NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2015-2016

MA1002 – FUNDAMENTAL ENGINEERING MATERIALS

April/May 2016 Time Allowed: 2 hours

Seat No:

Matriculation No:

INSTRUCTIONS

1. This paper contains 3 questions and comprises 16 printed pages and 1 blank page.
2. Answer all 3 questions.
3. Marks for each question are as indicated.
4. This is a **Closed-Book** examination.
5. All your answers should be contained in this booklet and within the space provided after the question. **No extra paper will be provided**.

EXAMINERS USE ONLY	
Question	Marks
1	
2	
3	
Total	

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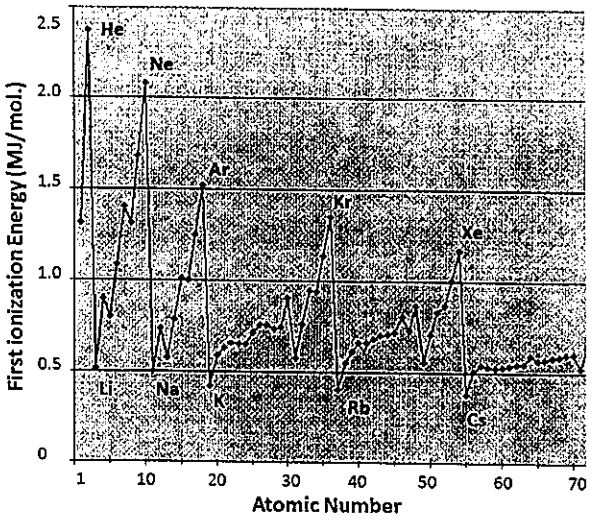

Figure 1

1(a) The *first ionization energy* is the amount of energy required to remove the first electron from the outer shell of an atom. Explain why the energy periodically swings from high to low as the atomic number increases.

(6 marks)

Note: Question No.1 continues on page 3.

(b) Iodine has an *orthorhombic* unit cell for which the lattice parameters a, b, and c are 0.479, 0.725, and 0.981, nm respectively.

(i) If the atomic packing factor and atomic radius are 0.547 and 0.177 nm respectively, determine the number of atoms in each unit cell.

(4 marks)

(ii) The atomic weight of iodine is 126.91 g/mol; compute its theoretical density.

(4 marks)

Note: Question No.1 continues on page 4.

(iii) If the electronic configuration (in short hand notation) of iodine is [Kr] $4d^{10}$ $5s^2$ $5p^5$, determine its valency.

(2 marks)

(c) Name a suitable technique for each of the following, describing in detail how the technique is used, how the material is prepared, and how the results are analysed. Assume that the material is metallic.

(i) Grain size determination

(4 marks)

(ii) Crystal structure identification

(4 marks)

Note: Question No.1 continues on page 5.

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(d) The steady state diffusion flux through a metal plate is 5.4×10^{-10} Kg/m^2.s at a temperature of 727 °C and when the concentration gradient is -350 Kg/m^4.

(i) Calculate the diffusion flux at 1,027 °C for the same concentration gradient and assuming an activation energy for diffusion of 125 kJ/mol. The gas-constant R is given as 8.31 J/mol-K.

(6 marks)

(ii) What role do vacancies play in the process of diffusion?

(4 marks)

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2 (a) (i) A tensile load of 70 kN is applied to the axis of a cylindrical metal rod with a diameter of 10 mm, and the diameter was reduced to 9 mm. Assuming no volume change during the loading, calculate the following stress and strains in the table provided below (including their units).

(8 marks)

Ans:

Engineering Stress	
Engineering Strain	
True Stress	
True Strain	

(ii) Explain the difference between Engineering Stress and True Stress.

(3 marks)

Note: Question No.2 continues on page 7.

(b) (i) What are grain boundaries and how are they created?

(2 marks)

(ii) How can they be eliminated (annihilated)?

(2 marks)

(iii) How can grain boundaries strengthen a material?

(2 marks)

(iv) Using a sketch, explain the difference between low-angle and high angle grain boundaries.

(3 marks)

(v) What is meant by intergranular fracture?

(2 marks)

Note: Question No.2 continues on page 8.

(c) Figure 2 schematically shows two types of binary phase diagrams.

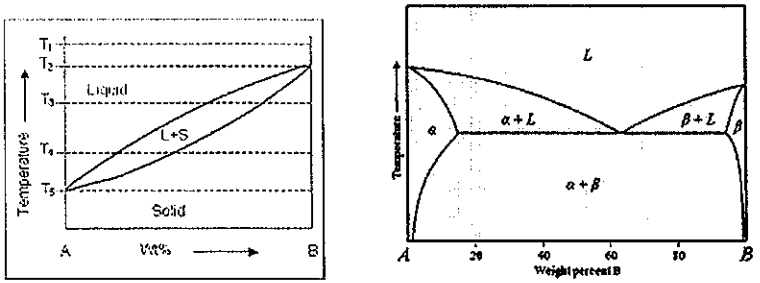

Figure 2

(i) What is the major difference between the TWO types of binary phase diagrams?

(3 marks)

(ii) Sketch in the space provided in Figure 3 a schematic binary phase diagram of TWO components, A and B, which are insoluble in each other.

(4 marks)

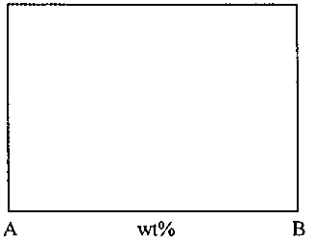

Figure 3

(iii) State the FOUR features that determine the degrees of solubility of solute and solvent atoms.

(4 marks)

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3 (a) Determine the theoretical density of lithium chloride given that the ionic radii of Lithium and Chloride ions are 0.076 nm and 0.181 nm, respectively. The relative atomic mass of lithium chloride is given as 42.39 g/mol and Avogadro's number is 6.023×10^{23} molecules/mol.

(Hint: Lithium Chloride has the same crystal structure as Sodium Chloride)

(4 marks)

(b) Discuss briefly why diamond is mechanically harder than metals.

(3 marks)

Note: Question No.3 continues on page 10.

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(c) (i) What kind of silicate structure would be obtained if the repeating silicate tetrahedron is $Si_2O_5^{2-}$?

(1 mark)

(ii) Draw the final structure of this silicate and indicate clearly the repeating silicate tetrahedron.

(2 marks)

Note: Question No.3 continues on page 11.

(iii) Illustrate how this silicate structure achieves charge neutrality.

(2 marks)

(iv) What would you expect about the mechanical properties of this silicate to be and why?

(2 marks)

Note: Question No.3 continues on page 12.

(d) (i) Two identical volumes of molten atactic and syndiotactic polymers having the same molecular formulae were allowed to solidify to room temperature in two identical containers respectively. However, it was found that the final volumes of the solidified polymer were different. Which polymers would you expect to have a larger volume? Give your reasons.

(3 marks)

(ii) Draw simple diagrams to illustrate an atactic and a syndiotactic polymer structures.

(2 marks)

Note: Question No.3 continues on page 13.

(e) What would you expect about the impact of using reinforcement phase on the glass-transition temperature of a composite? Give your reasons.

(4 marks)

(f) A silicone prepolymer with a structural repeating unit molecular weight of 74 g/mol was found to have the following properties: (i) weight average molecular weight of 120,000 g/mol, and (ii) molecular weight distribution of 3.4.

(i) Calculate the number-average molecular weight of this polymer.

(2 marks)

(ii) Determine the number-average degree of polymerization of this polymer.

(2 marks)

Note: Question No.3 continues on page 14.

(g) A fibre-reinforced polymer composite was found to have a longitudinal elastic modulus of 24 GPa. If the elastic moduli of the polymer matrix and fibre reinforcement are 3 GPa and 75 GPa respectively, calculate the elastic modulus of this composite in the transverse direction.

(6 marks)

END OF PAPER

Selected Equations

1. $\frac{N_v}{N} = \exp\left(-\frac{Q_v}{kT}\right)$
2. $J = -D\frac{dC}{dx}$
3. $\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$
4. $\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$
5. $D = D_0 \exp\left(-\frac{Q_d}{RT}\right)$

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Appendix

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminium 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Caesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

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1a) In a period, there is an increasing trend in the first ionization energy of an element, but it can be seen that there are huge dips in first ionization energy from the end of one period, which is a noble gas to the beginning of the next period.
Taking an example of neon and sodium, we can see a large dip in first ionization energy. Neon has a fully filled outermost s & p shells, which gives it a stable "noble gas" configuration, thus a lot of energy is required to remove one electron. On the other hand, sodium has one electron in the 3s shell, and it would have to give off that one electron to attain the more stable noble gas configuration, thus much less energy is required to remove the first electron, which is shown by the huge dip in the graph.

bi) Volume of 1 unit cell $= 0.479 \times 0.725 \times 0.981$
$= 0.340676\ nm^3$

Volume occupied by iodine atoms $= 0.547 \times 0.340676$
$= 0.186350\ nm^3$

Volume of 1 iodine atom $= \frac{4}{3}\pi (0.177)^3$
$= 0.023229\ nm^3$

Number of atoms per unit cell $= \frac{0.186350}{0.023229}$
$= 8$

There are 8 iodine atoms per unit cell

bii) $0.340676\ nm^3 = 3.4067 \times 10^{-28}\ m^3$

Number of atoms in $1\ m^3 = \frac{1}{3.4067 \times 10^{-28}} \times 8$
$= 2.348 \times 10^{28}$ atoms

Number of moles $= (2.348 \times 10^{28}) \div (6.023 \times 10^{23})$
$= 38994.801$ mol

Density $= 38994.801\ mol/m^3 \times 126.91\ g/mol$
$= 494830\ g/m^3$
$= 4948\ kg/m^3$

iii) Valence of iodine is 1 (halogen).

ci) The grains can be observed under the microscope, like for example, an optical microscope. By observing the number of grains over a certain length, we can calculate the average grain size of the material. To prepare the material, the material is selectively etched and polished, which will improve the contrast of the grains for easier identification.

After observing, we can use the intercept method to obtain grain size. With the formula

$$\text{Grain} - \text{Size} = \frac{\text{Line length}}{N \times M}$$

where N is the number of grains, and M is the magnification, we can be able to determine the grain size of the material in question.

ii) Crystal structure identification can be done using X-ray diffraction. Crystal planes of target metal act as mirrors reflecting X-ray beam. If X-rays leaving a set of planes are out of phase, no reinforced beam is produced. A measurement of critical angle helps to provide a measure for atomic spacing. Scanning from low to high angles will allow for peaks to appear only at angles that satisfies Braggs Law, which is

$$2d_{hkl} \sin\theta = n\lambda$$

where d_{hkl} is the atomic spacing, n is usually an integer, typically with a value of 1 and λ is the X-ray wavelength. Knowing the angle at which peaks occur, we can derive the atomic spacing value. We can then use the equation

$$d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}}$$

to determine the crystal structure. Different crystal structures have different allowed h, k & l values, and these differences allow us to be able to identify the crystal structure.

di) $D = D_o \exp\left(\frac{-Q_d}{RT}\right)$

$J = -D\frac{dC}{dx}$

$5.4 \times 10^{-12} = D(350)$

$D = 1.54 \times 10^{-12}\ m^2/s$

$1.54\times10^{-12} = D_o \exp\left[\frac{-125\times10^3}{8.31(727+273.15)}\right]$

$D_o = 5.239\times10^{-6}\ m^2/s$

At 1027°C

$D_{1027} = 5.239\times10^{-6} \exp\left[\frac{-125\times10^3}{(8.31)(1027+273.15)}\right]$

$D_{1027} = 4.9507\times10^{-11}\ m^2/s$

$J_{1027} = -(4.9507\times10^{-11})(-350)$

$= 1.73\times10^{-8}\ kg\ m^{-2}s^{-1}$

dii) Vaccanies provide empty spaces so that adjacent atoms are able to break free and move into the vaccancies, allowing for diffusion to occur. It also allows for acceleration of interstitial diffusion by providing more space to move.

2ai) Engineering stress $= \frac{70\times10^3}{(\frac{16}{2}\times10^{-3})^2\pi}$

$= 89126768.1\ Pa$

$= 891.2MPa$

Initial height $= \frac{V}{(5\times10^{-3})^2\pi}$

Final height $= \frac{V}{(4.5\times10^{-3})^2\pi}$

Δ Height $= V\left(\frac{1}{(4.5\times10^{-3})^2\pi} - \frac{1}{(5\times10^{-3})^2\pi}\right)$

$= 2986.6V$

Engingeering strain $= \frac{2986.6V}{12732.395V}$

$= 0.235$ (3sf)

True stress $= \sigma(1+\varepsilon)$

$= 891.2(1+0.235)$

$= 1100.2MPa$

$= 1.10GPa$ (3sf)

True strain $= \ln(1+\varepsilon)$

$= \ln(1+0.235)$

$= 0.211$ (3sf)

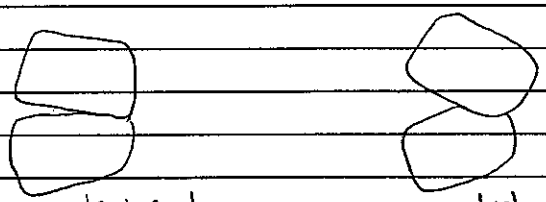
ii) Engineering stress is the stress measured over the initial surface area without taking into consideration the change in cross sectional area during elongation, while true stress is the instantaneous stress, where the instantaneous area is used to calculate the stress.

bi) Grain boundaries are regions seperating two small grains of crystals having different crystallographic orientations. They are formed when grains of different crystallographic orientations grow in size, which causes atomic misalignment between different grains thus causing the formation of grain boundaries.

ii) They can be eliminated during the process of grain growth, where they are left to be heated of higher temperatures. During this process, larger grains will consume smaller grains, thus reducing the grain boundary area, in effect eliminating them.

iii) Grain boundaries are barriers to slip, which increases with mis orientation. This increased barriers to slip means more energy is required for dislocation motion, thus increasing the strength of the material.

iv)

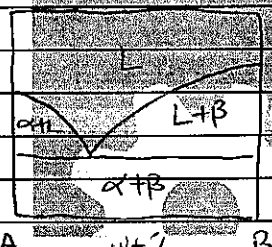


Low angle grain boundaries are boundaries with a small angle between them. The lower angles mean their orientations are close to each other making for easier slip.
High angle grain boundaries are boundaries with a large angle between them. Larger angles mean greater mis orientation meaning greater barriers to slip.

v) Intergranular fracture is a fracture that occurs between grains, usually as as a result of brittle fracture.

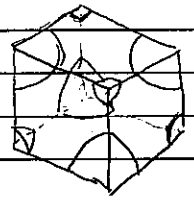
ci) The major difference between the two binary phase diagrams is the presence of a eutectic temperature in the eutectic binary phase diagram, where at that composition, the transition temperature from liquid to solid is lowest.

cii)



iv) The four factors that determine the solubility of solute and solvent atoms are temperature, pressure, composition of solute & composition of solvent.

3a)



* not to scale

Has a BCC structure

Length of unit cell = 0.076 + 0.181

= 0.257 nm

$= 2.57 \times 10^{-10}$ m

Volume of one unit cell $= (2.57 \times 10^{-10})^3$

$= 1.697 \times 10^{-29}$ m^3

In one unit cell,
there is $\frac{1}{2}$ Li and $\frac{1}{2}$ Cl atoms

Number of NaCl ion pairs = $\frac{4}{(1.697\times10^{-29})}\left(\frac{1}{2}\right)$
$= 2.946\times10^{28}\ /m^3$

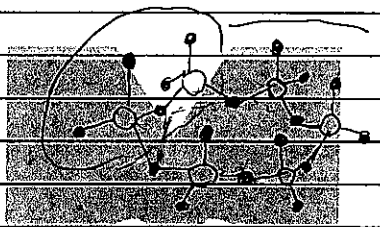
Number of moles of NaCl = $\frac{2.946\times10^{28}}{6.023\times10^{23}}$
$= 48905 mol\ /m^3$

Density = 48905×42.39
$= 2073104\ g/m^3$
$= 2073 kg/m^3$

b) Diamond is mechanically harder as the sp^3 hybridized carbon atoms are held together in a tetrahedral order by strong covalent bonds, which have a high bond energy. In contrast, metals are generally held in a regular order by metallic bonds, with a sea of electrons around. The atoms can slip across each other, making it softer compared to diamond.

ci) We will get a 2D layered silicate structure.

ii)

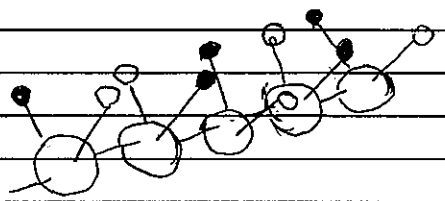


iii) The negative charges are balanced by the adjacent plane, which are rich in positively charged atoms, thus maintaining charge neutrality.

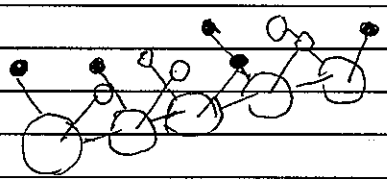
iv) It should have soft and lubricative properties as the layers of the silicate structures have Aerospace Engineering

di) The atactic polymer will have a larger volume. This is because stereotactic polymers have stereo-regularities, which allow them to closepack and hence form 3D crystalline structures. On the other hand, atactic polymers cannot closepack to form stereo-regular structures and thus forms amorphous structures with larger volume.

ii)



Syndiotactic



atactic

e) Using reinforcement phase on the glass transition temperature of composite would mean that the reinforcement phase is sharing a greater proportion of the load when a force is applied. At glass transition temperature, the polymer would have a much lower modulus. Given the same volume fraction, the proportion of load able to be supported by the polymer decreases and thus the reinforcement phase would have to take a greater portion of the load.

f) i) From question,

$M_w = 120{,}000\ g/mol$

$MWD = 3.4$

$MWD = \frac{M_w}{M_n}$

$M_n = \frac{M_w}{MWD}$

$= \frac{120000}{3.4}$

$= 35294\ g/mol$

ii) Degree of polymerisation $= \frac{35294}{74}$

$= 476.9$

≈ 477

g) For longitudinal, composite is at upper bandary

Let M be volume fraction of matrix

Let R be volume fraction of reinforcement

$24 = 3M + 75R \quad -①$

$M + R = 1 \quad -②$

By simultaneous equations,

$M = 0.708$

$R = 0.292$

For tranverse direction, lower bandary

$\frac{1}{E_c} = \frac{0.708}{3} + \frac{0.292}{75}$

$E_c = 4.17\ GPa\ (3sf)$

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MA1002 – FUNDAMENTAL ENGINEERING MATERIALS

November/December 2016 Time Allowed: 2 hours

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2. Answer **ALL** questions.
3. Marks for each question are as indicated.
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6. Please make use of the information in the Appendices.

EXAMINERS USE ONLY	
Question	Marks
1	
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1 (a) (i) Circle the correct electronic configuration of chromium.

$1s^2.2s^2.2p^6.3s^2.3p^6.3d^5.4s^1$

or

$1s^2.2s^2.2p^6.3s^2.3p^6.3d^4.4s^2$.

Explain your answer.

(4 marks)

(ii) Rhodium (Rh) has an atomic radius of 0.1345 nm and a density of 12.21 g/cm^3. Determine whether it has an FCC or BCC structure.

(6 marks)

Note: Question 1 continues on page 3.

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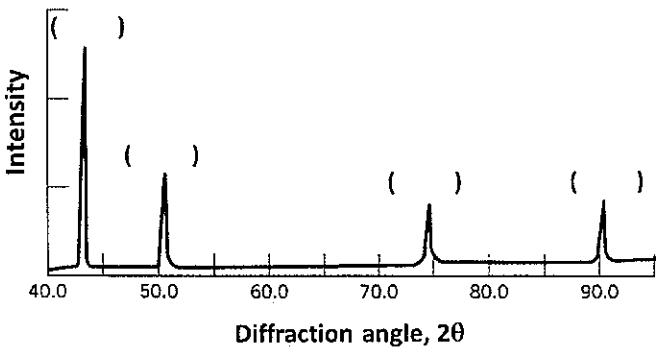

Figure 1

(iii) Figure 1 shows the first four peaks of the X-ray diffraction pattern for copper, which has an FCC structure; monochromatic X-radiation having a wavelength of 0.154 nm was used. On the figure provided, index (i.e. give h, k, and l indices) each of these diffraction peaks.

(4 marks)

(b) (i) Calculate the number of vacancies per cubic meter in iron (Fe) at 855 °C. The energy for vacancy formation is 1.08 eV/atom. The density of Fe is 7.65 g/cm^3.

(4 marks)

Note: Question 1 continues on page 4.

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Figure 2

(ii) Identify the dislocation segment (*x*-*y*) illustrated in Figure 2.

(2 marks)

(c) (i) Briefly explain the concept of *steady state* as applied to diffusion.

(2 marks)

Note: Question 1 continues on page 5.

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(ii) Nitrogen gas is to be diffused into pure iron at 700 °C. If the surface concentration is maintained at 0.1 wt.% N, what will be the concentration 1mm from the surface after 10 hours? The diffusion coefficient for nitrogen in iron at 700 °C is 2.5×10^{-11} m^2/s.

(6 marks)

(iii) Explain how crystalline defects influence the diffusion of impurity atoms in a metal. Illustrate you answer with examples including a 0, 1, 2, and 3 dimensional defect.

(6 marks)

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2 (a) (i) Sketch schematically the THREE most common metallic crystal structures in the space below.

(6 marks)

(ii) Which of the THREE crystal structures is the most ductile at room temperature and why?

(4 marks)

(iii) Explain how the ductility (formability) of a metal can be improved?

(2 marks)

Note: Question 2 continues on page 7.

(b)

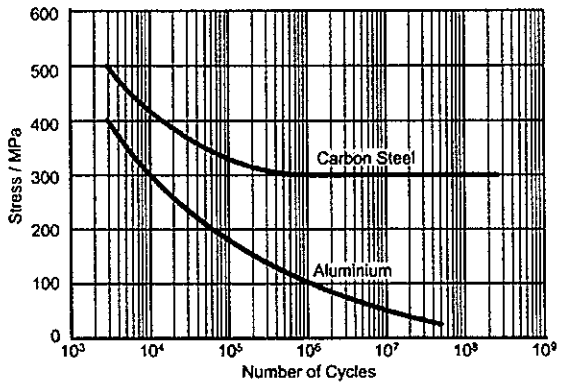

Figure 3

(i) Figure 3 shows the fatigue behavior of carbon steel and aluminium. Determine the fatigue strength and fatigue limit for both materials.

(8 marks)

	Carbon Steel	Aluminium
Fatigue Strength (at 10^7 cycles)		
Fatigue Limit (MPa)		

(ii) In general, for carbon steels, what is the estimated fatigue limit as a percentage of tensile strength?

(3 marks)

Note: Question 2 continues on page 8.

(c) Figure 4 shows the phase diagram of aluminium and lithium

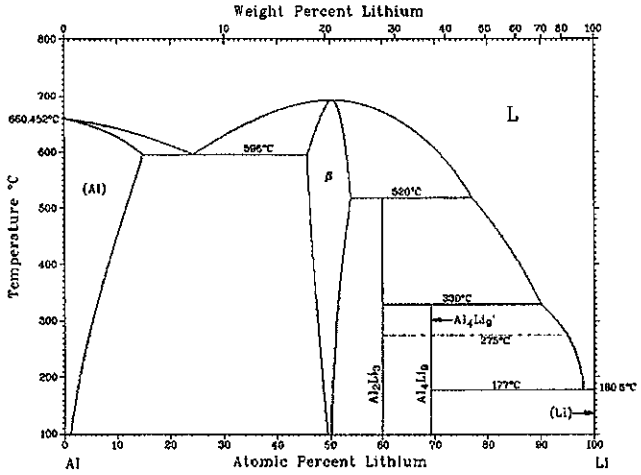

Figure 4

(i) Does aluminium have greater solubility in lithium, or lithium has greater solubility in aluminium, or there is there no difference?

(2 marks)

(ii) What is the eutectic temperature?

(2 marks)

(iii) What is the melting temperature of lithium?

(2 marks)

(iv) For a composition of 10 wt.% Li, what phase/s is/are present at 600°C ?

(2 marks)

(v) What is the largest wt. % of Li in Al solution, without melting (i.e. no liquid phase)?

(2 marks)

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3 (a) The physical and structural properties of copper and oxygen are given in Table 3(a).

Table 3(a):

Physical Properties	Copper	Oxygen	
Ionic radius	0.087 nm	0.126 nm	
Atomic mass	64 g/mol.	16 g/mol.	
Electronegativity	1.9	3.5	
Cation/Anion Radius Ratio	**Co-ordination Number**	**Crystal Structure**	**Anion Packing**
< 0.155	2	-	
0.156 – 0.225	3	-	
0.226 – 0.414	4	ZnS	FCC
0.414 - 0.732	6	NaCl	FCC
0.733 - 1.0	8	CsCl	SC

Avogadro's number = 6.023×10^{23} molecules or atoms per mole.

Determine the following:

(i) The percentage ionic character of the bond between copper and oxygen.

(2 marks)

(ii) The type of crystal structure for this CuO sample

(2 marks)

(iii) The theoretical density for this CuO crystal

(4 marks)

Note: Question 3 continues on page 11.

Official Use Only

(b) (i) When Fe_2O_3 was heated in a reducing environment at an elevated temperature, some Fe^{3+} ions become Fe^{2+} ions. What crystalline defect would you expect to occur when this happens?

(2 marks)

(ii) How many Fe^{3+} ions are required for the formation of each defect?

(2 marks)

(c) Given the following carbon compound (see Figure 5), determine the hybridization state of the carbons indicated by the arrows:

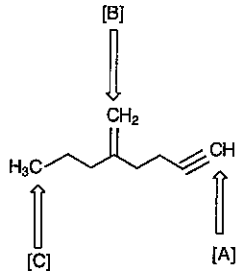

Figure 5

Note: Question 3 continues on page 12.

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(i) Hybridisation of Carbon [B] is _____

(2 mark)

(ii) Which of the THREE carbon bonds is the strongest? Give your reason.

(2 marks)

(iii) Give the molecular formula for quartz. What do diamond and quartz have in common that provides both ceramics their mechanical strengths?

(2 marks)

Note: Question 3 continues on page 13.

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(d) Three polymer samples were subjected to thermomechanical analysis to determine their mechanical moduli at various temperatures. The polymer samples were (1) amorphous polystyrene, (2) syndiotactic polystyrene, and (3) network polystyrene.

(i) Draw on the modulus-temperature plot (see Figure 6) to show how the modulus of each polymer changes with temperature. Label clearly the polymers on the plot.

(3 marks)

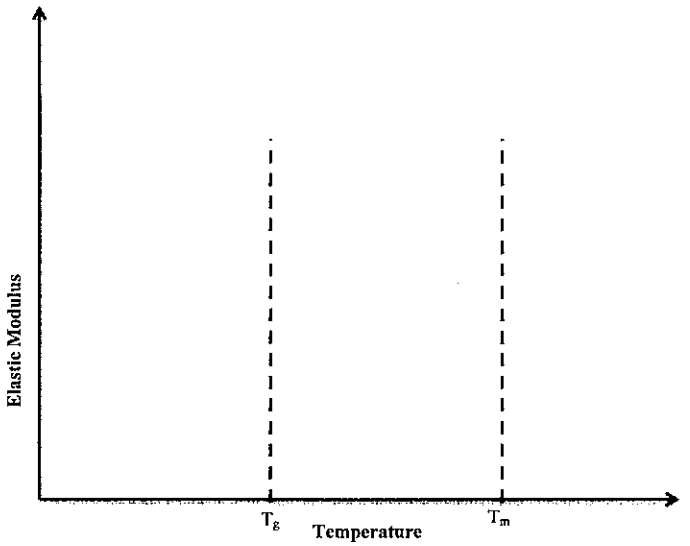

Figure 6

(ii) Discuss TWO factors that will DECREASE the glass transition temperature of thermoplastic polymers.

(2 marks)

Note: Question 3 continues on page 14.

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(e) Analysis of a degraded polyethylene polymer shows the following polymer fragments and their molecular weight ranges (see Table 3(e)).

Table 3(e):

Fragment Number	Number fraction	Weight fraction	Molecular weight range ($g\ mol^{-1}$)
1	0.30	0.22	31,000 – 50,000
2	0.16	0.10	51,000 – 70,000
3	0.26	0.28	71,000 – 90,000
4	0.18	0.10	91,000 – 110,000
5	0.10	0.30	111,000 -130,000

The molecular formula of polyethylene structural repeating unit is given as (CH_2-CH_2) and the molar masses of carbon and hydrogen are 12g/mol and 1g/mol respectively.

(i) Determine the Number and Weight average molecular weights of this degraded polyethylene.

(4 marks)

(ii) Determine the weight-average degree of polymerization of this polymer.

(2 marks)

Note: Question 3 continues on page 15.

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(f) The elastic moduli of long continuous carbon fibres and PEEK polymer used in a composite are 400GPa and 3.8GPa respectively. Given that the volume fraction of the polymer in the composite is 0.4, determine the **minimal** elastic modulus of this composite and the **condition** when this occurs.

Assume that the carbon fibres are uni-directionally aligned in the composite.

(4 marks)

END OF PAPER

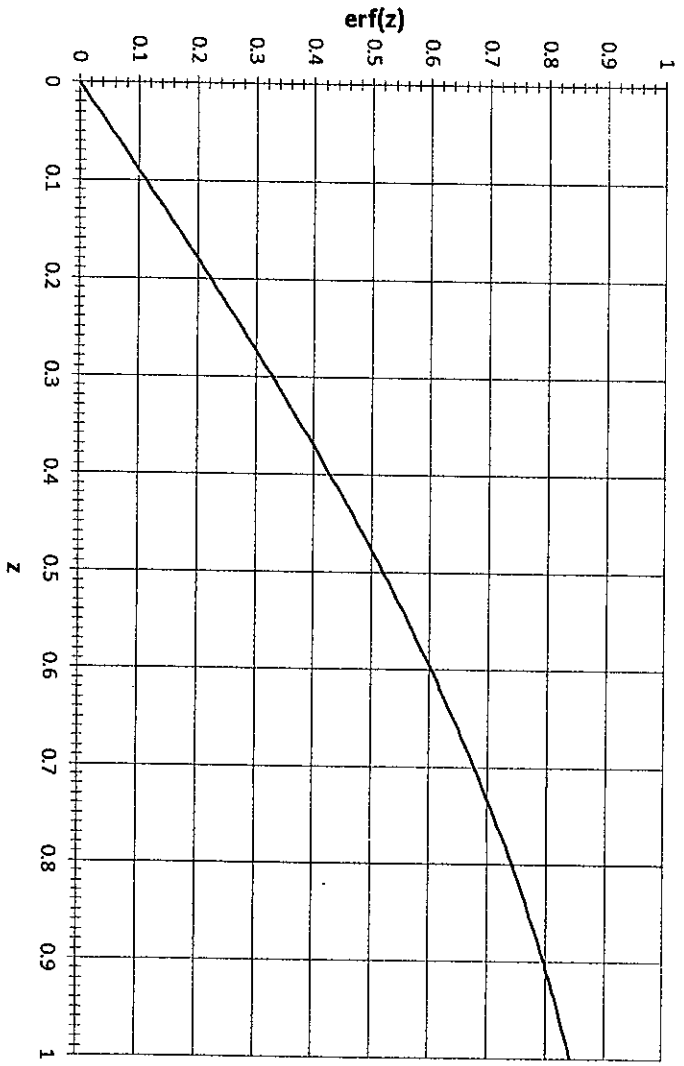
Appendix A – *Periodic Table* 9.

1 H Hydrogen 1.00794																		2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminium 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Caesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)						

Appendix B – *Selected Equations and Constants*

1. $\frac{N_v}{N} = \exp\left(-\frac{Q_v}{kT}\right)$
2. $\frac{1}{E_t} = \left\{\frac{V_f}{E_f} + \frac{(1-V_f)}{E_m}\right\}$
3. $J = -D\frac{dC}{dx}$
4. $\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$
5. $\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$
6. $E_t = E_f V_f + E_m(1-V_f)$
7. $\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$
8. $D = D_0 \exp\left(-\frac{Q_d}{RT}\right)$
9. Boltzmann's constant, k, is 8.62×10^{-5} eV/atom.K.
10. Avogadro 's number, N_A, is 6.023×10^{23} atoms/mol.

Appendix C – *Error Function*



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1. (a)(i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$ (first option)

Chromium is a special case. As a transition metal, it originally forms $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 4s^2$. This is because transition metals form incomplete d subshells with complete s subshells. However, the most stable configuration for d subshells is either fully filled (d^{10}) or half filled (d^5). Hence, one electron will jump from $4s^2$ to $3d^4$ to stabilise, resulting in the final $4s^1$ and $3d^5$.

stability! ☆

(ii) $\rho = 12.21\ g/cm^3$ $N_A = 6.023 \times 10^{23}\ atoms/mol$ $R = 0.1345\ nm = 0.1345 \times 10^{-7}\ cm$

$A = 102.90550\ g$ (Table) $V_c = a^3$

$$\rho = \frac{nA}{V_c N_A} \rightarrow \frac{V_c}{n} = \frac{A}{\rho N_A}$$

$$\frac{a^3}{n} = \frac{A}{\rho N_A} = \frac{102.90550}{(12.21)(6.023\times10^{23})} = 1.399 \times 10^{-23}\ cm^3$$

If BCC: $n = 2$, $V_c = a^3 = \left(\frac{4}{\sqrt{3}}R\right)^3 = 2.9968 \times 10^{-23}\ cm^3$

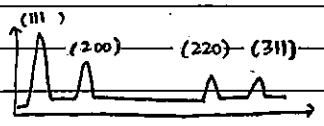
$$\frac{a^3}{n} = \frac{2.9968\times10^{-23}}{2} = 1.498 \times 10^{-23}\ cm^3$$

If FCC: $n = 4$, $V_c = a^3 = (2\sqrt{2}R)^3 = 5.50556 \times 10^{-23}\ cm^3$

$$\frac{a^3}{n} = \frac{5.50556\times10^{-23}}{4} = 1.376 \times 10^{-23}\ cm^3$$

$\frac{a^3}{n}$ of FCC calculation is nearer. Therefore, Rhodium has FCC structure.

(iii)



(b) (i) $Q_v = 1.08\ eV/atom$ $\rho = 7.65\ g/cm^3 = 7.65 \times 10^6\ g/m^3$

$k = 8.62 \times 10^{-5}\ eV/atom\,K$ $A = 55.845\ g/atom$

$T = 855^\circ C = 1128.15\ K$ $N_A = 6.023 \times 10^{23}\ atoms/mol$

$$N = \frac{\rho N_A}{A} = \frac{(7.65\times10^6)(6.023\times10^{23})}{55.845} = 8.25 \times 10^{23}\ atoms/m^3$$

$$N_v = N \exp\left(-\frac{Q_v}{kT}\right) = (8.25\times10^{23}) \exp\left(-\frac{1.08}{(8.62\times10^{-5})(1128.15)}\right) = 1.24 \times 10^{19}\ atoms/m^3$$

(1)

(ii) Screw dislocation

(c) (i) Steady state diffusion refers to diffusion where the rate of mass transfer (J) is not dependent on time. Time does not affect J.

(ii) $T = 700\,^{\circ}C = 973.15K$

$D = 2.5 \times 10^{-11}\ m^2/s$

$C_s = 0.1$ wt% N

$t = 10$ hours $= 36000$ s

$x = 1$ mm $= 0.001$ m

$C_o = 0\ kg/m^3$

$$\frac{C_x - C_o}{C_s - C_o} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \quad (z)$$

(in terms of wt% N)

$$\frac{C_x - 0}{0.1 - 0} = 1 - \text{erf}\left(\frac{0.001}{2\sqrt{2.5\times10^{-11}\times 36000}}\right)$$

$$\frac{C_x}{0.1} = 1 - \text{erf}(0.527) \quad (z)$$

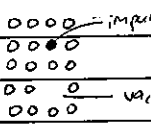
From error function graph, @ $z = 0.527$,

$\text{erf}(z) = 0.542$

$\therefore \frac{C_x}{0.1} = 1 - 0.542$

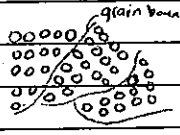
$C_x = 0.0458$ wt% N

(iii) 0 dimensional defect: Vacancies are required for diffusion to occur as the atoms in the metal would need space in order for it to move. Surrounding atoms will be able to move into the vacancy and therefore, allow more impurity atoms to move into the metal.

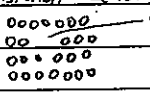


1 dimensional defect: Dislocations. There is more open space at areas with dislocations, allowing for lower activation energy for diffusion. This helps diffusion move faster.

2 dimensional defect: Atomic mismatch between different grains form the grain boundary, which is a 2 dimensional defect. The grain boundaries are more chemically reactive, causing impurity atoms to prefer to move along them as they have higher energy state. This allows for easier diffusion.



3 dimensional defect: Pores are 3 dimensional defects. Porosity in metal can be thought of as a cluster of vacancies. This helps diffusion move along faster due to space for movement.



2. (a)(i)

BCC  FCC  HCP 

(ii) FCC. It has the highest packing density (APF) and also the most slip planes, having 12 slip planes. This means it can slip in more directions easily, making it more ductile. Also, due to its close packed structure, the "re-created" crystal structure that happens after slip and deformation is more easily maintained. This leads to higher ductility.

slip planes ↑ | APF ↑

Ductility ↑

(iii) Ductility can be improved through annealing. During annealing, the heat gives the required energy for atoms to break their bonds. The atoms move around and this will cause a decrease in the number of dislocations. A decrease in dislocation allows for a lower internal stress, causing the metal to be more ductile.

	Carbon steel	Aluminium
(b)(i) Fatigue strength (at 10^7 cycles)	300 MPa	50 MPa
Fatigue Limit (MPa)	300 MPa	No fatigue limit.

(ii) 25% to 50% of tensile strength (UTS)

(c)(i) Aluminium has greater solubility in lithium

(ii) 596°C

(iii) 180.5°C

(iv) $L + \beta$

(v) 7.8%

3. (a)(i) % ionic $= \{1 - \exp[-\frac{1}{4}(x_A - x_B)^2]\} \times 100\%$

$= \{1 - \exp[-\frac{1}{4}(3.5 - 1.9)^2]\} \times 100\%$

$= 47.27\%$ ionic

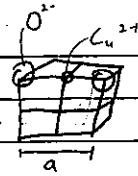
(ii) $\frac{r_{cation}}{r_{anion}} = \frac{0.087}{0.126}$

$= 0.6905$

∴ According to table, coordination number = 6

Crystal structure = Sodium Chloride (NaCl)

(iii) For NaCl structure, $n' = 4$ (4 molecules per cell unit)



$$\rho = \frac{n'(\Sigma A_c + \Sigma A_a)}{V_c N_A}$$

$a = 2r_{anion} + 2r_{cation}$

$a = 2(0.126) + 2(0.087)$

$a = 0.426\ nm = (0.426 \times 10^{-7})\ cm$

$V_c = a^3 = (7.73 \times 10^{-23})\ cm^3$

$$\rho = \frac{4(64+16)}{(7.73\times10^{-23})(6.023\times10^{23})}$$

$\rho = 6.87\ g/cm^3$

(b)(i)

number of ions × charge →

Fe_2O_3 → use 20 Fe ions, use 30 O ions

Originally		After	
positive	negative	positive	negative
$20 \times 3^+ = 60^+$	$30 \times 2^- = 60^-$	$(17\times3^+)+(3\times2^+) = 57^+$	$30 \times 2^- = 60^-$
nett charge = 0		nett charge = 3^+	

As cation vacancy (Fe^{3+}) is easier to achieve than anion interstitial (O^{2+}), the crystalline defect would be an Fe^{3+} vacancy.

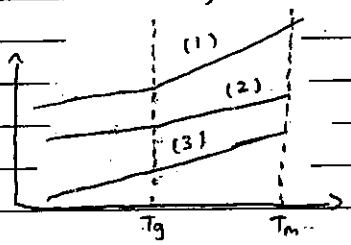
(ii) One Fe^{3+} ion is required for each defect.

(c)(i) sp^2

(ii) A is the strongest. It has triple bond, which is stronger than double bonds. * The reason why diamond has double bonds, and is the strongest material is not because double bonds are stronger than triple bonds. It is because the carbon atoms form a network structure that makes it so strong.

(iii) SiO_2. Both quartz and diamond forms a network structure, which is what gives them high strength and melting point.

(d)(i)



(ii) Shorter side groups allows for lower Tg

Single bonds, instead of double bonds, will lower Tg

(e) (i) $\bar{M}_n = \sum x_i M_i$

$= (0.30)\left(\frac{31000+50000}{2}\right) + (0.16)\left(\frac{51000+70000}{2}\right) + (0.26)\left(\frac{71000+90000}{2}\right) + (0.18)\left(\frac{91000+110000}{2}\right) + (0.10)\left(\frac{111000+130000}{2}\right)$

$= 12150 + 9680 + 20930 + 18090 + 12050$

$= 72900$ g/mol

$\bar{M}_w = \sum w_i M_i$

$= (0.22)\left(\frac{31000+50000}{2}\right) + (0.10)\left(\frac{51000+70000}{2}\right) + (0.28)\left(\frac{71000+90000}{2}\right) + (0.10)\left(\frac{91000+110000}{2}\right) + (0.30)\left(\frac{111000+130000}{2}\right)$

$= 8910 + 6050 + 22540 + 10050 + 36150$

$= 83700$ g/mol

(ii) m of $(CH_2-CH_2) = 2(12) + 4(1)$

$2C, 4H = 28$ g/mol

$DP = \frac{\bar{M}_w}{m} = \frac{83700}{28}$

$= 2989.29$

(f) Minimal elastic modulus = lower boundary

$\therefore$ use $\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$

Matrix (polymer)

$E_m = 3.8$ GPa

$V_m = 0.4$

Reinforcement (fibre)

$E_f = 400$ GPa

$V_f = 1 - 0.4 = 0.6$

$\frac{1}{E_c} = \frac{0.4}{3.8} + \frac{0.6}{400}$

$\frac{1}{E_c} = \frac{4057}{38000}$

$E_c = 9.37$ GPa

Condition: The composite must be pulled in the transverse direction, where it is the weakest. This is due to it being uni-directional and therefore, anisotropic.

Good Luck!!!

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2016-2017

MA1002 – FUNDAMENTAL ENGINEERING MATERIALS

April/May 2017 Time Allowed: 2 hours

Seat No:

Matriculation No:

INSTRUCTIONS

1. This paper contains **THREE (3)** questions and comprises **FOURTEEN (14)** pages including **THREE (3)** pages of Appendices.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is a **CLOSED-BOOK** examination.
5. All your answers should be contained in this booklet and within the space provided after the question.
6. Please make use of the information in the Appendices.

EXAMINERS USE ONLY	
Question	Marks
1	
2	
3	
Total	

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1 (a) (i) Calculate the force of attraction between a Ca^{2+} and an O^{2-} ion, the centers of which are separated by a distance of 1.25 nm.

(6 marks)

(ii) The microstructure of polycrystalline copper is to be analysed by optical microscopy. Explain how a sample is to be prepared, so that the grain boundaries are clearly visible.

(4 marks)

(iii) Describe what happens to dislocations as they move towards a grain boundary.

(2 marks)

Note: Question 1 continues on page 3.

(b) Three different crystallographic planes from a unit cell of a *hypothetical* metal are illustrated in Figure 1.

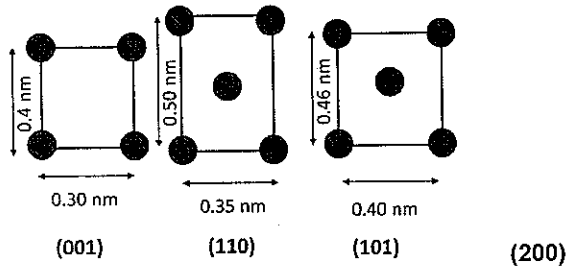

Figure 1

(i) To what crystal system does the unit cell belong?
(1 mark)

(ii) What would this crystal structure be called?
(1 mark)

(iii) Make a sketch of a (200) plane in the space provided in Figure 1.
(4 marks)

(iv) If the density of this metal is 8.90 g/cm^3 determine its atomic weight.
(4 marks)

Note: Question 1 continues on page 4.

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(c) (i) An FCC iron–carbon alloy initially containing 0.55 wt% C is exposed to an oxygen-rich and carbon-free atmosphere at 1,052 °C. Under these circumstances the carbon concentration at the surface position is maintained at 0 wt% C. At what position, x, will the carbon concentration be 0.25 wt% after a 10-heat treatment? The value of diffusivity, D, at this temperature is 4.3×10^{-11} m^2/s.
(8 marks)

(ii) Compare and contrast the self-diffusion of potassium atoms in metallic potassium with the diffusion of potassium ions within a ceramic such as KCl.
(4 marks)

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2 (a) (i) A tensile load of 32 kN is applied to the tensile axis of a cylindrical metal rod which has a diameter of 12 mm producing only elastic deformation. What is the resulting diameter? (Young's modulus of the material is given as 70 GPa).

(5 marks)

(ii) Describe what takes place microstructually when the radius of the rod is plastically reduced in a tensile test.

(2 marks)

(iii) Suggest a method to improve this same material's yield strength?

(2 marks)

(iv) What is the Poisson Ratio of this material; and what is a typical value of Poisson Ratio for metals?

(4 marks)

Note: Question 2 continues on page 6.

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(b) Figure 2 shows the results from the Charpy (Impact) Test of A36 Steel and material from the Titanic ship (1912).

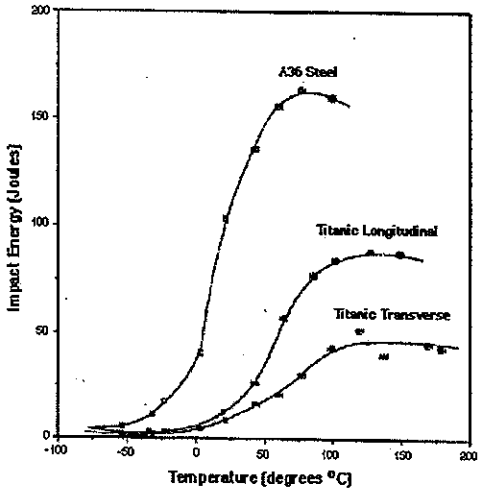

Figure 2

(i) Which mechanical property does the test measure?

(2 marks)

(ii) From the figure, what is the Ductile-Brittle Transition Temperature (DBTT) of A36 steel?

(2 marks)

(iii) If given a choice between longitudinal and transverse direction, which is the preferred direction for the Titanic specimen along the ship's hull? Give your reason.

(2 marks)

(iv) Name TWO strategies that can be employed to alleviate the detrimental effects of DBTT?

(4 marks)

Note: Question 2 continues on page 7.

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(c) Figure 3 shows the Fe-C phase diagram.

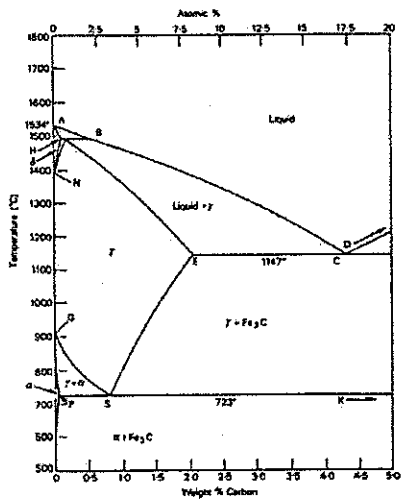

Figure 3

(i) What are the eutectoid composition and eutectoid temperature?

(4 marks)

Composition (wt %)	
Temperature (°C)	

(ii) Sketch in the space provided below, the eutectoid structure.

(2 marks)

(iii) Given that cementite (Fe_3C) contains 6.7 wt% C, calculate the relative amounts of ferrite and cementite in the eutectoid structure at room temperature.

(4 marks)

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3 (a) Give ANY TWO reasons why ceramics are brittle unlike most metals which are relatively ductile by comparison?

(4 marks)

(b) Calculate the **"number of formula units per unit cell"** for sodium chloride (NaCl) crystal given the following parameters:

(i) Ionic radii of Na^+ and Cl^- are 0.102 nm and 0.181 nm respectively,

(ii) Molar mass of NaCl is 58.44 g/mol,

(iii) Density of NaCl crystals is 2.165 g/cm^3,

(iv) NaCl crystal has a FCC anionic packing.

(5 marks)

Note: Question 3 continues on page 9.

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(c) What is the basic structural unit of quartz? Explain the high mechanical strength of quartz in terms of the arrangement of it's structural units.

(4 marks)

(d) Syndiotactic and atactic polystyrene were injection moulded using the same mould. However, the two groups of moulded products were not labeled according to the type of polystyrene used. But, it was found that one group of moulded products (Group A) was about 3-5% heavier than the other group (Group B).

(i) Describe the structural difference between "syndiotactic" and "atactic" polymers.

(2 marks)

(ii) Which group of the moulded products do you think uses the atactic polystyrene? Give your reason.

(3 marks)

Note: Question 3 continues on page 10.

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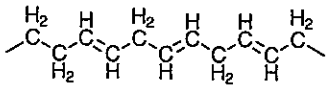
(e) (i) Explain the term "glass transition temperature, Tg" of a polymer?

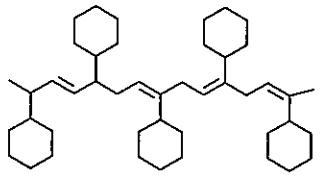
(2 marks)

(ii) Rank in increasing order their expected Tg (i.e. from low to high value) of the following three polymers and give your reasons for the ranking.

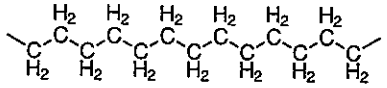
(3 marks)



Polymer (A)



Polymer (B)



Polymer (C)

Note: Question 3 continues on page 11.

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(f) A sample of poly(butylene) was found to have a molecular weight distribution of 2.5. The number-average molecular weight given as 500,000 g/mol and the molecular weight of the structural repeating unit of poly(butylene) is 56 g/mol. Calculate the weight-average degree of polymerisation of this polymer.

(4 marks)

(g) What is the difference between "alloys" and "composites"?

(3 marks)

(h) Discuss ANY THREE factors that will enhance the strength of fibre-reinforced composites.

(3 marks)

Appendix A – *Periodic Table*

1 Hydrogen 1.00794																	2 Helium 4.0026
3 Lithium 6.941	4 Beryllium 9.012182											5 Boron 10.811	6 Carbon 12.0107	7 Nitrogen 14.00674	8 Oxygen 15.9994	9 Fluorine 18.9984032	10 Neon 20.1797
11 Sodium 22.989770	12 Magnesium 24.3050											13 Aluminium 26.981538	14 Silicon 28.0855	15 Phosphorus 30.973761	16 Sulfur 32.066	17 Chlorine 35.4527	18 Argon 39.948
19 Potassium 39.0983	20 Calcium 40.078	21 Scandium 44.955910	22 Titanium 47.867	23 Vanadium 50.9415	24 Chromium 51.9961	25 Manganese 54.938049	26 Iron 55.845	27 Cobalt 58.933200	28 Nickel 58.6934	29 Copper 63.546	30 Zinc 65.39	31 Gallium 69.723	32 Germanium 72.61	33 Arsenic 74.92160	34 Selenium 78.96	35 Bromine 79.904	36 Krypton 83.80
37 Rubidium 85.4678	38 Strontium 87.62	39 Yttrium 88.90585	40 Zirconium 91.224	41 Niobium 92.90638	42 Molybdenum 95.94	43 Technetium (98)	44 Ruthenium 101.07	45 Rhodium 102.90550	46 Palladium 106.42	47 Silver 107.8682	48 Cadmium 112.411	49 Indium 114.818	50 Tin 118.710	51 Antimony 121.760	52 Tellurium 127.60	53 Iodine 126.90447	54 Xenon 131.29
55 Caesium 132.90545	56 Barium 137.327	57 Lanthanum 138.9055	72 Hafnium 178.49	73 Tantalum 180.9479	74 Tungsten 183.84	75 Rhenium 186.207	76 Osmium 190.23	77 Iridium 192.217	78 Platinum 195.078	79 Gold 196.96655	80 Mercury 200.59	81 Thallium 204.3833	82 Lead 207.2	83 Bismuth 208.98038	84 Polonium (209)	85 Astatine (210)	86 Radon (222)
87 Francium (223)	88 Radium (226)	89 Actinium (227)	104 Rutherfordium (261)	105 Dubnium (262)	106 Seaborgium (263)	107 Bohrium (262)	108 Hassium (265)	109 Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

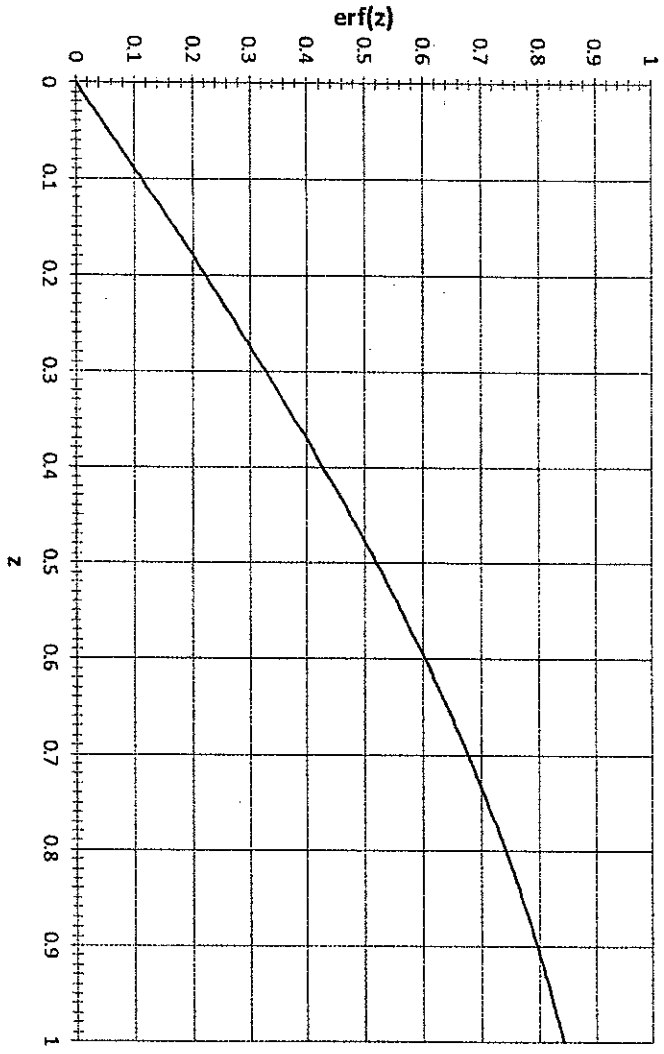
58 Cerium 140.116	59 Praseodymium 140.90765	60 Neodymium 144.24	61 Promethium (145)	62 Samarium 150.36	63 Europium 151.964	64 Gadolinium 157.25	65 Terbium 158.92534	66 Dysprosium 162.50	67 Holmium 164.93032	68 Erbium 167.26	69 Thulium 168.93421	70 Ytterbium 173.04	71 Lutetium 174.967
90 Thorium 232.0381	91 Protactinium 231.03588	92 Uranium 238.0289	93 Neptunium (237)	94 Plutonium (244)	95 Americium (243)	96 Curium (247)	97 Berkelium (247)	98 Californium (251)	99 Einsteinium (252)	100 Fermium (257)	101 Mendelevium (258)	102 Nobelium (259)	103 Lawrencium (262)

Appendix B – *Selected Equations and Constants*

1. $\frac{N_v}{N} = \exp\left(-\frac{Q_v}{kT}\right)$
2. $\frac{1}{E_l} = \left\{\frac{V_f}{E_f} + \frac{(1-V_f)}{E_m}\right\}$
3. $J = -D\frac{dC}{dx}$
4. $\frac{F_f}{F_m} = \frac{E_f V_f}{E_m V_m}$
5. $\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$
6. $E_N = -\frac{A}{r} + \frac{B}{r^n}$ where A is generally equal to $\frac{1}{4\pi\epsilon_0}(Z_1 e)(Z_2 e)$.
7. $E_l = E_f V_f + E_m(1-V_f)$
8. $\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$
9. $D = D_0 \exp\left(-\frac{Q_d}{RT}\right)$
10. Boltzmann's constant, k, is 8.62×10^{-5} eV/atom.K.
11. Avogadro 's number, N_A, is 6.023×10^{23} atoms/mol.
12. Charge on an electron, e, is 1.6×10^{-19} C
13. Permittivity of free space, ϵ_0, is = 8.85 x 10^{-12} F/m

*All symbols carry their usual meaning

Appendix C – *Error Function*



END OF PAPER

MA1002 April 2017

(1)(a) i) $F_A = \frac{1}{4\pi\varepsilon_0 r^2}(Z_1 e)(Z_2 e)$

$= \frac{1}{4\pi \times 8.85\times10^{-12} \times (1.25\times10^{-9})^2} \times (2\times1.6\times10^{-19}) \times (2\times1.6\times10^{-19})$

$= 5.893\times10^{-10}$ N

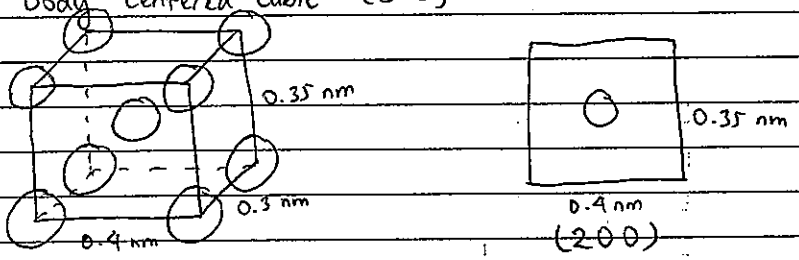
ii) The sample is first polished and etched in HNO_3. Since grain boundaries are in higher energy state, it will react more with HNO_3, which makes the grain boundaries more corroded compared with the surrounding grains. Reflectivity of the grains under microscope also varies due to different reactivity with HNO_3 caused by different orientation of grains. Hence, with these different reflectivity of grains and grain boundaries, the sample can be analysed with enough contrast and visibility of the grain boundaries.

iii) Since the grains are in different orientation, the critical resolved shear stress / minimum stress for the dislocations to move varies from grain to grain. Dislocations will be trapped as they arrive at the grain boundary. As there are increasing number of dislocations trapped, the stress in that area also increases. When the stress becomes high enough to match the critical resolved shear stress of the next grain, then the dislocations can move to the next grain.

(b) i) Orthorhombic

ii) Body Centered Cubic (BCC)

iii)



iv) $\rho = \frac{nA}{V N_A}$; $n = 8\times\frac{1}{8} + 1 = 2$

(continues to the next page)

1(b) iv) continued

$$8.90 \times 10^{3} = \frac{2 \times A}{(0.4 \times 10^{-9}) \times (0.3 \times 10^{-9}) \times (0.35 \times 10^{-9}) \times 6.02 \times 10^{23}}$$

$$A = 0.1125 \text{ kg/mol}$$

$$= 112.5 \text{ g/mol}$$

(c) i) $$\frac{C_x - C_o}{C_s - C_o} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{0.25 - 0.55}{0 - 0.55} = 1 - \text{erf}\left(\frac{x}{2\sqrt{(4.3 \times 10^{-11}) \times (10 \times 3600)}}\right)$$

$$\text{erf}\left(\frac{x}{2.488 \times 10^{-3}}\right) = 0.455$$

$$\frac{x}{2.488 \times 10^{-3}} = 0.43$$

$$x = 0.00107 \text{ m}$$

$$x = 1.07 \text{ mm}$$

ii) The diffusion of potassium ions within KCl is low because the movement of K^+ ions is restrained due to strong attractive and repulsive ionic forces from the surrounding ions. K^+ ions need to have large energy to break the ionic bonds between ions. In contrast, the movement of K atoms in metallic potassium is relatively easy. This is because the metallic bonds between atoms can be broken with lower energy due to weaker bonds, resulting in higher mobility and diffusivity.

(2) (a) i) $$\frac{F}{A_o} = E\varepsilon = E\frac{l - l_o}{l_o} = E\left(\frac{l}{l_o} - 1\right)$$

$$\frac{32 \times 10^{3}}{\frac{1}{4} \times \pi \times 0.012^2} = 70 \times 10^{9}\left(\frac{l}{l_o} - 1\right)$$

$$\frac{l}{l_o} = 1.004092$$

Assume volume is constant

$$\left(\tfrac{1}{4}\pi d_o^2\right) l_o = \left(\tfrac{1}{4}\pi d^2\right) l$$

$$d = d_o\sqrt{\frac{l_o}{l}} = 12 \times \frac{1}{\sqrt{1.004092}} = 11.976 \text{ mm}$$

ii) During plastic deformation, bonds between atoms stretch and planes shear. The shearing of planes causes the specimen to elongate and since the volume of specimen is assumed constant (number of atoms also conserved), hence, the cross-sectional area and diameter decrease.

iii) Cold working (by forging or drawing or rolling). Through this method, the material is deformed at low temperature which causes dislocations to entangle with each other. As a result, the yield strength increases

iv) $\varepsilon = \frac{l - l_o}{l_o} = \frac{l}{l_o} - 1 = 0.004042$

$\varepsilon_l = \frac{d - d_o}{d_o} = \frac{11.976 - 12}{12} = -0.002$

$\nu = -\frac{\varepsilon_l}{\varepsilon} = \frac{0.002}{0.004042} = 0.495$

Typical ν for metals = 0.33

(b) i) Ductile brittle transition temperature (DBTT)

ii) Around 0°C

iii) Longitudinal, because it has lower DBTT which means it's safer to operate at lower temperature

iv) - Use naturally ductile material such as FCC metals
- Operate above DBTT to ensure the ductility of the material

(c) i) Composition : 0.8 wt % C

Temperature : 723 °C

ii)

iii) At room temperature → C_α = 0 % wt C ; C_{Fe_3C} = 6.7 % wt C

$W_\alpha = \frac{6.7 - 0.8}{6.7 - 0} \times 100\% = 88.06\%$

$W_{Fe_3C} = \frac{0.8}{6.7 - 0} \times 100\% = 11.94\%$

③(a) - In ceramics, ions are held by strong ionic bonds and each ion is surrounded by oppositely charged ions. Thus, any attempt by the ions to slip past one another is faced by strong repulsive force, resulting in brittle failure.
- Pores and cracks in ceramics act as stress concentrators which cause failure easily when force is applied.

(b) $a = 2(r_+ + r_-)$

$= 2(0.102 + 0.181) = 0.566$ nm

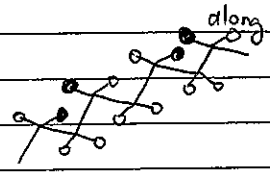
$$\rho = \frac{n' A}{N_A a^3}$$

$$2.165 \times 10^3 = \frac{n' \times 58.44 \times 10^{-3}}{6.02 \times 10^{23} \times (0.566 \times 10^{-9})^3}$$

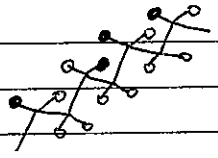
$n' = 4.043 \approx 4$

(c) Quartz consists of repeating SiO_4 units with a general formula of SiO_2. They form a network structure similar to diamond which gives quartz the rigidity, strength, and high melting point.

(d) i) Syndiotactic → side group atoms are arranged in alternating fashion along a chain



Atactic → side group atoms are randomly arranged along a chain



ii) Group B uses atactic polystyrene. Unlike syndiotactic polystyrene, atactic polystyrene cannot be close packed due to its random arrangements. Hence, given the same volume, atactic polystyrene will be less dense than the syndiotactic one → less heavy.

(e) i) Below T_g, the polymer becomes rigid glass and very brittle, but above T_g, the polymer becomes rubbery and ductile because in higher temperature, long range chain motion is possible. So, T_g is the temperature when polymer changes from brittle to ductile and vice versa.

ii) (low) C - A - B (high)

Polymer A has higher T_g than polymer C because it has double bonds which increases chain stiffness and T_g as well.

Polymer B has the highest T_g because in addition to having double bonds, it has bulky side groups which increases the chain stiffness and T_g.

(f) $MWD = \frac{\bar{M}_w}{\bar{M}_n}$

$2.5 = \frac{\bar{M}_w}{500\,000} \rightarrow \bar{M}_w = 1250000$ g/mol

(g) Alloys are made by mixing two / more different metals which then forms new phase inside the material and can be treated as solid solution.

Composites are made by combining two / more constituents which can be metal, ceramic, or polymer but they are not soluble in each other and they maintain their original physical phases.

(h) - Use longer fibre → more effective stress transfer from matrix to the dispersed phase

- Use suitable interfacial phase → can glue the matrix and reinforcement phase effectively to increase strength
- Different orientation of fibres → creates anisotropy so there is no "weak" direction where the force is applied

NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2018-2019

MA1002 – FUNDAMENTAL ENGINEERING MATERIALS

April/May 2019 Time Allowed: 2 hours

Seat No:

Matriculation No:

INSTRUCTIONS

1. This paper contains **SEVEN (7)** questions and comprises **SIXTEEN (16)** pages including **TWO (2)** pages of Appendices.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is a **CLOSED-BOOK** examination.
5. All your answers should be contained in this booklet and within the space provided after the question. Please make use of the information in the Appendices.

EXAMINERS USE ONLY	
Question	Marks
1	
2	
3	
4	
5	
6	
7	
Total	

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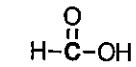
1 (a) Explain the terms "atomic mass" and "atomic weight"

(2 marks)

(b) Silver has two isotopes, namely ^{107}Ag and ^{109}Ag. If the atomic weight of silver is 107.8682 amu, calculate their abundance of each isotope in atomic percentage.

(3 marks)

(c) What is the hybridsation of the carbon atom in this compound? Give your reason.



(2 marks)

(d) (i) Given the atomic number of an element is 86, write its electronic configuration **in the order of electron filling.**

(2 marks)

(ii) What is the valence electrons for this element?

(1 mark)

Note: Question 1 continues on page 3.

(e) A compound, AX, is known to be approximately 49% ionic character. Given that the electronegativity of X is 3.5, determine the electronegativity of element "A".
(Note: The Maximum electronegativity value possible is 4.0)

(4 marks)

(f) Which of the two compounds, i.e. hydrogen fluoride (HF) and ethane (CH_3CH_3), would you expect to have the lower boiling point? **Give your reason.**

(2 marks)

/ 16

2 (a) (i) Define the terms "melting" and "glass transition" temperatures commonly used to describe the thermal behavior materials.

(3 marks)

(ii) Do thermoset polymers have melting temperature? Give your reasons.

(2 marks)

(b) Why is the melting temperature of crystalline polymers lower than that of ionic crystalline ceramics or metals?

(3 marks)

Note: Question 2 continues on page 5.

(c) Compound A and B are difunctional monomers used to produce a thermoplastic which is soluble in an organic solvent and with a glass transition temperature of 50°C. However, on one occasion, small quantities of a reactive tetra-functional compound was accidentally added into the reaction mixture. Predict the impact that this accident has on the following properties of the polymer and give your reason in each case:

(i) Structure

(2 marks)

(ii) Glass transition temperature

(2 marks)

(iii) Mechanical properties

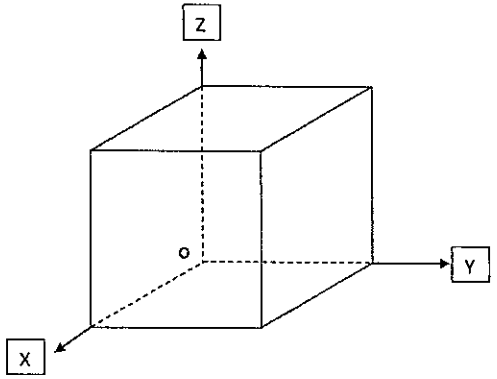
(2 marks)

(d) Polymer A having a structural repeating unit of 110 g/mol was found to have a number average degree of polymerization of 30,000. Given that the polymer has a molecular weight distribution of 2.5, what is the weight-average molecular weight of this polymer?

(2 marks)

/ 18

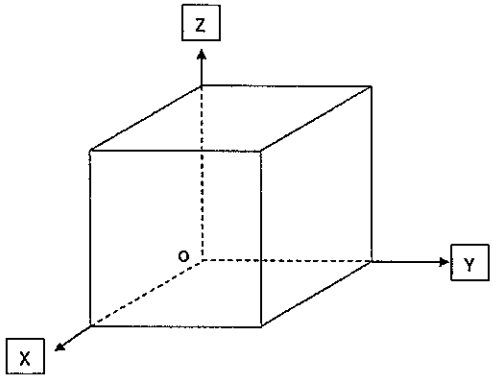
3 (a) Determine the Miller Indices and draw the plane that passes through the following three points with the following co-ordinates: **0,0,1; 1,0,0; ½, ½,0**



(2 marks)

(b) Given the following Millar Indices, sketch the plane or direction within the cubic unit cell shown below:

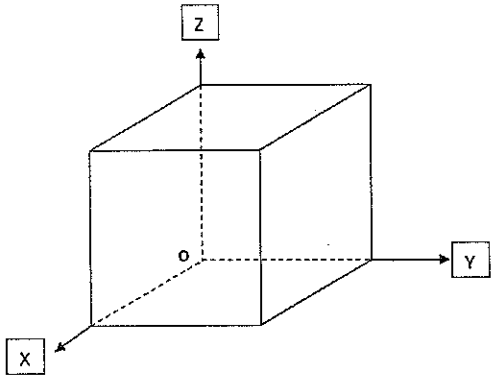
(i) (102)



(2 marks)

Note: Question 3 continues on page 7.

(ii) $[1\,2\,\bar{2}]$



(2 marks)

(c) A thin piece of iron sheet weighs 10g and has a BCC crystallographic arrangement. Given that the lattice parameter is 2.866×10^{-8}cm and the materials density is $7.878 g/cm^3$, determine the following:

(i) The number of unit cells present in this sheet of iron

(3 marks)

(ii) The number of atoms present in this iron sheet

(2 marks)

Note: Question 3 continues on page 8.

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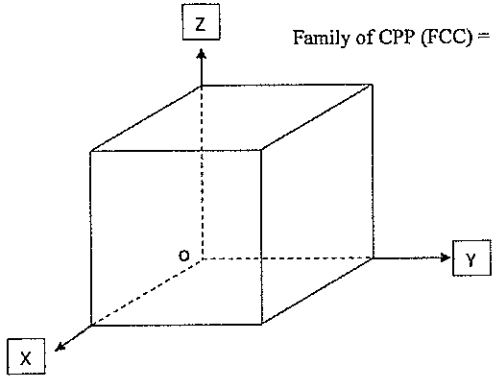
(d) (i) Determine the planar density for FCC nickel in the (110) plane, show your working.

(4 marks)

(ii) Identify the family of closed packed planes CPP in FCC nickel. Use the correct symbol for family of planes in your answer. **Draw to illustrate your answer.**

Family of CPP (FCC) =



(3 marks)

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4 (a) What is an isomorphous system? State the 'rules' that need to be satisfied in order for a binary system to be isomorphous.

(6 marks)

(b) (i) Label the different phase fields that are on the equilibrium phase diagram for the Cu-Ag binary system displayed below in Figure (4b).

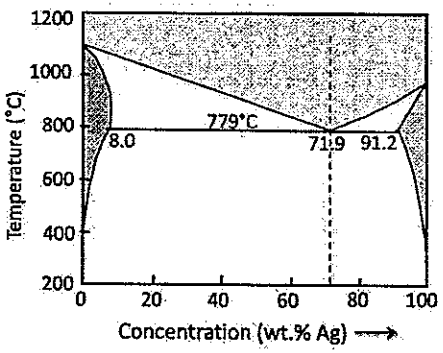

Figure (4b): Equilibrium phase diagram for the Cu-Ag binary system

(5 marks)

Note: Question 4 continues on page 10.

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(ii) Write down the reaction that occurs when an alloy with 71.9 wt.% Ag composition is slowly cooled from 800 to 778 °C. What is the name of this reaction?

(4 marks)

(iii) Calculate the approximate weight fractions of the different phases in the 71.9 wt.% Ag alloy at (i) 778 °C and at (ii) 200 °C.

(6 marks)

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5 (a) Provide at least TWO contrasting features of ductile and brittle fractures. (4 marks)

(b) What is 'ductile-to-brittle transition temperature (DBTT)? Illustrate, schematically, the variations of impact toughness with temperature for a steel that exhibits DBTT at -30 °C and an Al alloy over the temperature range of -50 to +30 °C. (4 marks)

Note: Question 5 continues on page 12.

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(c) Identify the geometries of the indenter tips used for measuring Brinell, Vickers, and Knoop hardness values of materials. Provide simple sketches of the indentation impressions (top view) made by these three indenters on a ductile metal piece. (3 marks)

6 (a) What are Schottky and Frenkel defects in ionic crystals?

(4 marks)

/ 10

(b) The diffusion coefficients, D, of interstitial nitrogen in face centered cubic phase of iron at 1000 and 1100 °C are 11.535×10^{-12} and 36.664×10^{-12} m^2/s respectively. What is the value of D at 1050 °C ? The gas constant = 8.31 J/(mol.K).

(6 marks)

7 (a) What constitutes a slip system?

(2 marks)

/ 08

(b) Identify the slip systems for body centered cubic (BCC) and face centered cubic (FCC) metals?

(4 marks)

(c) How many slip systems are there in FCC and BCC materials?

(2 marks)

Appendix A – Periodic Table

1. H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminium 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Caesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	(269)	(272)	(277)						

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Appendix B – Electronegativity Table for Elements

Electronegativity values of the elements (Pauling scale)

H 2.1																	He
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6
Cs 0.7	Ba 0.9	La 1.1	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn 2.4
Fr 0.7	Ra 0.7	Ac 1.1															

Ce 1.1	Pr 1.1	Nd 1.1	Pm 1.1	Sm 1.1	Eu 1.1	Gd 1.1	Tb 1.1	Dy 1.1	Ho 1.1	Er 1.1	Tm 1.1	Yb 1.1	Lu 1.2
Th 1.3	Pa 1.5	U 1.7	Np 1.3	Pu 1.3	Am 1.3	Cm 1.3	Bk 1.3	Cf 1.3	Es 1.3	Fm 1.3	Md 1.3	No 1.3	Lr

Appendix C – Cation-Anion radius Ratio and Co-ordination Number

R_c/R_a radius ratio	Co-Ordination Number
< 0.155	2
0.156 – 0.225	3
0.226 – 0.414	4
0.415 – 0.732	6
0.733 – 1.0	8

Appendix D

Avogadro's Number = 6.023×10^{23} per mole

END OF PAPER

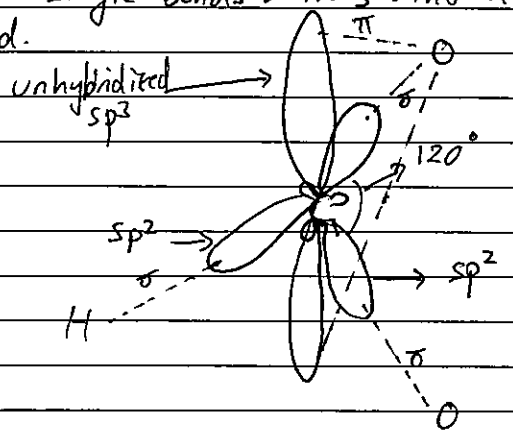
1a) Atomic mass is the total mass of protons and neutrons in an individual atom or isotope. Atomic weight is the average mass of all naturally occuring isotopes of an element.

1b) let x equal the abundance of ^{107}Ag isotope

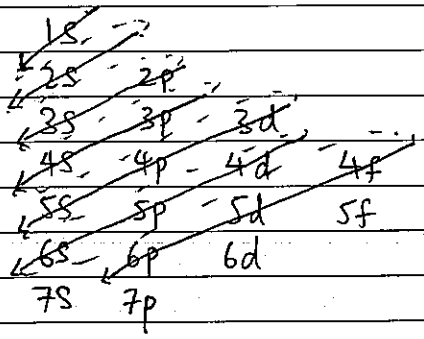
$$x(107) + (1-x)(109) = 107.8682$$
$$107x + 109 - 109x = 107.8682.$$
$$1.1318 = 2x$$
$$x = 0.5659$$
$$1-x = 0.4341$$

The Abundance of ^{107}Ag is 56.59%.
The Abundance of ^{109}Ag is 43.41%.

1c) The hybridization is sp^2. The carbon atom forms 1 double bond and 2 single bonds with 3 other atoms, forming 3 σ bonds and 1 π bond.



di) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 \cancel{5d^{10}} 4f^{14} 5d^{10} 6p^6$



dii) The valence level is $6s^2 6p^6$, it has 8 valence electrons.

e) $49 = \left(1 - e^{-\frac{1}{4}(3.5 - X_A)^2}\right) \times 100$

$e^{-\frac{1}{4}(3.5 - X_A)^2} = 0.51$

$-\frac{1}{4}(3.5 - X_A)^2 = \ln(0.51)$

$3.5 - X_A = \sqrt{-4 \ln(0.51)}$

$X_A = 1.859$ #

f) Ethane would have a lower boiling point. HF molecules are bonded with each other through strong hydrogen bonding while ethane molecules are bonded together through weak van der waal forces of attraction. Less energy is required to break apart ethane molecules than HF molecules, hence lower boiling point.

2) ai) Melting temperature is the temperature at which a substance changes from a solid to liquid state

Glass transition temperature is the temperature at which significant and reversible transition of an amorphous substance from its soft and pliable state to a hard and brittle state occurs.

2a ii) Themoset polymers do not have melting temperature. They are irreversibly hardened by curing from a resin, forming network polymers. Only excessive heating would cause severance of the crosslinks in the network which results in polymer degradation.

b) Individual chain folded lamellar crystals are sepeiated by amorphous material where polymer molecules van deer waals forces of attraction whichare weaker than the covalent or metallic bonds found throughout the crystalline matrix of ceremics and metals. Hence less enogy is required to seperate and melt crystalline polymers.

c) i) polymer changes from linear to crosslinked. Tetra functional monomers are able to link two linear polymer chains together.

ii) Glass transition temperatwe increase as increased cross-linkage decrease long range segmental motion and more energy is required to overcome this restriction.

iii) The polymer would be less elastic. More energy is required to ~~sper~~ separate polymer chains linked togethr through covalent bonds.

d) $DP = \frac{\bar{M}n}{M_o}$

$30,000 = \frac{\bar{M}n}{110}$

$\bar{M}n = 30,000 \times 110$

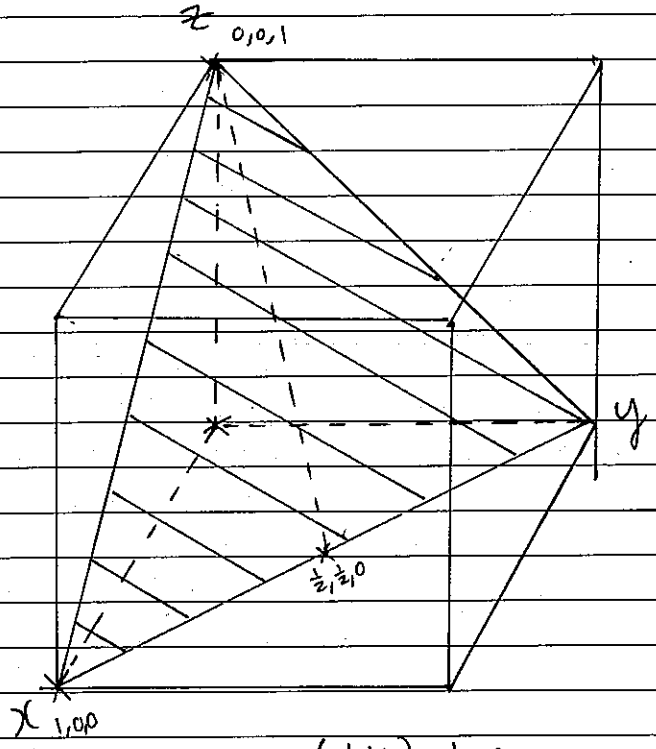
$= 3,300,000$

$\bar{M}w = 2.5\,\bar{M}n$

$= 2.5 \times 3,300,000$

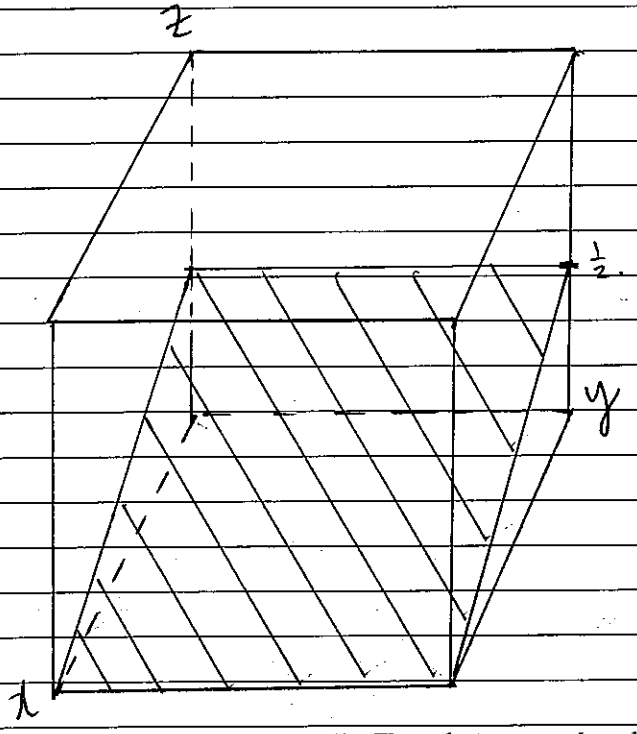
$= 8,250,000$ g/mol

3a)



(111) plane.

bi)

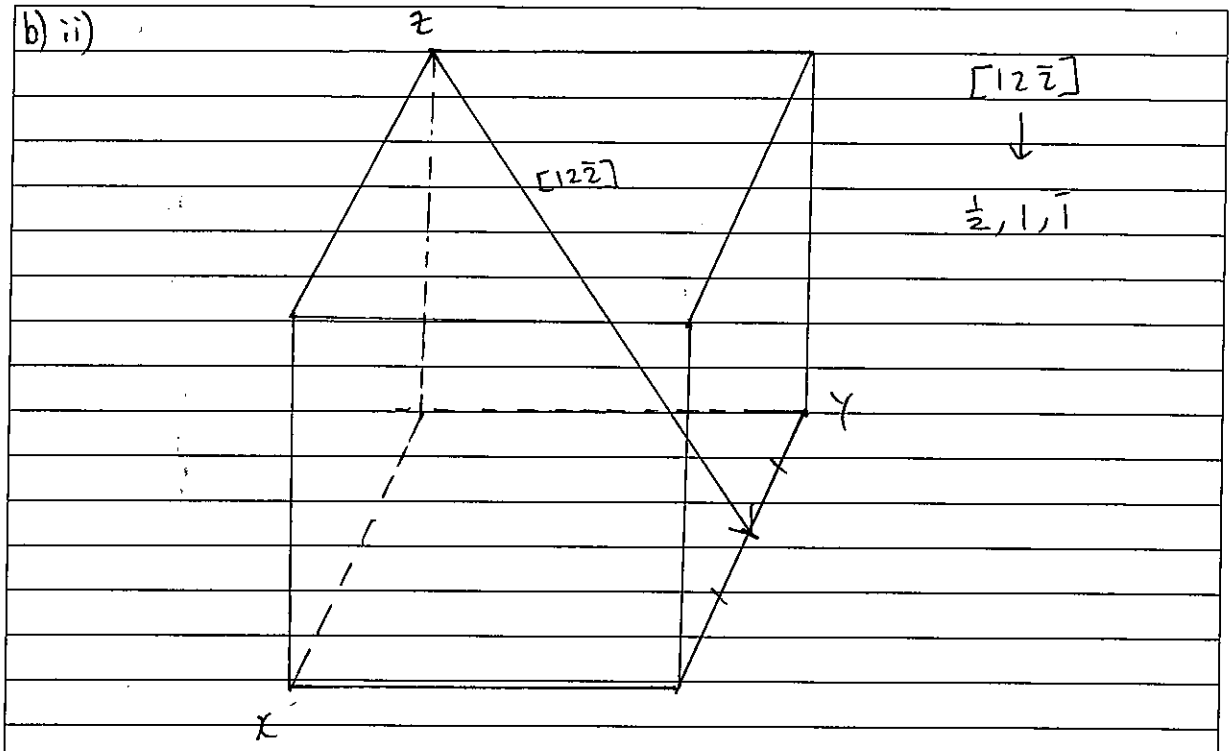


(102)

↓

1, α, ½.

b) ii)



c) i) volume = $\frac{\text{mass}}{\text{density}}$

$= \frac{10}{7.878}$

$= 1.269\ cm^3$

volume of 1 unit cell = $(2.886 \times 10^{-8})^3$

$= 2.354 \times 10^{-23}\ (m^3$

No. of lattice cubes = $1.269 / (2.354 \times 10^{-23})$

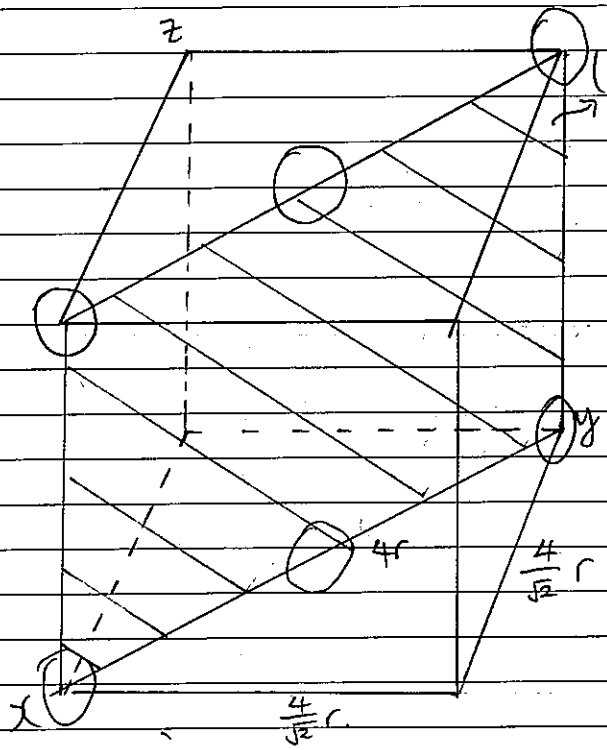
$= 5.39 \times 10^{22}$ unit cells.

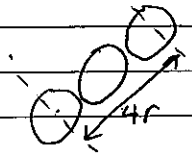
ii) Iron is BCC → 2 atoms per unit cell.

number of atoms = $5.39 \times 10^{22} \times 2$

$= 1.08 \times 10^{23}$ atoms.

d i)





Let the atomic radius of Nickel be r,

diagonal = 4r.

lattice parameter, $a_0 = \frac{4}{\sqrt{2}}r$.

Area of plane = $4r \times \frac{4}{\sqrt{2}}r$

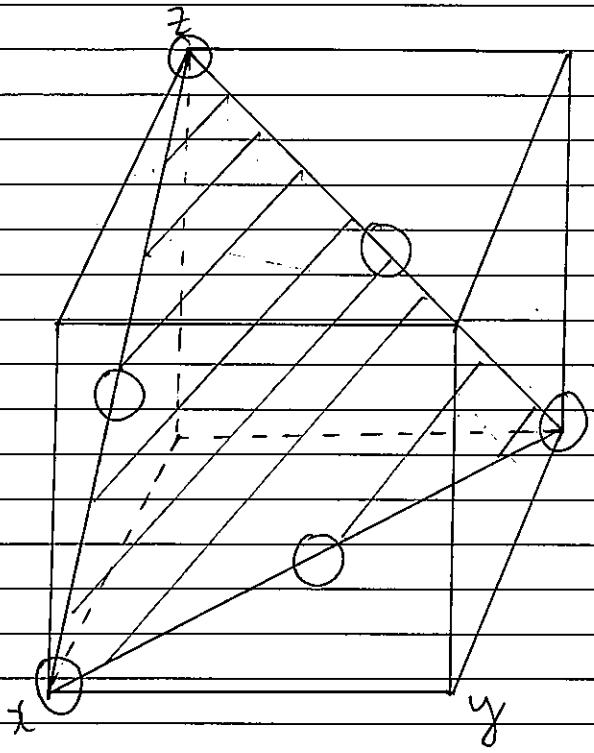
$= \frac{8\sqrt{2}}{\sqrt{2}}r^2 = 8\sqrt{2}r^2$

planar density = $\frac{\text{No. of atoms centred on plane}}{\text{AREA of plane}}$.

$= \frac{2}{8\sqrt{2}r^2}$

$= \frac{1}{4\sqrt{2}r^2}$ #

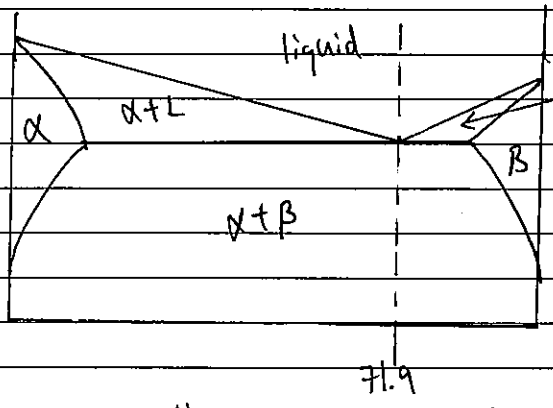
ii)



Family of CPP(FCC) = {111}

4a) An isomorphous system is one where its components are completely soluable in each other, forming a complete solid solution.
For a binary system, the two components must have about the same: radii, electronegativity, crystal structure and valance.

bi)



ii) $L(71.9\%\text{ wt\% Ag}) \xrightarrow{\text{cooling}} \alpha(8.0\text{ w\% Ag}) + \beta(91.2\%\text{ wt Ag})$

(eutectic reaction.)

iii) i) $W_\alpha = \frac{91.2 - 71.9}{91.2 - 8.0}$

$= 0.232$

$W_\beta = 1 - 0.232 = 0.768$

ii) $W_\alpha = \frac{100 - 67}{100 - 0}$

$= 0.33$

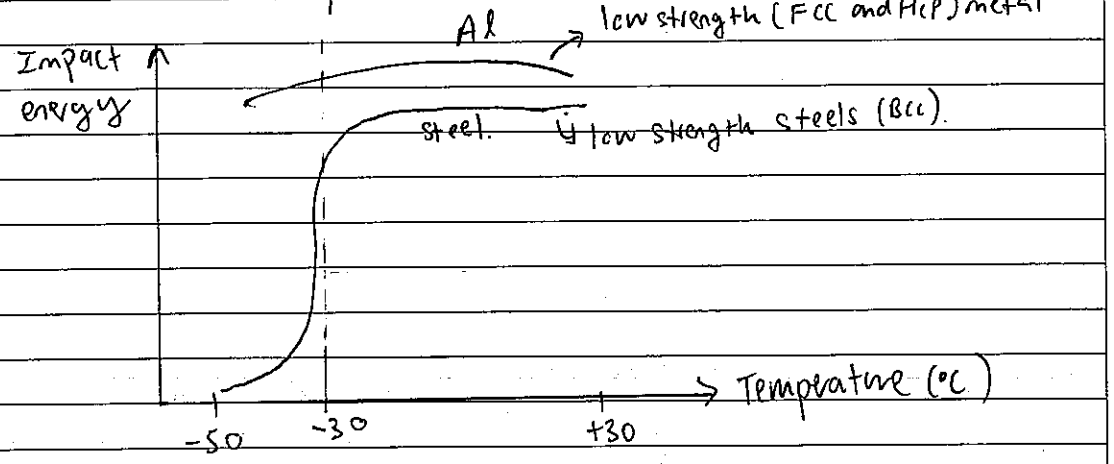
$W_\beta = 1 - W_\alpha$

$= 1 - 0.33$

$= 0.67$

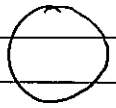
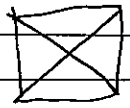
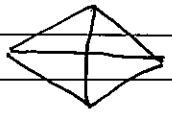
5a) In ductile fracture, extensive plastic deformation occurs before fracture while no apparent deformation takes place for brittle failure.
Due to deformation, material absorbs a significant amount of energy before ductile fracture, while little energy is absorbed for brittle fracture.

b) The ductile brittle temperature is the temperature in which there is a large change in ductility (impact energy absorbtion) over a small interal of temperature.



c) Brinell. Vickers. Knoop

Indenter: Sphere. Diamond pyramid. Diamond pyramid

Top view  Top view.  Top view. 

6a) Shottky defects are point defects that forms when oppositely charged ions leave their lattice shells, leaving vacancies. These vacancies are ~~of~~ formed in stoichometric units to maintain overall charge neutrality

Frenkel defects are point defects when an atom or smaller ion (usually cation) leaves its place in the lattice, creating a vacancy, and becomes an interstitial by lodging in a nearby location.

b) $D = D_0 \exp\left(-\frac{Q_T}{RT}\right)$

$11.535 \times 10^{-12} = D_0 \exp\left(\frac{-Qd}{(8.31)(1273.15)}\right)$ — ①

$36.664 \times 10^{-12} = D_0 \exp\left(\frac{-Qd}{(8.31)(1373.15)}\right)$ — ②

$\frac{①}{②}: \frac{11.535 \times 10^{-12}}{36.6644 \times 10^{-12}} = \exp\left(\frac{Qd}{8.31 \times 1273.15} - \left(-\frac{Qd}{8.31 \times 1373.15}\right)\right)$

$\ln\left(\frac{11.535 \times 10^{-12}}{36.6644 \times 10^{-12}}\right) = Qd\left(\frac{1}{8.31 \times 1273.15} - \frac{1}{8.31 \times 1273.15}\right)$

$Qd = 167911.3918$ J/mol

$D_0 = 9.01 \times 10^{-5}$ m²/s

$D = 9.01 \times 10^{-5} \exp\left(-\frac{167911.3918}{8.31 \times 1323.15}\right)$

$= 21.02 \times 10^{-12}$ m²/s

7a) A slip system describes a set of symmetrically identical slip planes and associated family of slip directions for which dislocation can easily occur

b) BCC ⇒ $\{110\}, \langle 111 \rangle$

FCC ⇒ $\{111\}, \langle \bar{1}10 \rangle$

c) FCC ⇒ 12 slip systems.

BCC ⇒ 12 slip systems.