derivative of the concentration gradient.
   (c) decrease proportionally with the diffusion coefficient.
   (d) increase proportionally with the diffusion coefficient.
   (e) Fick's first law does not have anything to do with flux.

11. A steel gear is to be carburized (carbon dioxide gas diffused into the steel). It has been determined that the current procedure takes to long. What can be done to decrease the time required to obtain the required carbon concentration?
   (a) use a low carbon steel so that the concentration gradient is higher.
   (b) increase the temperature.
   (c) increase the concentration of carbon dioxide gas.
   (d) both b and c.
   (e) none of the above would reduce the required time.

12. In a binary eutectic system, which statement is generally not correct?
(a) a two phase region always separates a single phase regions.
(b) the solvus line separates two solid phases.
(c) the solidus line separates two solid phases.
(d) in an eutectic reaction, a material can go from a solid to a liquid with no solid + liquid phase.
(e) the isothermal line passes through the invariant point.

13. In the iron-iron carbide system, which statement is not true with respect to pearlite?
(a) pearlite is a microstructure of eutectoid steel.
(b) pearlite consists of alternating layers of ferrite and cementite.
(c) within a grain/colony of pearlite, the lamellae change direction randomly.
(d) the ferrite component in pearlite is 0.022 %wt C.
(e) pearlite looks like mother of pearl under low magnification.

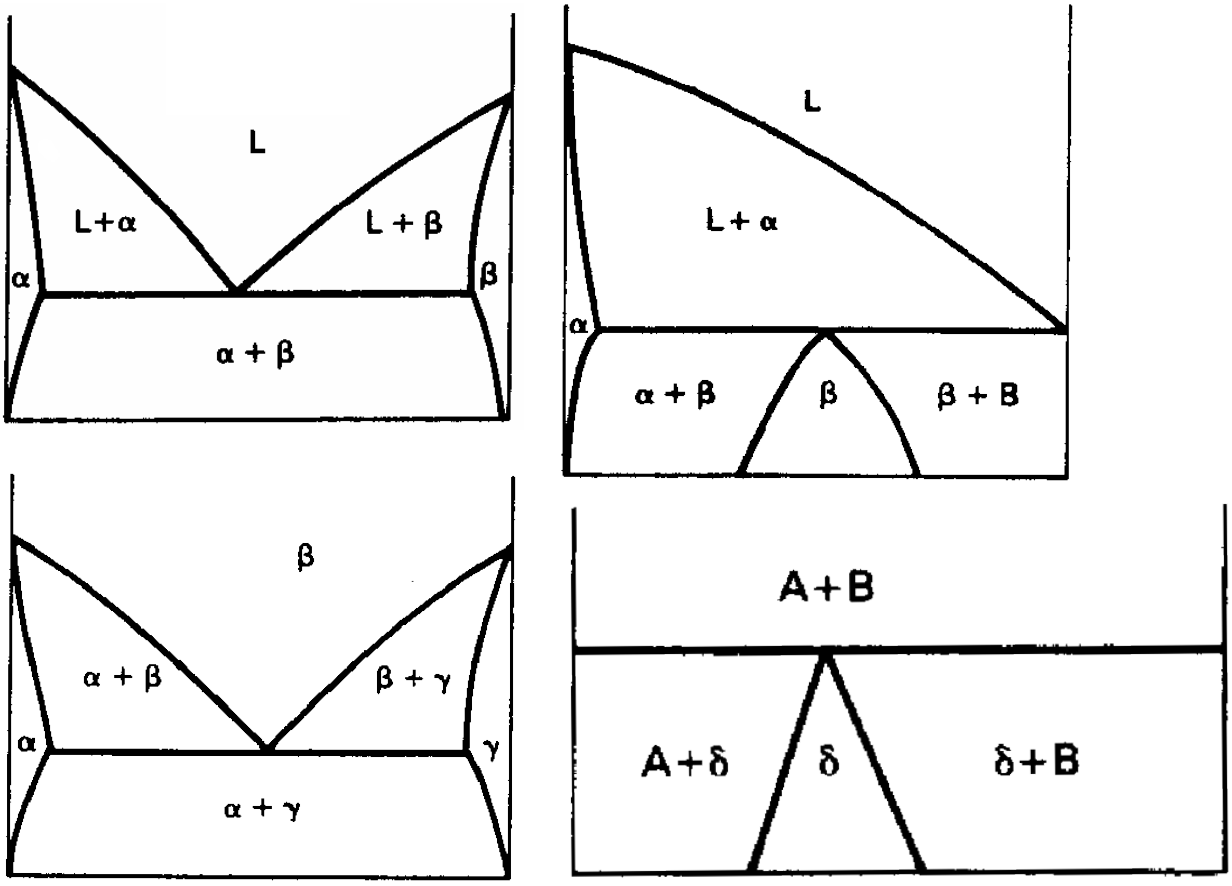
14. Tempering of glass by surface cooling is used in order to:
(a) make it more transparent.
(b) make it more ductile.
(c) add colour.
(d) glaze ceramic products.
(e) make it more impact resistant.

15. If the cation-anion ratio is known for a ceramic structure, it is possible to determine:
(a) cation-anion mass ratio.
(b) coordination number.
(c) cation-anion electronegativity ratio.
(d) the wave length of the light emitted from its crystal.
(e) none of the above.

16. The strength of a ceramic typically decreases for larger samples since larger samples tend to have:
(a) a larger melting temperature.
(b) larger bond lengths.
(c) a larger probability of containing a flaw capable of fracturing the sample.
(d) a smaller modulus of elasticity.
(e) none of the above.

17. Diamond and graphite are both composed of carbon atoms but diamond is harder and stronger than graphite because:
(a) diamond contains only covalent bonds whereas graphite contains only van der Waals bonds.
(b) graphite contains only covalent bonds whereas diamond contains only van der Waals bonds.
(c) diamond contains both covalent and van der Waals bonds whereas graphite contains only van der Waals bonds.
(d) graphite contains both covalent and van der Waals bonds whereas diamond contains only van der Waals bonds.
(e) diamond contains only covalent bonds whereas graphite contains both covalent and van der Waals bonds.

Use the following graphs to answer the next three questions




18. The eutectoid reaction is?
  (a) $L + \alpha \rightarrow \beta$
  (b) $L \rightarrow \alpha + \beta$
  (c) $A + B \rightarrow \delta$
  (d) $\beta \rightarrow \alpha + \gamma$
  (e) None of the above

19. The peritectic reaction is?
  (a) $L + \alpha \rightarrow \beta$
  (b) $L + \alpha \rightarrow \alpha + \beta$
  (c) $A + B \rightarrow \delta$
  (d) $L \rightarrow \alpha + \beta$
  (e) $L + \alpha \rightarrow \beta$

20. The eutectic reaction is?
  (a) $L + \alpha \rightarrow \beta$
  (b) $L + \beta \rightarrow \beta$
  (c) $\beta \rightarrow \alpha + \gamma$
  (d) $L \rightarrow \alpha + \beta$
  (e) $A + B \rightarrow \delta$

21. Which of the following statements is false?
(a) crystalline ceramics in general have high elastic moduli and high compressive strengths.
(b) brittle fracture caused by small surface and internal defects are a common cause of failure in crystalline ceramic materials.
(c) plastic deformation at room temperature by dislocation motion is impossible in these materials.
(d) the viscosity of silica glass can be lowered by the addition of metal oxides which cause disruptions in the silica network.
(e) glasses can be made resistant to fracture by developing a surface tensile residual stress by special heat treatment.

22. As the porosity of refractory ceramic bricks increases, the:
(a) strength decreases and thermal insulation increases.
(b) strength increases and thermal insulation decreases.
(c) strength decreases and thermal insulation decreases.
(d) strength increases and thermal insulation increases.
(e) porosity does not affect the thermal conductivity of the ceramic materials.

23. Which of the following will increase the thermal shock resistance of a ceramic material?
(a) decreasing the modulus of elasticity
(b) decreasing the material's coefficient of thermal expansion.
(c) increasing the material's ability to reduce internal temperature gradients (i.e. material's thermal conductivity).
(d) increasing the material's fracture strength.
(e) all of the above.

24. Which of the following statements is false?
(a) diamonds and Graphite are two different crystalline forms of carbon.
(b) diamonds are crystalline forms of carbon whereas Graphite is an amorphous form of carbon.
(c) fullerenes are carbon molecules arranged in geometric structures like spheres (buckyballs).
(d) diamonds are very hard and strong whereas graphite can be used as a lubricant.
(e) diamonds are used industrially for grinding and cutting purposes as well as thin films.

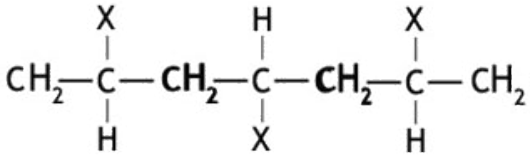
25. A ceramic is most likely to fail under which condition (consider the crack tip radius to be equal in all cases).
(a) there is a surface flaw 2 μm in length with its long axis perpendicular to the stress.
(b) there is an internal flaw 0.5 μm in length with its long axis parallel to the stress.
(c) there is an internal flaw 2 μm in length with its long axis parallel to the stress.
(d) there is a surface flaw 1 μm in length with its long axis parallel to the stress.
(e) there is an internal flaw 0.5 μm in length with its long axis perpendicular to the stress.

26. Which of the following accompanies the ceramic firing process?
(a) polymerization
(b) annealing
(c) vitrification
(d) plasticizing
(e) tempering

27. A polymer that consists of more than one type of repeat unit is called
(a) aisopolymer
(b) copolymer
(c) homopolymer
(d) bifuncitional polymer
(e) multimer

28. Elastomers generally have which of the following molecular structures?
(a) branched polymer
(b) cross-linked polymer
(c) linear polymer
(d) networked polymer
(e) none of the above

29. The stereoisomerism shown is of what configuration?



(a) isotactic
(b) stereotactic
(c) syndiotactic
(d) atactic
(e) cis

30. With respect to the crystallinity of a polymer:
(a) the strength of the polymer increases
(b) the strength of the polymer decreases
(c) the strength of the polymer is not effected.
(d) the percentage of the crystallization can be increased by decreasing the cooling rate after heating.
(e) both (a) and (d)

31. Which of the following statements about polymers, in general, is false?
(a) polymers have lower elastic moduli than ceramics or metals.
(b) most polymers are amorphous or partly-crystalline materials.
(c) most polymers are made from oil.
(d) the basic structure of thermoplastics is a covalently bonded carbon chain.
(e) all polymers have covalent cross-linking.

32. Compression molding of thermosetting polymers:
(a) can be performed after melting the polymer.
(b) should be conducted after softening the polymer.
(c) the reaction should take place in the mold while applying pressure.
(d) thermosets cannot be fabricated by compression molding.
(e) none of the above.

33. Thermosetting polymers:
(a) are also known as thermoplastic polymers.
(b) can be “uncured” by rapid cooling.
(c) readily cross-link during curing.
(d) can be reheated and reshaped.
(e) all of the above.

34. A viscoelastic polymer is loaded statically in tension. The material will:
(a) have an instantaneous increase in strain that will stay constant.
(b) have an instantaneous increase in strain that will slowly increase.
(c) have an instantaneous increase in strain that will slowly decrease.
(d) have no instantaneous increase in strain but will slowly increase.
(e) have no instantaneous increase in strain but will slowly decrease.

35. Which of the following statements are true about vulcanized rubber:
(a) vulcanized rubber is less chemically stable then unvulcanized rubber.
(b) the vulcanization process turns a thermosetting rubber into a thermoplastic rubber.
(c) for a given strain, vulcanized rubber will have a higher stress then an equivalent unvulcanized rubber.
(d) increases the number of cross-links between polymer chains.
(e) both (c) and (d)

36. Which of the following is not a common additive to polymers
(a) plasticizers
(b) stabilizers
(c) condensers
(d) fillers
(e) flame retardants

37. For a p-type semiconductor,
(a) the Fermi level is located in the middle of the band gap.
(b) electron concentration < Hole concentration.
(c) electron concentration = Hole concentration.
(d) electron concentration > Hole concentration.
(e) this occurs only in ionic materials with high concentration of cations.

38. The electrical conductivity of a piece of metal generally decreases with:
(a) increasing deformation.
(b) increasing impurity content.
(c) increasing temperature.
(d) both (a) and (b)
(e) (a), (b) and (c)

39. The quantity of heat required to produce a unit rise in temperature for one mole of a substance is called:
(a) kinetic energy capacity
(b) heat capacity
(c) heat capacitance
(d) debye heat
(e) thermal conductivity

40. In general, the expansion of a solid material when heated is due to:
(a) a break-down in the crystalline structure to form a glassy structure.
(b) increased diffusion into the material causing it to swell.
(c) increased interatomic bond spacing.
(d) change in the type of crystalline structure (i.e. FCC becomes BCC which is less dense).
(e) increased energy means that more electrons can fill the out orbits.

41. For a solid material, which of the following are not primarily responsible for heat transfer?
(a) proton decay
(b) free electrons
(c) vibrational lattice waves
(d) phonons
(e) all of the above are primarily responsible for heat transfer in solid material.

42. You have been tasked with choosing a material that will be resistant to thermal shock. Which properties would be important in preventing thermal shock.
(a) all ceramics are generally thermal shock resistant
(b) high fracture strength
(c) high thermal conductance
(d) both (a) and (b)
(e) both (b) and (c)

**For Questions 43 – 83, decide whether the following statements are True or False. Shade in (a) for True and (e) for False.**

43. The atomic number of an atom is equal to the sum of the protons and neutrons in the nucleus.

44. The coordination number for the FCC structure is 12.

45. The higher the atomic packing factor the more empty space is between the atoms.

46. The triclinic crystal system has interaxial angles that are all unequal.

47. (1011) is a valid plane in the hexagonal crystal system.

48. When determining Miller indices the plane must pass through the origin of the coordinate system.

49. If the strength of a material is the same in all directions it is said to be isotropic.

50. The position of atoms in a crystalline structure can be determined by X-ray diffraction.

51. In a solid metal, the number of vacancies decreases with an increase in temperature.

52. Most dislocations are either pure screw or edge dislocations but not a mix of the two.

53. In steady-state solid-state diffusion, the concentration gradient is linear.

54. Carburizing is the process of coating an object with a layer of blacking carbon.

55. Metals have the same strength in compression as in tension.

56. For most solid metals, the modulus of elasticity decreases with increasing temperature.

57. The modulus of elasticity is proportional to the slope of the atomic force vs atomic separation curve in the elastic region of the stress strain curve.

58. Toughness is a measure of a material's ability to absorb energy until it fractures.

59. True stress and engineering stress are different, but true strain and engineering strain are the same.

60. During plastic deformation, the grain boundaries often act as a barrier for the dislocation motion.

61. High purity metals are generally softer then alloys due to solid-solution strengthening.

62. Ductile metals, generally, become softer when plastically deformed and this is called cold working.

63. Grains, in metals, can be increased in size by heating the material and slowly cooling it.

64. The melting temperature of an alloy is independent of the composition of its components.

65. The Ni-Cu alloy is a binary isomorphous system and therefore, the amount of Cu can ranging from 0 to 100%.

66. In order to use standard phase diagrams, alloys must be cooled rapidly.

67. In a binary eutectic system, the invariant point is always above the eutectic isotherm.

68. In a binary eutectic system, it is generally possible to estimate the composition by looking at a micrograph of an alloy that has been cooled from a liquid state to a solid state.

69. In an iron-iron carbide alloy, the three principle phases are ferrite, austenite and cementite.

70. A hypoeutectoid alloy has a composition below the eutectoid composition.

71. The predominant bonding in ceramics is ionic because it is composed of a metals and non-metals.

72. Fullerenes are polymophic form of carbon and are unstable at room temperature.

73. A common atomic point defect in ceramic is to have a missing cation but the anion is present.

74. Porosity in ceramics increases the modulus of elasticity (E)

75. The larger the clay particles, the more shrinkage will occur during drying.

76. As the crystallinity increases in a polymer, the modulus of elasticity also increases.

77. In polymers, the modulus of elasticity can change drastically within a narrow temperature range.

78. The creep modulus ($E_c$) varies with time since the strain changes with time.

79. During plastic deformation in polymers, the amorphous chains align in a process called drawing.

80. In addition polymerization, a catalyst is used to join polymers together.

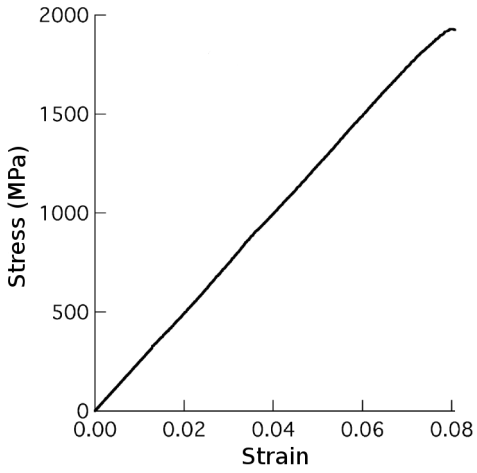
81. As the temperature of a pure metal increases the electrical resistance decreases.

82. In an intrinsic semiconductor the hole and electron travel in the same direction.

83. In an n-type extrinsic semiconductor an extra electron is present from the doping atom.

**Answer the questions in the booklet provided. The value of each question is given in parenthesis beside the question number.**

84. For the given stress-strain diagram:
   (a) (1 point) What is the modulus of elasticity (E)?
   (b) (4 points) A 10-cm rod with a diameter of 1-cm has 125 kN of force applied in tension. The approximate final length of the loaded rod will be?

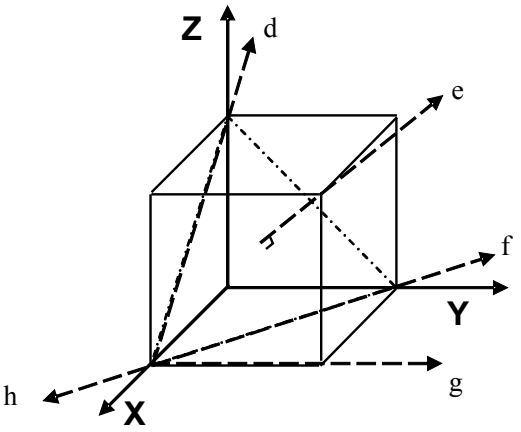



85. (2 points) Lead has an FCC structure and an atomic radius of 0.175 nm. What is the volume of the unit cell?

86. (3 points) Two hypothetical metals, A and B, have identical densities; however A has an FCC crystal structure whereas B is BCC. If the length of the unit cell of A and B are 0.3 and 0.4 nm respectively, determine which one has the heaviest atom? (i.e. Which has the highest atomic weight?)

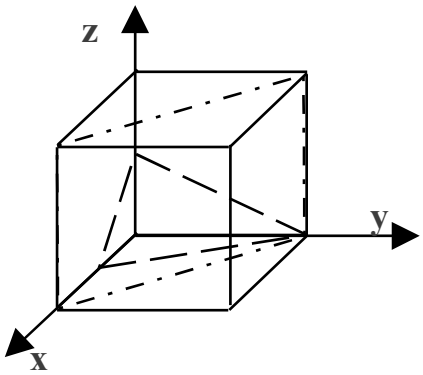
87. (6 points) The activation energy and pre-exponential term ($D_0$) values for carbon diffusing in BCC-iron are 80 kJ/mol and 6.2E-7 $m^2/s$, respectively. The corresponding values for carbon diffusing in FCC-iron are 148 kJ/mol and 2.3E-5 $m^2/s$. At 910°C the carbon atoms determine which one (FCC or BCC) has a higher diffusion rate and approximately how much faster?

88. Using the attached diagram:
(a) (2 point) What is the direction vector of "e" and miller indice of the triangular shaped plane with the direction vector "e"?
(b) (4 points) What are the direction vectors of "d", "f", "g" and "h"?
(c) (2 point) Which vector or vectors is/are slip direction(s) in the copper unit cell (FCC)?



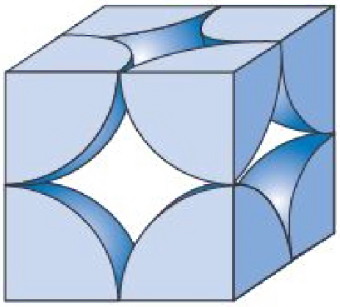

89. (2 points) For an ASTM grain size of 7, approximately how many grains would there be per square inch when the magnification is 100 times?

90. (2 points) What are the the Miller indices of the two dotted planes shown?



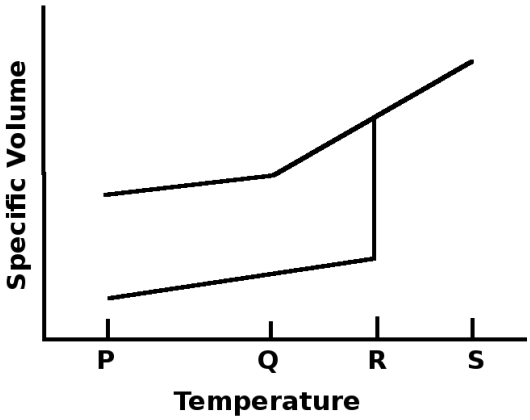

91. (8 points) A cylindrical specimen of a hypothetical metal alloy is stressed in compression. If its original and final diameters are 30.00 and 30.04 mm, respectively, and its final length is 105.20 mm. Compute its original length if the deformation is totally elastic. The elastic and shear moduli for the alloy are 65.5 and 25.4 GPa receptively.

92. (3 points) Some hypothetical metal has a simple cubic structure that is shown in the figure. If the atomic radius is 0.185 nm and the atomic weight is 84.5 g/mol, determine the density..



93. (2 points) What is the composition of carbon, in weight percent, of an alloy that contains 105 Kg of iron, 20 Kg of carbon and 10 Kg of chromium.

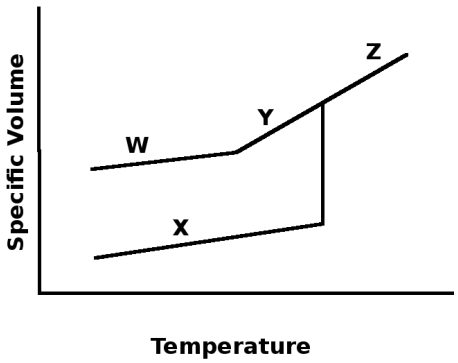
94. Identify the following points on the graph showing the relationship between specific volume and temperature of two types of ceramics:
(a) (1 point) Glass transition temperature, $T_g$,
(b) (1 point ) Melting temperature, $T_m$.




95. (2 points) The energy of formation for a metal is 1.10 eV/atom and the metal is at 1000°C. What percentage of the binding sites are vacant?.

96. (2 points) The density of of a sample of a polymer is 1.05 g/cm$^3$. The amorphous portion has a density of 0.76 g/cm$^3$ and the crystalline portion has a density of 1.13 g/cm$^3$. What is the percentage of crystallinity?

97. (4 points) Which of the following best describes the material behaviour exhibited at the designated regions in the graph showing the relationship between specific volume and temperature of two types of ceramics?

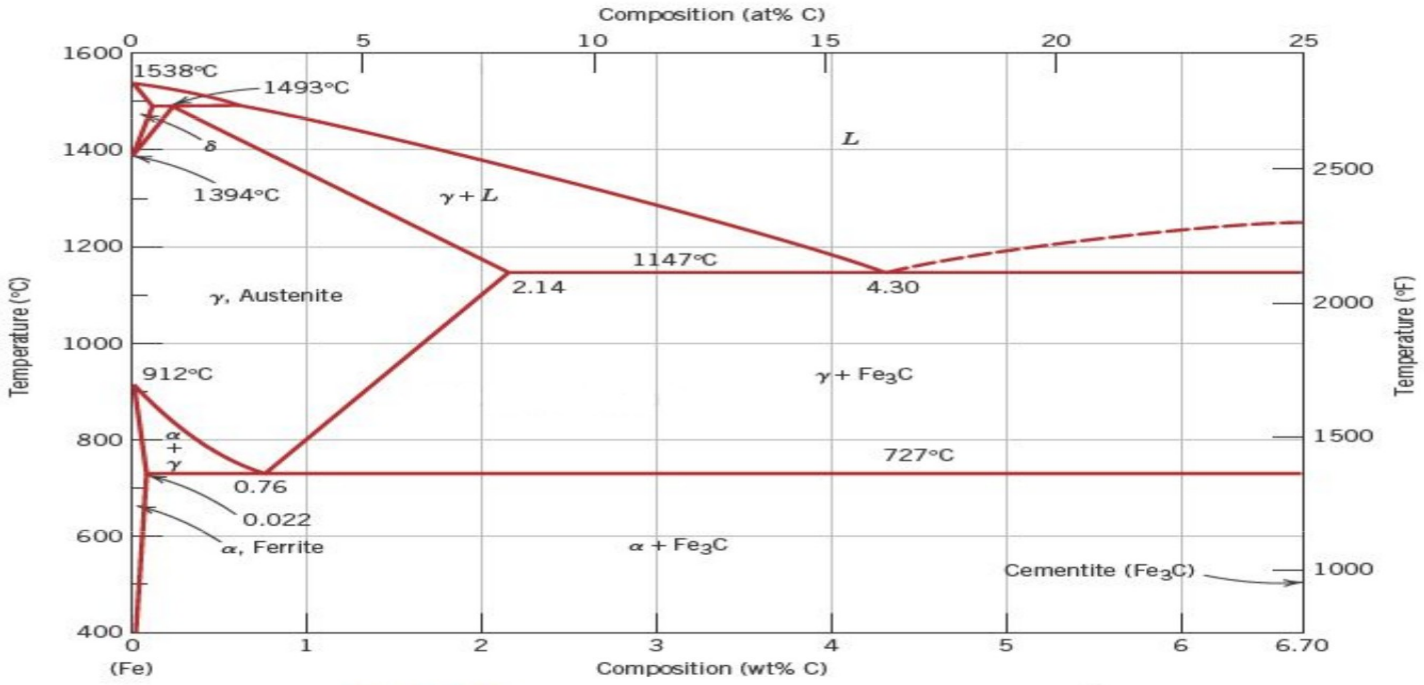



| | Zone |
|---|---|
| Crystalline | _____ |
| Glassy | _____ |
| Supercooled liquid | _____ |
| Liquid | _____ |

98. (4 points) Using the following data to determine the number-average molecular weight and the degree of polymerization for polyvinyl chloride ($C_2H_3Cl$). The atomic weights are: C=12.011 g/mol; H=1.0080 g/mol and Cl=35.453.

| **Molecular Weight Range (g/mol)** | $x_i$ |
|---|---|
| 8,000 - 20,000 | 0.05 |
| 20,000 – 32,000 | 0.15 |
| 32,000 – 44,000 | 0.21 |
| 44,000 – 56,000 | 0.28 |
| 56,000 – 68,000 | 0.18 |
| 68,000 – 80,000 | 0.10 |
| 80,000 – 92,000 | 0.03 |

99. (15 points) For an iron-carbon alloy with a composition of 3 wt% C-97 wt% Fe at the following temperatures a) 1250°C, b) 1144°C, c) 700°C determine the composition of C and weight fraction of each phase. Also, sketch the micro-structure and label each phase.



**Equation Sheet**

$$F_{Net} = F_A + F_R \qquad E = \int F dr \qquad E_{Net} = E_A + E_R \qquad \rho = \frac{nA}{V_c N_A} \qquad n\lambda = 2d_{hkl}\sin\theta$$

$$\%ionicity = \left\{1 - \exp\left(-0.25\left[X_A - X_B\right]^2\right)\right\} x100 \qquad N_v = N\exp\left(\frac{-Q}{kT}\right) \qquad D = D_o \exp\left(\frac{-Q}{RT}\right)$$

$$\frac{C_X - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right) \qquad d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \qquad N = 2^{n-1} \qquad J = -\frac{M}{At}$$

$$J = -D\frac{dc}{dx} \qquad \frac{dC}{dt} = D\frac{d^2c}{dx^2} \qquad C_1 = \frac{m_1}{m_1 + m_2} x100$$

$$\tau = \frac{F}{A_0} = G\gamma \qquad \%El = \left(\frac{l_f - l_0}{l_o}\right) x100 \qquad E = 2G(1+\nu)$$

$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z} \qquad \%AR = \left(\frac{A_o - A_i}{A_o}\right) x100 \qquad U_r = \frac{1}{2}\sigma_y\varepsilon_y = \frac{\sigma_y^2}{2E}$$

$$\tau = G\gamma \qquad \%crystallinity = \frac{\rho_c(\rho_s - \rho_a)}{\rho_s(\rho_c - \rho_a)} \qquad TS = TS_\infty - \frac{A}{\overline{M}_n}$$

$$K_{1c} = Y\sigma\sqrt{\pi a} \qquad \sigma_{fs} = \sigma_o \exp(-nP) \qquad E = E_o(1 - 1.9P + 0.9P^2)$$

$$\sigma_{fs} = \frac{3F_f L}{2bd^2} \qquad \sigma_{fs} = \frac{F_f L}{\pi R^3} \qquad E = \frac{F}{\delta}\frac{L^3}{4bd^3} \qquad E = \frac{F}{\delta}\frac{L^3}{12\pi R^4}$$

$$\Delta V = I\,R \qquad R = \frac{\rho L}{A} = \frac{L}{A\sigma} \qquad \rho_{total} = \rho_{thermal} + \rho_{impurity} + \rho_{def} \qquad \rho_{thermal} = \rho_o + aT$$

$$\rho_{impurity} = Ac_i(1 - c_i) \qquad \sigma = n|e|\mu_e + p|e|\mu_h \qquad C = \frac{dQ}{dT}\ \text{[J/mol - K]} \qquad \sigma_{TH} = E\alpha_l\Delta T$$

$$C_V = \left(\frac{\delta q}{dT}\right)_V \qquad C_P = \left(\frac{\delta q}{dT}\right)_P \qquad \frac{\Delta L}{L_o} = \alpha(T_2 - T_1) \qquad q = -k\frac{dT}{dx} \qquad TSR \cong \frac{\sigma_f k}{E\alpha_l}$$

$E = h\nu = hc/\lambda$ $\qquad I_0 = I_T + I_A + I_P$

**Constants**

$N_A = 6.023 \times 10^{23}$ atoms/mol  speed of light = $3 \times 10^8$ m/s

$k = 8.62 \times 10^{-5}$ eV/atom-K or $1.38 \times 10^{-23}$ J/atoms-K

Planck's constant = $6.63 \times 10^{-34}$ J-s = $4.13 \times 10^{-15}$ eV-s

R = 8.314 J/(mol.K)