Solutions

Student Name:______________________ ID Number:______________________

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DEPARTMENT OF MECHANICAL ENGINEERING

CONCORDIA UNIVERSITY

MATERIALS SCIENCE - MECH 221/2 - Sections T & X MIDTERM 2003

Instructors: Dr. M.Pugh & Dr. M.Medraj

Time Allowed: one (1) hour.
Materials Allowed: Pens/pencils, eraser, ruler, calculator; **No books/notes.**
Answer all questions. Put your answers on this exam paper in the spaces provided.
Marking Scheme: Questions 1-20, worth 1 mark each. Other questions; marks as indicated.

For these multiple choice questions, select the best answer and shade in the letter in brackets for that answer e.g. (a). Use a pencil in case you change your mind.

1. The interstitial solid solution of carbon in body centred cubic Fe known as ferrite, can best be described as:
   (a) grains of carbon randomly mixed with grains of iron.
   (b) a random distribution of carbon atoms in between the iron atom positions of BCC iron.
   (c) a random arrangement of iron atoms at the FCC crystal lattice positions of carbon.
   (d) a very specific arrangement of carbon atoms at the lattice positions of the BCC iron.
   (e) a random arrangement of carbon atoms at the lattice positions of the BCC iron.

2. 15wt% tin can be added to copper in the molten state and cooled to give a substitutional solid solution known as bronze. This means that the crystal structure of the solid solution :
   (a) consists of unit cells of FCC copper interspersed with unit cells of FCC tin.
   (b) is basically that of FCC copper with some of the copper atoms replaced by tin atoms.
   (c) consists of grains of pure copper which make up 85% of the weight of the material. The remaining 15% occurs as grains of pure tin.
   (d) is that of tin with the copper atoms squeezed in the gaps between the tin atoms.
   (e) is that of copper with the tin atoms squeezed into the spaces between the copper atoms.

3. Which of the following best describes covalent bonding?
   (a) One atom shares its outer electron(s) with a neighbouring atom(s) and they both become energetically more stable.
   (b) One atom donates its outer electron(s) to a different atom and they are electrostatically attracted.
   (c) Hydrogen molecules join the atoms together.
   (d) The atoms plastically deform and necking occurs between them making them stick to each other.
   (e) One atom forms a random dipole and attracts an atom with an induced dipole.

4. Which of the following best describes ionic bonding?
   (a) The electrons of one atom join with electrons of other atoms to produce a "sea" of electrons around the ions.
   (b) The ions of the positive atoms form dipoles which attract the dipoles of the negative atoms.
   (c) Electrons from both ions join in the middle and are shared.
   (d) One atomic species gives up electrons to become positive ions, and the other atomic species accept electrons to become negative ions, which are then electrostatically attracted to each other.
   (e) One atom gives up electrons to become an anion and another atom accepts the electron to become a cation: these are then electrostatically attracted to each other.

5. Which of the following best describes a body centred **cubic** unit cell?
   (a) $a = b = c$, $\alpha = \beta = \gamma = 90^\circ$ with an atom at each corner.
   (b) $a = b \neq c$, $\alpha = \beta = \gamma = 90^\circ$ with an atom at each corner and one in the centre.
   (c) $a = b = c$, $\alpha = \beta = \gamma = 90^\circ$ with an atom at each corner plus one at the centre.
   (d) $a \neq b \neq c$, $\alpha = \beta = \gamma = 90^\circ$ with an atom at each corner plus one at the centre.
   (e) $a = b \neq c$, $\alpha = \beta = \gamma = 90^\circ$ with an atom at each corner and one in the centre of each face.

6. The Atomic Packing Factors (APF) for the BCC : FCC : HCP crystal systems are respectively:
   (a) 0.68 : 0.74 :0.74
   (b) 0.86 : 0.68 : 0.68
   (c) 0.74 : 0.68 : 0.68
   (d) 0.74 : 0.74 : 0.68
   (e) 0.68 : 0.74 : 0.68

7. The ranking of the following parts of a piece of metal in terms of energy (highest to lowest) is:
(a) bulk : surface : grain boundary
(b) surface: bulk : grain boundary
(c) grain boundary : surface : bulk
(d) grain boundary : bulk : surface
(e) surface : grain boundary : bulk

8. Materials such as metals and ceramics are held together by atomic bonds between atoms. The equilibrium separation distance between adjacent atoms is the distance where:
(a) the net force between the atoms is highest
(b) the net force between the atoms is lowest
(c) the potential energy between the atoms is zero
(d) the potential energy between the atoms is lowest
(e) the potential energy between the atoms is highest

9. Crystalline materials are composed of grains which can have a wide range of sizes. Apart from this, the difference between adjacent grains in a pure metal or ceramic is their different:
(a) Densities
(b) Compositions
(c) Lattice parameters
(d) Crystal structures
(e) Crystal Orientations

10. Tantalum has a body centred cubic (BCC) structure. The unit cell thus contains:
(a) 1 atom
(b) 2 atoms
(c) 4 atoms
(d) 6 atoms
(e) 9 atoms

For these True/False questions, circle the response that you think is <u>correct</u>. E.g. Circle (T) if you think the statement is TRUE or (F) if you think the statement is False.

T (F) **(11)** The burger's vector for an edge dislocation is parallel to the dislocation line.

(T) F **(12)** The burger's vector for a screw dislocation is parallel to the dislocation line.

T (F) **(13)** To see the grains in a piece of metal, the metal just has to be polished until it is very flat and reflective and then examined under the microscope.

T (F) **(14)** In order to examine the crystal structure of materials, they are systematically bombarded with filtered, monochromatic X-rays of a known wavelength and the resulting diffracted rays are collected and the intensities of these rays are plotted as a function of the angular position of the source, specimen and collector and then the interplanar spacings, d_{hkl} can be calculated using Bouchard's Law.

T (F) **(15)** {100} represents the family of planes that make up the sides of the cube of the BCC unit cell and for the FCC unit cell it is the {110} family of planes.

T (F) **(16)** In order to form an interstitial solid solution (for example, carbon in iron) the radius of the interstitial atom must be within ± 15% of the atomic radius of the solvent (host) atom.

T (F) **(17)** Vacancy (substitutional) diffusion is faster than interstitial diffusion because the atoms move into vacant atomic sites rather than having to push into the spaces in between atoms.

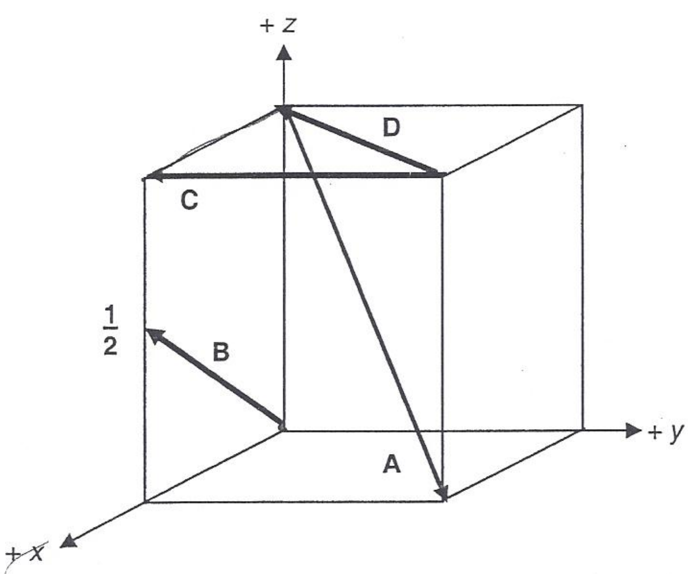
(T) F **(18)** Steady state diffusion involves diffusion of species down a linear concentration gradient.

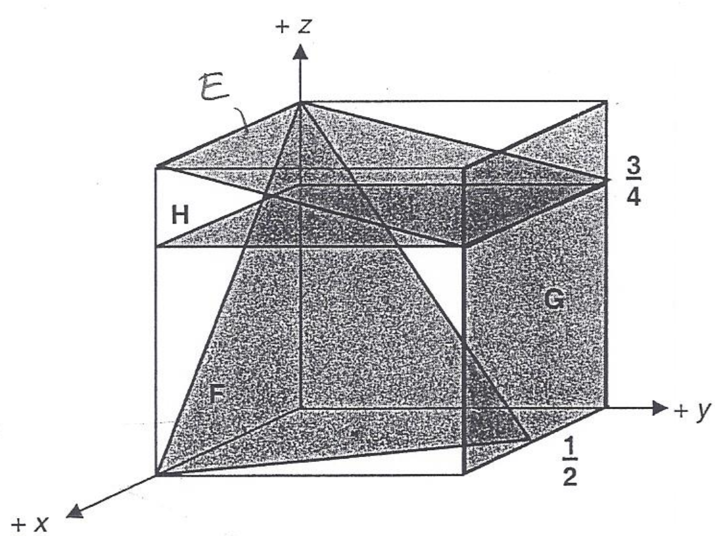
T (F) **(19)** Non-steady diffusion such as diffusion of carbon into steel during carburizing, is not very dependant on temperature. Time of diffusion is much more important.

T (F) **(20)** When designing a steel crash barrier for highways it is important that the yield strength of the steel barrier is not exceeded during a crash. (The purpose of the barrier is so that if a truck goes off the road and crashes into the steel crash barrier along the side of the highway the barrier slows the truck and eventually stops the truck without letting the truck through the barrier into oncoming traffic or over a cliff).

(21) Determine the Miller indices for the directions and planes shown in the following cubic unit cells:
{8 marks}

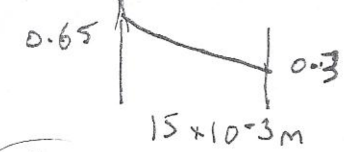
A) [1 1 $\bar{1}$]
B) [2 0 $\bar{1}$]
C) [0 $\bar{1}$ 0]
D) [$\bar{1}$ $\bar{1}$ 0]
E) (0 1 4)
F) (2 1 2)
G) (0 1 0)
H) (0 0 1) or (0 0 4)





(22) Carbon is allowed to diffuse through a steel plate 15 mm thick. The concentrations of carbon at the two faces are 0.65 and 0.30 kg C/m^3 Fe, which are maintained constant. If the preexponential and activation energy are $6.2 \times 10^{-7} m^2/s$ and 80,000 J/mol, respectively, compute the temperature at which the diffusion flux is $1.43 \; 10^{-9} \; kg/m^2.s$. *{4 marks}*

$D = D_0 e^{-Q/RT}$ $\quad J = -D \frac{dc}{dx}$



$1.43 \times 10^{-9} = \frac{-(0.65 - 0.3)}{15 \times 10^{-3}} D$ $\quad D = 6.13 \times 10^{-11} \; m^2 s^{-1}$

-ve slope

$$\ln\left(\frac{1.439 \times 10^{-9} \times 15 \times 10^{-3}}{6.2 \times 10^{-7} \times 0.35}\right) = \frac{-80,000}{8.314 \, T}$$

$$T = \frac{-80,000}{8.314 \times \ln\left(\frac{1.439 \times 10^{-9} \times 15 \times 10^{-3}}{6.2 \times 10^{-7} \times 0.35}\right)} \text{ K.}$$

$$= 1044 \text{ K} = 771\,°C$$

(4)

(23) At approximately what temperature would a specimen of γ-iron have to be carburized for 2 h to produce the same diffusion result as at 900°C for 15 h? *{4 marks}*

All factors constant except T and t (ie t and D)

ie $\sqrt{D_{900} 15} = \sqrt{D_T 2}$ or $D_T = 7.5 D_{900}$ (1)

$$D_0 \exp\left(-\frac{Q}{RT}\right) = 7.5 D_0 \exp\left(\frac{-Q}{R \, 1173}\right)$$

taking ln/ $\left(\frac{-Q}{R}\right)\frac{1}{T} = \ln 7.5 + \left(\frac{-Q}{R}\frac{1}{1173}\right)$

$$\left(\frac{-Q}{R}\right)\frac{1}{T} - \left(\frac{-Q}{R}\right)\left(\frac{1}{1173}\right) = \ln 7.5$$

$$\left(\frac{-Q}{R}\right)\left(\frac{1}{T} - \frac{1}{1173}\right) = \ln 7.5$$

(2)

~~assuming~~ $Q = 80,000$

$$\left(-\frac{80000}{8.314}\right)\left(\frac{1}{T} - \frac{1}{1173}\right) = \ln 7.5$$

$T = 1555$ K

$= 1282\,°C$

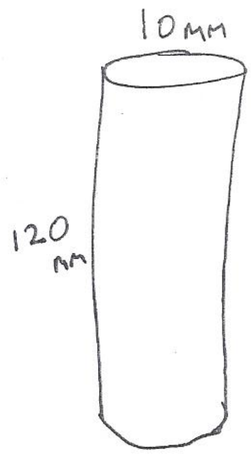
(1)

(24) A 10 mm diameter and 12 cm long titanium bar has a yield strength of 450 MPa, modulus of elasticity of 107 GPa and a tensile strength of 520 MPa.

i) If a force of ~~100~~ 40 kN is applied along the length of this bar, determine: (a) whether the bar will plastically deform, and (b) whether the bar will experience necking at this load.

ii) Determine the length and diameter of the bar when ~~50~~ 20 kN is applied knowing that Poisson's ratio for this metal is 0.34. {*6 marks*}

$A_o = 7.85 \times 10^{-5} m^2$



(i) $\sigma_1 = \frac{F}{A_o} = \frac{40,000 \times 4}{\pi \times (10 \times 10^{-3})^2} \Rightarrow 509.3$ MPa (1)

(1½) (a) Yes will plastically deform as 509 > 450 MPa

(1½) (b) will not experience necking as 509 < 520 MPa

(ii) $\sigma_2 = \frac{F}{A_o} = \frac{20,000 \times 4}{\pi \times (10 \times 10^{-3})^2} \Rightarrow 254.6$ MPa (½)

$\sigma = E\varepsilon$ and $\varepsilon = \frac{\Delta l}{l_o}$ $\qquad \varepsilon = \frac{\sigma}{E} = \frac{254.6 \times 10^6}{107 \times 10^9}$

$\varepsilon = 0.00238$

$\varepsilon = \frac{\Delta l}{l_o} = \frac{l_i - l_o}{l_o}$

$\therefore l_i = (l_o \varepsilon) + l_o$ $\qquad l_i = (120 \text{ mm} \times 0.00238) + 120$

$l_i = 120.29$ mm (1)

d =

$\nu = \frac{-\varepsilon_x}{\varepsilon_z} = 0.34 = \frac{-\varepsilon_x}{0.00238}$, $\qquad \varepsilon_x = -0.000809$

$d_i = (d_o \varepsilon_x) + d_o$ $\qquad d_i = (10 \times -0.000809) + 10$

$= 9.992$ mm (1½)