Student Name:______________________ Student ID Number: Solution

DEPARTMENT OF MECHANICAL ENGINEERING CONCORDIA UNIVERSITY

MATERIALS SCIENCE - MECH 221/2 - Sections T & X MIDTERM #1 – 2000

Instructors: Dr. M. Pugh & Dr. S. V. Hoa

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 1-15, one mark each, other questions marks as indicated.

Constants:

R (gas constant) = 8.314 $J.mol^{-1}.K^{-1}$
N_A (Avogadro's number) = 6.023×10^{23}
K (Boltzmann's constant) = 1.38×10^{-23} $J.atom^{-1}.K^{-1}$

For these True/False questions, circle the response that you think is correct. E.g. (True)

1. Covalent bonding can best be described as: *one atom forms a random dipole and attracts an atom with an induced dipole.* (True) (False).

2. Ionic bonding can best be described as: *the electrons of one atom join with electrons of other atoms to produce a "sea" of electrons around the ions.* (True) (False).

3. Ionic bonding can best be described as: *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.* (True) (False).

4. The body centred **tetragonal** unit cell can be described as: $a = b \neq c$, $\alpha = \beta = \gamma = 90°$ with an atom at each corner and one in the centre of each face. (True) (False).

5. 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 of the angular position of the source, specimen and collector and then the interplanar spacings, d_{hkl} can be calculated using Bouchard's Law. (True) (False).

6. The {100} Miller indices represent 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 that make up the sides of the cube. (True) (False).

7. The hydrogen bond is generally stronger than the other secondary bonds and is responsible for the abnormally high boiling point of water. (True) (False).

8. Plastics, for the most part, are materials which are based on carbon. (True) (False).

9. Ceramics are usually compounds of metals and non-metals. (True) (False).

10. The FCC unit cell contains 6 complete atoms. (True) (False).

11. The BCC unit cell contains 4 complete atoms. (True) (False).

12. Ionic bonding and metallic bonding are generally non-directional whereas covalent bonding (for example in diamond) is very directional. (True) (False).

13. When two atoms (isolated) are at their equilibrium separation distance, the net energy between them is zero. (True) (False).

14. In a cubic crystal lattice, the [111] direction is perpendicular to the (111) plane. (True) (False).

15. The FCC and HCP crystal structures both consist of close-packed planes, the only difference between the two structures being that the stacking sequence in FCC is ABCABC.... whereas for HCP it is ABABABAB.... (True) (False).

Answer the following questions in the space provided.

16. Some metal is known to have a cubic unit cell with an edge length of 0.4078 nm. Furthermore it has a density of 19.32 $Mg.m^{-3}$ ($g.cm^{3}$) and an atomic weight of 196.97 $g.mol^{-1}$. Deduce what this metal is from the list of metals given below: *{4 marks}*

Metal	Crystal structure	Atomic radius (nm)	Metal	Crystal structure	Atomic radius (nm)
Aluminum	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445 ✓
Copper	FCC	0.1278	Tantalum	BCC	0.1430
✓ Gold	FCC	0.1442	Titanium (α)	HCP	0.1445
Iron (α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332

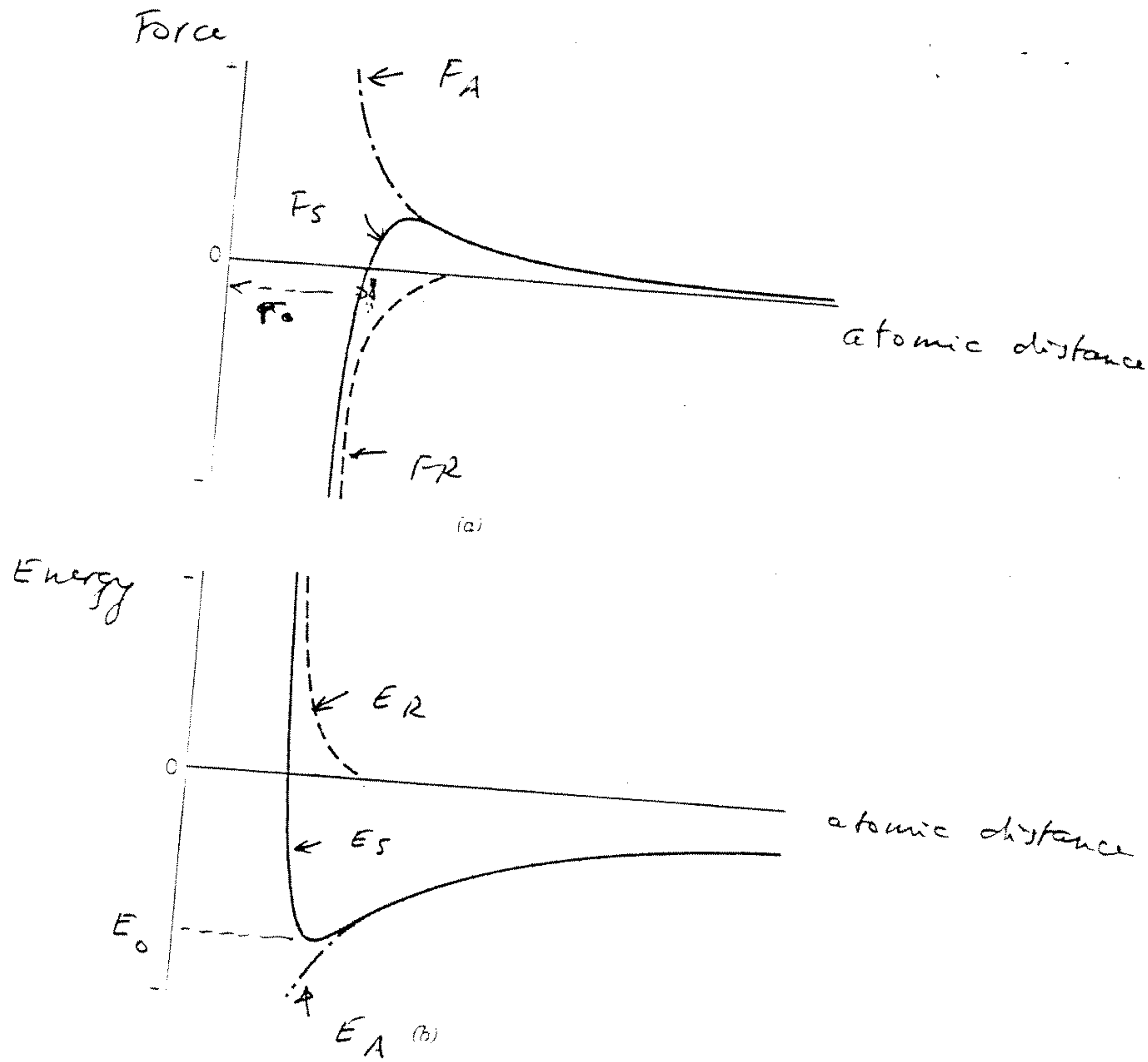
$a = 0.4078$ nm

For BCC: $a = \frac{4R}{\sqrt{3}} \Rightarrow R = \frac{a\sqrt{3}}{4} = 0.1766$ nm

For FCC: $a = \frac{4R}{\sqrt{2}} \Rightarrow R = \frac{a\sqrt{2}}{4} = 0.1442$ nm

Matching: gold

17. Shown below in Figure 1 (a) and (b) are two plots related to the interatomic separation of t isolated atoms. Identify the axes in each case and label each of the three curves in both pl In addition, label any other significant features on the graphs such as the equilibrium separation distance, r_0, and the bonding energy, E_0. **{ 4 marks}.**



18. Show that the Atomic Packing Factor for the Body Centred Cubic structure is 0.68. ***{4 marks}***

$$APF = \frac{\text{volume of atoms}}{\text{volume of cell}} = \frac{(2)\,\frac{4\pi R^3}{3}}{a^3}$$

$$a = \frac{4R}{\sqrt{3}}$$

$$APF = \frac{(2)\,\frac{4}{3}\pi R^3}{\left(\frac{4R}{\sqrt{3}}\right)^3} = 0.68$$

Continued ....

19. Determine the Miller indices for the directions and planes shown in the following cubic unit cells: ***{6 marks}.***

A) $[\bar{1}\,\bar{1}\,0]$

B) $[2\,0\,1]$

C) $[0\,2\,1]$

D) $[0\,\bar{1}\,0]$

E) $[\bar{1}\,1\,\bar{1}]$

F) $[2\,1\,2]$

G) $(0\,1\,0)$

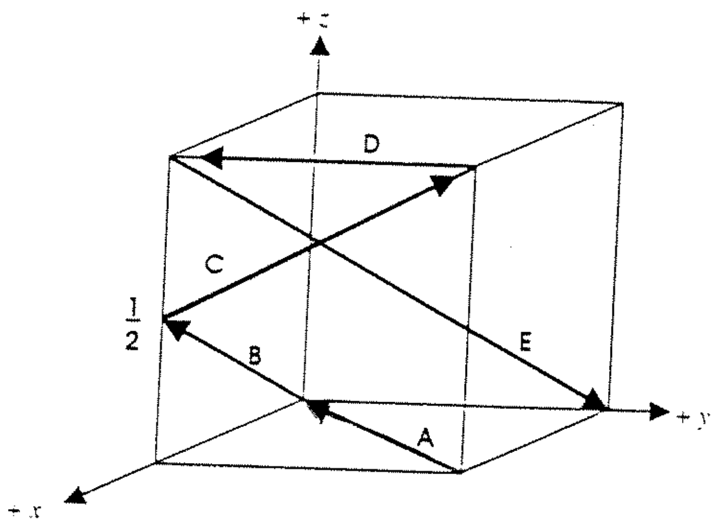
H) $(4\,3\,\bar{6})$

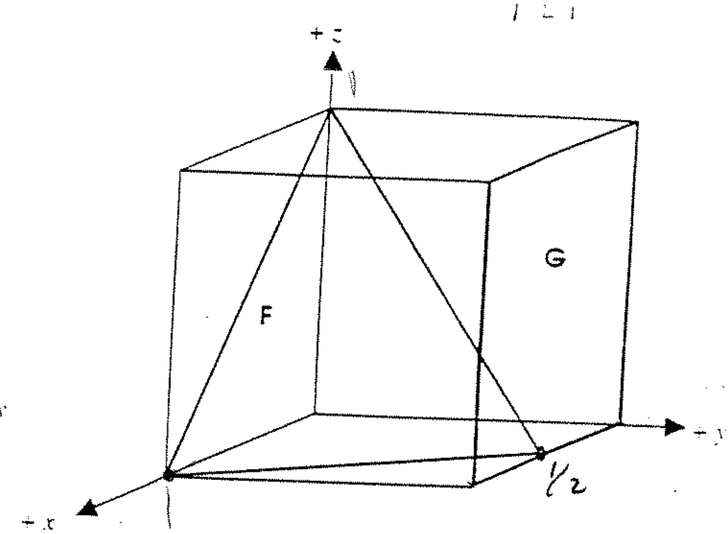
I) $(0\,0\,2)$

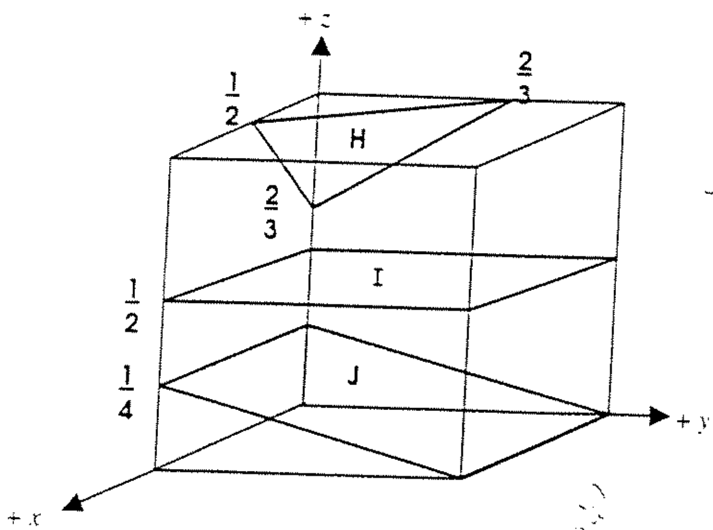
J) $(0\,1\,4)$

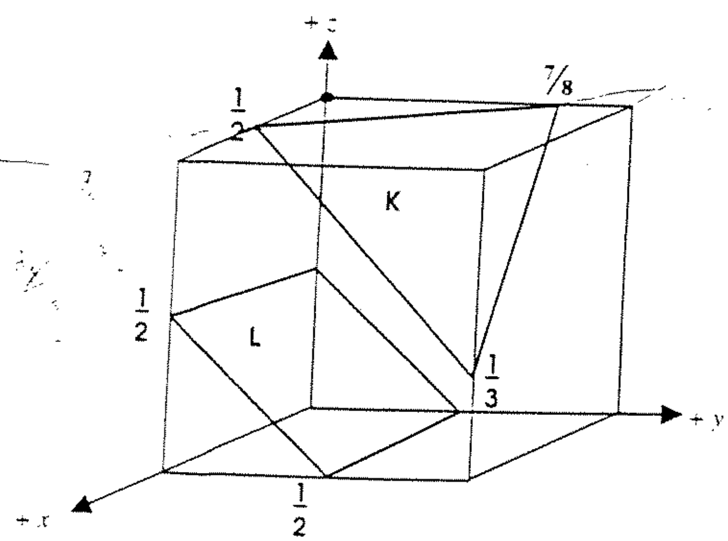
K) $(28\,16\,45)$

L) $(0\,2\,2)$









Student Name:______________________ ID Number:______________

C

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. 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

2. 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

3. 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

4. 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.

5. 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.

6. 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.

$\frac{15}{20} + \frac{14}{22} = \frac{29}{42}$

T F 0 **(18)** 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 0 **(19)** 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 1 **(20)** Steady state diffusion involves diffusion of species down a linear concentration gradient.

$J = D\frac{dC}{dx}$ ← concentration gradient

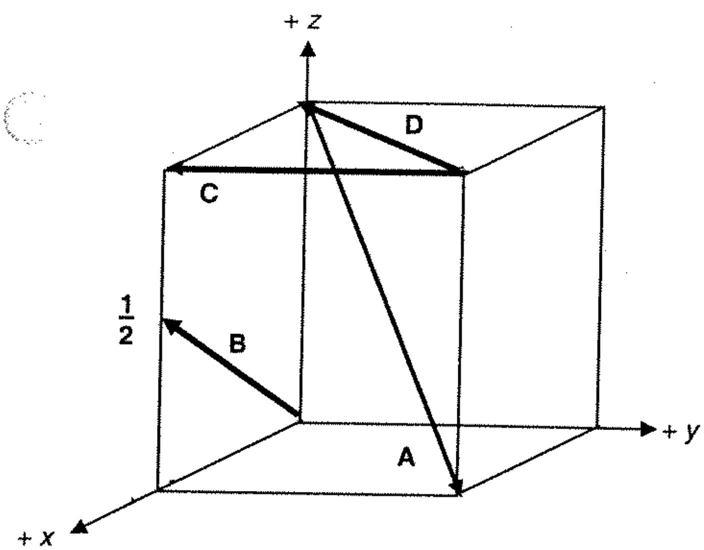
(21) Determine the Miller indices for the directions and planes shown in the following cubic unit cells:
{8 marks}

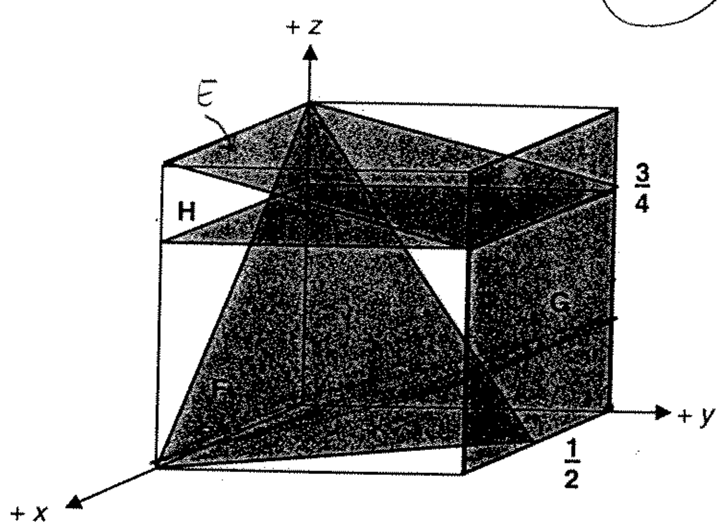
A) $[1\,1\,\bar{1}]$ 1
B) $[1\ \tfrac{1}{2}\ 0] \rightarrow [2\ 1\ 0]$ 1
C) $[0\,\bar{1}\,0]$ 1
D) $[\bar{1}\,\bar{1}\,0]$ 1

intercepts → invert

E) $(\infty\ 1\ \bar{1/4}) \rightarrow (0\ 1\ \bar{4})$ X
F) $(\tfrac{1}{2}\ 1\ \tfrac{1}{2}) \rightarrow (2\ 1\ 2)$ 1
G) $(\infty\ 1\ \infty) \rightarrow (0\ 1\ 0)$ 1
H) $(\infty\ \infty\ 3/4) \rightarrow (0\ 0\ 4/3) \rightarrow (0\ 0\ 4)$ 1

(7)





(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 kN~~ 40kN 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.

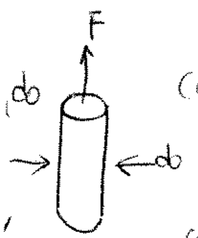
ii) Determine the length and diameter of the bar when ~~50 kN~~ 20kN is applied knowing that Poisson's ratio for this metal is 0.34. *{6 marks}*

yield $\sigma = 450\,MPa = 450 \times 10^6\,Pa$ $d = 10mm = 0.01m$ $l = 12cm = 0.12m$

tensile $\sigma = 520\,MPa = 520 \times 10^6\,Pa$ $E = 107\,GPa = 107 \times 10^9\,Pa$

(i) $F = 40\,kN = 40\,000\,N$ $\sigma = F/A_0$

$$\sigma = \frac{40\,000}{\pi\left(\frac{0.01}{2}\right)^2} = \frac{40\,000}{\pi(0.000025)} = 5.09 \times 10^8\,Pa = \boxed{509\,MPa}$$ ✓ ✓



(a) The bar will plastically deform since the calculated σ for the applied load is greater than the yield strength. (450<509)

(b) The bar will not experience necking as the calculated σ is less than the tensile strength. (509 < 520) MPa ✓

(ii) $F = 20\,000\,N$ $\nu = 0.34$ $\nu = -\frac{\varepsilon_x}{\varepsilon_z}$

$\sigma = \varepsilon_z E$ $E = 107\,GPa = 107 \times 10^9\,Pa$

$$\sigma = \frac{20\,000\,N}{\pi\left(\frac{d_0}{2}\right)^2} = \frac{20\,000\,N}{\pi(0.000025)} = 2.54 \times 10^8\,Pa$$ ✓

$\rightarrow 2.54 \times 10^8\,Pa = \varepsilon_z (107 \times 10^9\,Pa)$ bar stretches when pulled

$$\varepsilon_z = \frac{2.54 \times 10^8}{107 \times 10^9} = -0.0024$$ (since there is a contraction)

$\rightarrow 0.34 = \frac{\varepsilon_x}{-0.024}$ $\varepsilon_x = (0.34)(0.024) = 0.00816$

(4½)

To find length. $\varepsilon_z = \frac{\Delta l}{l_0} \rightarrow (-0.0024)(12cm) = \Delta l = -0.0288cm$

new length $= 12cm + 0.0288cm = \boxed{11.97cm}$

12.0288 cm

To find diameter: $\varepsilon_x = \frac{\Delta d}{d_0} = (0.00816)(10) = \Delta d = 0.0816\,mm$

new diameter $= 10 + 0.0816 = \boxed{10.0816\,mm}$

4.992m ✗

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DEPARTMENT OF MECHANICAL ENGINEERING CONCORDIA UNIVERSITY

MATERIALS SCIENCE - MECH 221/2 - Sections T & X MIDTERM – 2004

Instructors: Dr. M. Pugh & Dr. P. Wood-Adams

Time Allowed: one (1) hour.

Materials Allowed: Pens/pencils, eraser, ruler, calculator; **No books/notes.** Equation sheet is attached.
Answer all questions. Put your answers on this exam paper in the spaces provided.
Marking Scheme: Questions 1-20, one mark each, other questions marks as indicated.

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

T F (1) Covalent bonds are directional.

T F (2) It is possible to have bonds that are partially ionic and partially covalent.

T F (3) In an ionic bond, the atomic species donate or accept electrons to result in unstable electron configurations.

T F (4) Secondary bonds have no effect on the properties of polymers because of the presence of strong primary bonds.

T F (5) Krypton (electronic structure $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$) is a highly reactive gas.

T F (6) The linear density of the BCC cell in the [111] direction is 0.877

T F (7) Polymorphic (allotropic) transformations are when the material changes from one crystal structure to another when, for example, the temperature or pressure are changed.

T F (8) The FCC unit cell contains only 2 complete atoms.

T F (9) Ceramics have high electrical conductivity because of free electrons.

T F (10) BCC and FCC crystals have the same atomic arrangements on the (110) plane.

T F (11) The only difference between the lattice parameter relationships of the cubic and the hexagonal crystal systems is that the interaxial angles are all equal in the cubic system and are not equal in the hexagonal system.

T F (12) When two atoms (isolated) are at their equilibrium separation distance, r_0, the net energy between them is zero.

T F (13) The highest possible atomic packing factor that a pure crystalline solid can have is 0.74

T F (14) In a cubic crystal lattice, the [111] direction is perpendicular to the (111) plane.

T F (15) Crystallographic directions are equivalent if their linear densities are the same.

T F (16) 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 (17) In steady-state diffusion the flux is proportional to the concentration gradient.

T F (18) The interstitial diffusion coefficient for a small atom diffusing in a metal is usually larger than the diffusion coefficient for an atom that diffuses in that same metal via vacancy diffusion.

T F (19) The crystal structure of a metal can be found by X-Ray diffraction in which X-Rays are shone through a metal and the delay in transmission is measured and used to calculate the number of atoms in a unit cell.

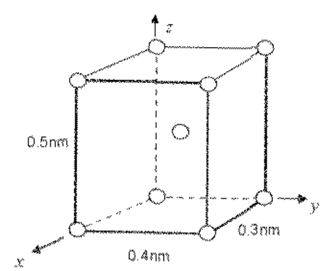
T F (20) In a pure, isotropic, polycrystalline metal, adjacent grains have the same composition and crystal structure but will have random orientation of that crystal structure.

Answer the following questions in the space provided.

21. In the figure below is a sketch of the orthorhombic unit cell of some hypothetical metal, "Dilithium". The circles represent atom centres.
[6 marks]
a) What would this crystal structure be called?

b) Draw a sketch of the following planes from the unit cell shown including the atomic arrangement (indicating atom centres) and giving the lengths of the sides of each plane: (110), (100) and (101).

c) If the density of this metal is 8.95 g/cm³ determine the atomic weight (A) of Dilithium.



22. Show that the Atomic Packing Factor for the Face Centred Cubic structure is 0.74. ***[5 marks]***

23. Iron undergoes a polymorphic transition from BCC to FCC at 912°C. Some iron, initially containing 0.05 wt% carbon is heated to 912°C in an atmosphere that produces 1.2 wt% carbon at the surface and is held at this temperature for 37.5 hours.

a) Calculate the carbon *content* at 0.5*mm* beneath the surface if the iron is in its BCC state.
b) If the iron has transformed to the FCC state (*still at* ≈ 912°C) do you think that carbon diffusion will be slower or faster than in the BCC state? Give your reasoning.
[5 marks total]

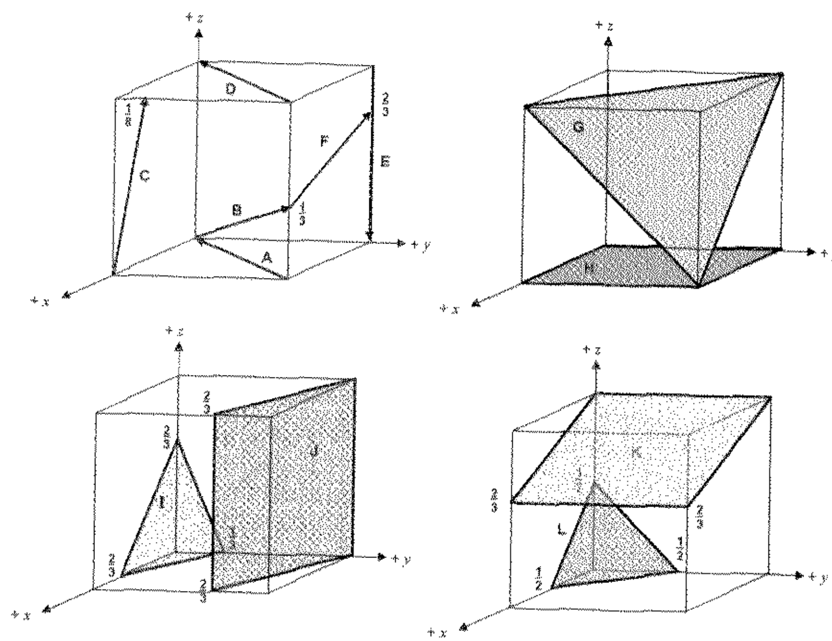
NOTE: Error function Table is attached at end of exam paper.

Diffusing species	Host metal	D_0 ($m^2.s^{-1}$)	Activation Energy, Q_D ($kJ.mol^{-1}$)
Carbon	α-Fe (BCC)	6.2 x 10^{-7}	80

24. Determine the Miller indices for the directions and planes shown in the following cubic unit cells:
(9 marks).

A)
B)
C)
D)
E)
F)

G)
H)
I)
J)
K)
L)



MECH 221 Equations

These equations will be given to you during the exam in Mech221. It is important that you know how to use them and know what they mean. We assume that you already know the normal general geometric formulae (eg. Area of circle) and physical formulae (eg., *density*). Constants such as the gas constant R, and Boltzmann's constant, K are given.

$F_{Net} = F_A + F_R$ $\qquad E_{Net} = E_A + E_R$ $\qquad \rho = \frac{nA}{V_c N_A}$

$n\lambda = 2d_{hkl}\sin\theta$ $\qquad d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}}$ $\qquad N_v = N\exp\left(\frac{-Q}{kT}\right)$

$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$ $\qquad D = D_o\exp\left(\frac{-Q}{RT}\right)$ $\qquad \frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$

Constants

Avogadro's number $N_A = 6.023 \times 10^{23}$ atoms/mol

Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/(atom.K) or 8.62×10^{-5} eV/atom

$R = 8.31$ J.mol^{-1}.k^{-1}

Tabulation of Error Function Values

z	erf(z)	z	erf(z)	z	erf(z)
0	0	0.55	0.5633	1.3	0.9340
0.025	0.0282	0.60	0.6039	1.4	0.9523
0.05	0.0564	0.65	0.6420	1.5	0.9661
0.10	0.1125	0.70	0.6778	1.6	0.9763
0.15	0.1680	0.75	0.7112	1.7	0.9838
0.20	0.2227	0.80	0.7421	1.8	0.9891
0.25	0.2763	0.85	0.7707	1.9	0.9928
0.30	0.3286	0.90	0.7970	2.0	0.9953
0.35	0.3794	0.95	0.8209	2.2	0.9981
0.40	0.4284	1.00	0.8427	2.4	0.9993
0.45	0.4755	1.1	0.8802	2.6	0.9998
0.50	0.5205	1.2	0.9103	2.8	0.9999