SCHOOL OF MINING, METALLURGY & CHEMICAL ENGINEERING

DEPARTMENT OF METALLURGY

BACHELOR OF ENGINEERING TECHNOLOGY: PHYSICAL METALLURGY

SUBJECT:	**Physical Metallurgy 2A**
CODE:	**PMTMTA2**
ASSESSMENT:	**Main Exam**
WEIGHT:	**40:60**
EXAMINER:	**Mr TG Langa**
MODERATOR:	**Mr LG Juganan**
DATE:	**Monday , 27 May 2019**
DURATION:	**3 hours**
TIME:	**08:30**
NUMBER OF PAGES:	**8 (Including Cover page and Appendices)**
TOTAL MARKS:	**100**

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Instructions:

- **Use the appendices provided at the end of the question paper to answer some of the questions**
- **Scientific Calculator**
- **Answer all the questions**

Question 1: (13 marks)

1.1 Define physical metallurgy **(2)**

1.2 Describe the enabling material property for each of the following and give reasons why.

a) Aluminium for automobile bodies **(2)**

b) Titanium alloys for hip replacements **(2)**

c) Polyethylene terephthalate (PET) for water bottles **(2)**

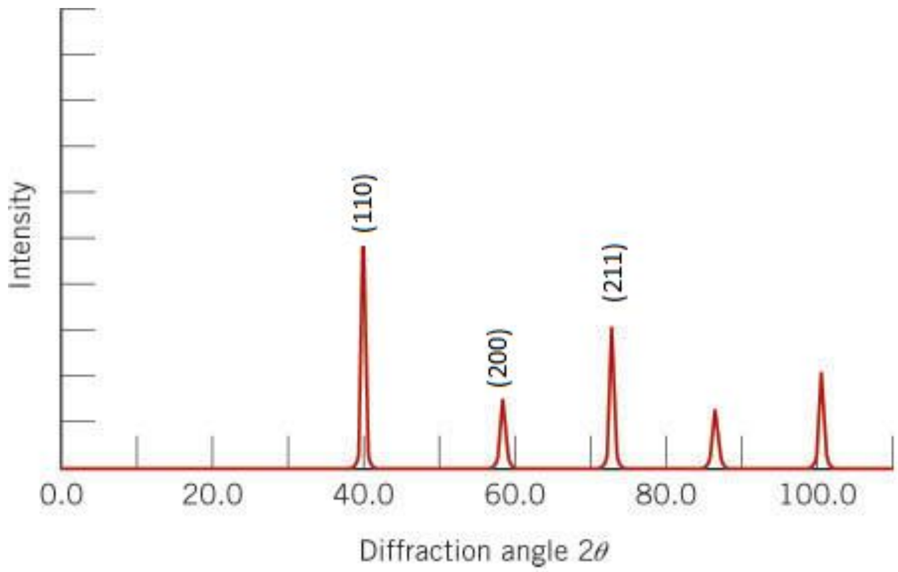
1.3 Explain how processing affects the mechanical properties of a material. **(5)**

Question 2: (24marks)

2.1 The figure below shows the first five peaks of the x-ray diffraction pattern for tungsten (W), which has a BCC crystal structure; monochromatic x-radiation having a wavelength of 0.1542 nm was used. For the labelled peaks,

a) Determine the interplanar spacing for each of the peaks. **(6)**

b) For each peak, determine the atomic radius **(6)**



2.2 Tabulate the main differences between a SEM and TEM. **(6)**

2.3 If the effective area of the raster of an electron microscope specimen, supplying information to the CRT of an electron microscope, has a 5nm diameter and the semicone angle, α, of the electron beam is 0.01 rad.:

a) What would be the maximum usable magnification of the microscope if a digital spot on the screen of the CRT has a 100 μm diameter? **(2)**

b) What would be the depth of field at this magnification? **(2)**

c) What would be the depth of field if this microscope were to be operated at a magnification of 2000X? **(2)**

Question 3: (33 marks)

3.1 Define diffusion and discuss factors affection diffusion**.** **(5)**

3.2 The diffusion coefficients for nickel in iron are given at two temperatures: At 1200ºC = 2.2×10^{-15} m^2/s and at 1400ºC = 4.8×10^{-14} m^2/s

a) Determine the values of Do and the activation energy Qd. **(8)**

b) What is the magnitude of D at 1300ºC **(5)**

3.3 The wear resistance of a steel shaft is to be improved by hardening its surface by increasing the nitrogen content within an outer surface layer as a result of nitrogen diffusion into the steel; the nitrogen is to be supplied from an external nitrogen-rich atmosphere at an elevated and constant temperature. The initial nitrogen content of the steel is 0.0025 wt%, whereas the surface concentration is to be maintained at 0.45 wt%. For this treatment to be effective, a nitrogen content of 0.12 wt% must be established at a position 0.45 mm below the surface. Specify an appropriate heat treatment in terms of temperature and time for a temperature between 475°C and 625°C. **(15)**

Question 4: (25 marks)

4.1 For the solidification of Silver, calculate the critical radius r* if the nucleation is homogeneous. The values for the surface free energy is 0.126J/m^2. **(5)**

4.2 Calculate the number of atoms found in a nucleus of critical size. Assume a lattice parameter of 4.0862 Å for solid silver at its melting temperature. **(5)**

4.3 Your company is currently producing a disk-shaped aluminium casting. 43.5 mm thick and 325 mm in diameter. You believe that by making the cast solidify 15% slower can improve the mechanical properties of the casting and will allow the casting to be lighter. Design the casting to allow this. Assume the mould constant to be 3.014×10^6 s/m^2 for this process and n=2. **(15)**

Question 5: (5 Marks)

Define annealing and list the 3 stages of annealing of metallic materials **(5)**

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APPENDIX

Diffusing Species	*Host Metal*	*$D_0(m^2/s)$*	*$Q_d(J/mol)$*
	Interstitial Diffusion		
C^b	Fe (α or BCC)^a	1.1×10^{-6}	87,400
C^c	Fe (γ or FCC)^a	2.3×10^{-5}	148,000
N^b	Fe (α or BCC)^a	5.0×10^{-7}	77,000
N^c	Fe (γ or FCC)^a	9.1×10^{-5}	168,000
	Self-Diffusion		
Fe^c	Fe (α or BCC)^a	2.8×10^{-4}	251,000
Fe^c	Fe (γ or FCC)^a	5.0×10^{-5}	284,000
Cu^d	Cu (FCC)	2.5×10^{-5}	200,000
Al^c	Al (FCC)	2.3×10^{-4}	144,000
Mg^c	Mg (HCP)	1.5×10^{-4}	136,000
Zn^c	Zn (HCP)	1.5×10^{-5}	94,000
Mo^d	Mo (BCC)	1.8×10^{-4}	461,000
Ni^d	Ni (FCC)	1.9×10^{-4}	285,000
	Interdiffusion (Vacancy)		
Zn^c	Cu (FCC)	2.4×10^{-5}	189,000
Cu^c	Zn (HCP)	2.1×10^{-4}	124,000
Cu^c	Al (FCC)	6.5×10^{-5}	136,000
Mg^c	Al (FCC)	1.2×10^{-4}	130,000
Cu^c	Ni (FCC)	2.7×10^{-5}	256,000
Ni^d	Cu (FCC)	1.9×10^{-4}	230,000

Argument of the Error Function $\frac{x}{2\sqrt{Dt}}$	Value of the Error Function erf $\frac{x}{2\sqrt{Dt}}$
0	0
0.10	0.1125
0.20	0.2227
0.30	0.3286
0.40	0.4284
0.50	0.5205
0.60	0.6039
0.70	0.6778
0.80	0.7421
0.90	0.7969
1.00	0.8427
1.50	0.9661
2.00	0.9953

Characteristics of Selected Elements

Element	Symbol	Atomic Number	Atomic Weight (amu)	Density of Solid, 20°C (g/cm^3)	Crystal Structure, 20°C	Atomic Radius (nm)	Ionic Radius (nm)	Most Common Valence	Melting Point (°C)
Aluminum	Al	13	26.98	2.71	FCC	0.143	0.053	3+	660.4
Argon	Ar	18	39.95	—	—	—	—	Inert	−189.2
Barium	Ba	56	137.33	3.5	BCC	0.217	0.136	2+	725
Beryllium	Be	4	9.012	1.85	HCP	0.114	0.035	2+	1278
Boron	B	5	10.81	2.34	Rhomb.	—	0.023	3+	2300
Bromine	Br	35	79.90	—	—	—	0.196	1−	−7.2
Cadmium	Cd	48	112.41	8.65	HCP	0.149	0.095	2+	321
Calcium	Ca	20	40.08	1.55	FCC	0.197	0.100	2+	839
Carbon	C	6	12.011	2.25	Hex.	0.071	~0.016	4+	(sublimes at 3367)
Cesium	Cs	55	132.91	1.87	BCC	0.265	0.170	1+	28.4
Chlorine	Cl	17	35.45	—	—	—	0.181	1−	−101
Chromium	Cr	24	52.00	7.19	BCC	0.125	0.063	3+	1875
Cobalt	Co	27	58.93	8.9	HCP	0.125	0.072	2+	1495
Copper	Cu	29	63.55	8.94	FCC	0.128	0.096	1+	1085
Fluorine	F	9	19.00	—	—	—	0.133	1−	−220
Gallium	Ga	31	69.72	5.90	Ortho.	0.122	0.062	3+	29.8
Germanium	Ge	32	72.64	5.32	Dia. cubic	0.122	0.053	4+	937
Gold	Au	79	196.97	19.32	FCC	0.144	0.137	1+	1064
Helium	He	2	4.003	—	—	—	—	Inert	−272 (at 26 atm)
Hydrogen	H	1	1.008	—	—	—	0.154	1+	−259
Iodine	I	53	126.91	4.93	Ortho.	0.136	0.220	1−	114
Iron	Fe	26	55.85	7.87	BCC	0.124	0.077	2+	1538
Lead	Pb	82	207.2	11.35	FCC	0.175	0.120	2+	327
Lithium	Li	3	6.94	0.534	BCC	0.152	0.068	1+	181
Magnesium	Mg	12	24.31	1.74	HCP	0.160	0.072	2+	649
Manganese	Mn	25	54.94	7.44	Cubic	0.112	0.067	2+	1244
Mercury	Hg	80	200.59	—	—	—	0.110	2+	−38.8
Molybdenum	Mo	42	95.94	10.22	BCC	0.136	0.070	4+	2617
Neon	Ne	10	20.18	—	—	—	—	Inert	−248.7
Nickel	Ni	28	58.69	8.90	FCC	0.125	0.069	2+	1455
Niobium	Nb	41	92.91	8.57	BCC	0.143	0.069	5+	2468
Nitrogen	N	7	14.007	—	—	—	0.01–0.02	5+	−209.9
Oxygen	O	8	16.00	—	—	—	0.140	2−	−218.4
Phosphorus	P	15	30.97	1.82	Ortho.	0.109	0.035	5+	44.1
Platinum	Pt	78	195.08	21.45	FCC	0.139	0.080	2+	1772
Potassium	K	19	39.10	0.862	BCC	0.231	0.138	1+	63
Silicon	Si	14	28.09	2.33	Dia. cubic	0.118	0.040	4+	1410
Silver	Ag	47	107.87	10.49	FCC	0.144	0.126	1+	962
Sodium	Na	11	22.99	0.971	BCC	0.186	0.102	1+	98
Sulfur	S	16	32.06	2.07	Ortho.	0.106	0.184	2−	113
Tin	Sn	50	118.71	7.27	Tetra.	0.151	0.071	4+	232
Titanium	Ti	22	47.87	4.51	HCP	0.145	0.068	4+	1668
Tungsten	W	74	183.84	19.3	BCC	0.137	0.070	4+	3410
Vanadium	V	23	50.94	6.1	BCC	0.132	0.059	5+	1890
Zinc	Zn	30	65.41	7.13	HCP	0.133	0.074	2+	420
Zirconium	Zr	40	91.22	6.51	HCP	0.159	0.079	4+	1852

Avogadro's number = 6.022×10^{23} atoms/mol

1 nanometer (nm) = 10^{-9} m = 10^{-7} cm = 10 Å

1 angstrom (Å) = 0.1 nm = 10^{-10} m = 10^{-8} cm

$$r^* = \frac{2\sigma_{sl} T_m}{\Delta H_f \Delta T}$$

Table 9-1 Values for freezing temperature, latent heat of fusion, surface energy, and maximum undercooling for selected materials

Material	Freezing Temperature (T_m) (°C)	Heat of Fusion (ΔH_f) (MJ/m^3)	Solid-Liquid Interfacial Energy (σ_{sl}) (J/m^2)	Typical Undercooling for Homogeneous Nucleation (ΔT) (°C)
Ga	30	488	56×10^{-3}	76
Bi	271	543	54×10^{-3}	90
Pb	327	237	33×10^{-3}	80
Ag	962	965	126×10^{-3}	250
Cu	1085	1628	177×10^{-3}	236
Ni	1453	2756	255×10^{-3}	480
Fe	1538	1737	204×10^{-3}	420
NaCl	801			169
CsCl	645			152
H_2O	0			40