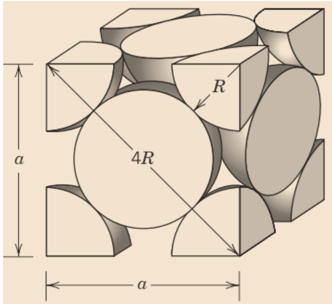
SCHOOL OF MECHANICAL ENGINEERING
CAT – I Paper Key
FALL SEMESTER 2023-2024

SLOT: B1+TB1

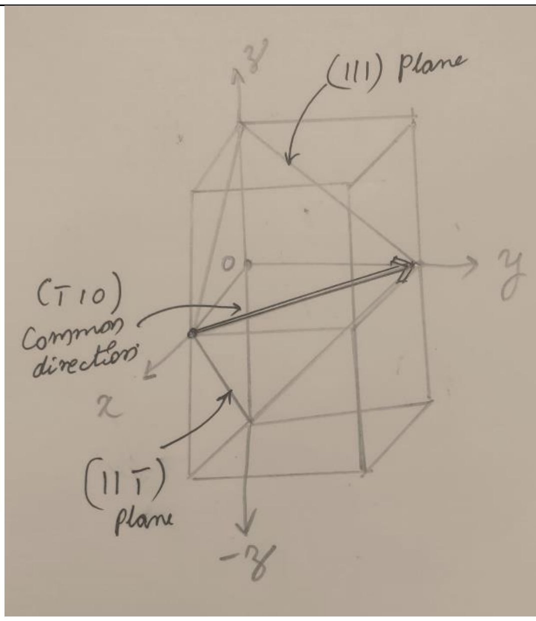
Programme Name & Branch	:	B.Tech. Mechanical Engineering
Course Code	:	BMEE209L
Course Name	:	Materials Science and Engineering CAT1 Key

Exam Duration: 90 minutes **Maximum Marks: 50**

General instruction(s): Answer **all**

Q. No.	Question
1.	(a) Determine the ASTM grain size number if 20 grains per square inch are measured at a magnification of x 300. ***(03 Marks)*** **Solution**: At magnifications other than 100X, use of the following modified form $N_M \left(\frac{M}{100}\right)^2 = 2^{n-1}$ $N_M = 20$; M = 300; n =? $20 \text{ x } (\frac{300}{100})^2 = 2^{n-1}$ $180 = 2^{n-1}$ log 180 = (n-1) log 2 n-1 = log 180 / log 2 n-1 = 7.492 n = 8.492
	(b) Copper an FCC crystal structure, has an atomic radius of 0.128 nm, and an atomic weight of 63.5 g/mol. Compute its theoretical density and compare the answer with its measured density. ***(04 Marks)*** **Solution**: The number of atoms per unit cell (n) for Cu with FCC crystal structure = 4. Atomic weight = 63.5 g/mol. Given, the atomic radius (R) = 0.128 nm Unit cell volume for FCC (V_c) can be determined in terms of R as follows:  $a^2 + a^2 = (4R)^2$ $a = 2R\sqrt{2}$ $V_C = a^3 = (2R\sqrt{2})^3 = 16R^3\sqrt{2}$ The theoretical density can be calculated by the following formula:

	$$\rho = \frac{nA_{\mathrm{Cu}}}{V_C N_{\mathrm{A}}} = \frac{nA_{\mathrm{Cu}}}{(16R^3\sqrt{2})N_{\mathrm{A}}}$$ $$= \frac{(4 \text{ atoms/unit cell})(63.5 \text{ g/mol})}{[16\sqrt{2}(1.28 \times 10^{-8} \text{ cm})^3/\text{unit cell}](6.023 \times 10^{23} \text{ atoms/mol})}$$ $$= 8.89 \text{ g/cm}^3$$ Measured density value for copper is **8.94 g/cm³** as per the literature available. The theoretical density of Cu is in very close agreement with the measured density value.
	(c) What are the traits that can be inferred from the macro and microstructure examination? Explain. ***(03 Marks)*** **Solution:** **Macrostructure examination:** Some structural elements in materials characterization are of macroscopic dimensions. Those elements can be large enough to be observed with the unaided eye. Shape and average size or diameter of the grains for a polycrystalline specimen are important structural characteristics. Example: Macroscopic grains are often evident on Al streetlight posts. **Microscopic examination:** In most materials, the constituent grains are of microscopic dimensions, having diameters that may be on the order of microns, and their details must be investigated using some type of microscope. It is an extremely useful tool in the study and characterization of materials. Some important applications of microstructural examinations are: • To ensure that the associations between the properties and structure (and defects) are properly understood • To predict the properties of materials once these relationships have been established • To design alloys with new property combinations • To determine whether or not a material has been correctly heat treated • To ascertain the mode of mechanical fracture Microstructure of a material can strongly influence properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behaviour or wear resistance of that material. Grain size, GB area, different phases present, different defects present, and the direction/orientation of grains are some major features which can be understood from a macro-microstructure evaluation. These features eventually control the material and mechanical properties of that material.
2.	Find out the direction common to (111) and $(11\bar{1})$ planes by (a) the geometric method and (b) the application of Weiss Zone Law. **Solution:** (a) Geometric Method:

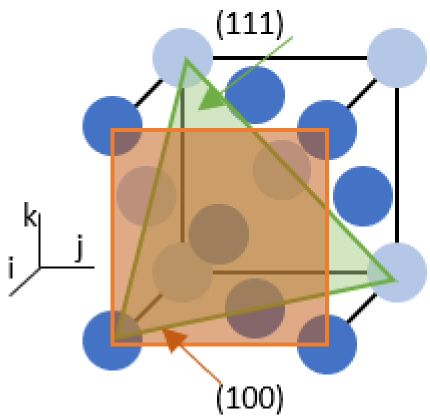


(b) From the ***Weiss Zone Law*** the following rule can be derived:
The direction, **[UVW],** of the intersection of **($h_1k_1l_1$) and ($h_2k_2l_2$)** is given by:
$U = k_1l_2 - k_2l_1$
$V = l_1h_2 - l_2h_1$
$W = h_1k_2 - h_2k_1$
Here **($h_1k_1l_1$) is (111) and ($h_2k_2l_2$) is $(11\bar{1})$**
U =(1*-1) – (1*1) = -1 -1 = -2
V = (1*1) – (-1*1) = 1- -1 = 2
W = (1*1) – (1*1) = 1-1= 0
Hence the resultant direction is **$(\bar{2}\ 2\ 0)$ ~= $(\bar{1}\ 1\ 0)$**

3. (a) Derive planar density expressions for FCC (100) and (111) planes in terms of the atomic radius. ***(06 Marks)***

<u>Solution</u>:

$$PD = \frac{\text{number of atoms centered on a plane}}{\text{area of plane}}$$



For FCC, $a = 2\sqrt{2}R$

For (100): Planar density = $(1+ 4*¼)/ a^2 = 2/ a^2 = 2/ (2\sqrt{2}R)^2 = 1/ 4R^2$ atoms/m^2

	For (111): Planar density = (3* 1/6 + 3 * ½)/ (√3* a^2 /2) = 1/2√3 R^2 atoms/m^2
	b) Why is that cross-slip in BCC and FCC metals much easier than HCP metals? How do these crystal structures influence the mechanical behaviour of metals? ***(04 marks)*** **Solution**: HCP metals have only 3 slip systems with one slip plane and 3 slip directions while BCC metals have at least 12 slip systems with 6 slip planes and 2 slip directions up to 24 slip planes and FCC metals have 12 slip systems with 4 slip planes and 3 slip directions. HCP metals are typically more brittle than FCC and BCC metals because there are fewer slip systems in HCP.
4.	(i) The strength of Ti-6Al-4V alloy is found to be 780 MPa when the grain size is 15 μm and 858 MPa when the grain size is 0.68 μm. Determine (i) the constants in the Hall-Petch equation and (ii) the strength of Ti-6Al-4V alloy when the grain size is reduced to 0.15 μm. ***(06 Marks)*** **Solution**: $\sigma_1 = 780\ MPa, d_1 = 15\mu m$ $\sigma_2 = 858\ MPa, d_2 = 0.68\ \mu m$ *Using Hall Petch Relation for given problem* $\sigma_d = \sigma_0 + kd^{-1/2}$ Using above Hall Petach relation two linear equations developed and then solving those two equations, we can get $\boldsymbol{\sigma_0} =$ **758.90 MPa** and ***k*=81.72 MPa*m$^{1/2}$**. Answer (i) $\boldsymbol{\sigma_d = 758.9 + 81.72\ d^{-1/2}}$ Thus, using final Hall Petch Relation, the strength of Ti6Al4V at grain size 0.15 μm would be **969.9MPa.**
	(ii) Why the phenomenon of slip is complex in poly-crystalline materials? ***(04 marks)*** **Answer:** The slip in materials is caused by dislocation motion. To move the dislocations, certain stresses must be applied to overcome the resistance of the dislocation. Slip occurs when the shear stress applied to the slip direction on the slip surface reaches a certain critical value for single crystal. However, the plastic deformation and slip in polycrystalline materials is even more complex due to additional constrain: Grain boundaries, as across grain boundaries crystallographic orientations are random, which means that the preferred slip system is different, that make dislocation moment more difficult to cross from one to another neighbouring grain.
5.	Discuss the conditions required for the two metallic elements to exhibit unrestricted solid solubility. Explain with an illustration and suitable example. Also determine the degrees of freedom in the alloy containing 60%A and 40%B at 1300°C, 1250°C and 1200°C. Answer:

Solubility and Solid Solutions - Unlimited Solubility

A solid solution is not a mixture.

- A mixture contains more than one type of phase, and the characteristics of each phase are retained when the mixture is formed. In contrast to this, the components of a solid solution completely dissolve in one another and do not retain their individual characteristics.

Conditions for Unlimited Solid Solubility

- In order for an alloy system, such as copper-nickel to have unlimited solid solubility, certain conditions must be satisfied. These conditions, the ***Hume-Rothery rules***

Hume-Rothery rules

The *Hume-Rothery rules*, are as follows:

1. ***Size factor:*** The atoms or ions must be of similar size, with no more than a 15% difference in atomic radius, in order to minimize the lattice strain (i.e., to minimize, at an atomic level, the deviations caused in interatomic spacing).
2. ***Crystal structure:*** The materials must have the same crystal structure; otherwise, there is some point at which a transition occurs from one phase to a second phase with a different structure.
3. ***Valence:*** The ions must have the same valence; otherwise, the valence electron difference encourages the formation of compounds rather than solutions.
4. ***Electronegativity:*** The atoms must have approximately the same electronegativity. Electronegativity is the affinity for electrons. If the electronegativities differ significantly, compounds form—as when sodium and chloride ions combine to form sodium chloride

Depending upon assumption of temperature in respected region, the Degree of Freedom can be obtained by using Gibb's Rule for binary isomorphous equilibrium phase diagram equation i.e.

$$P+F=C+1$$

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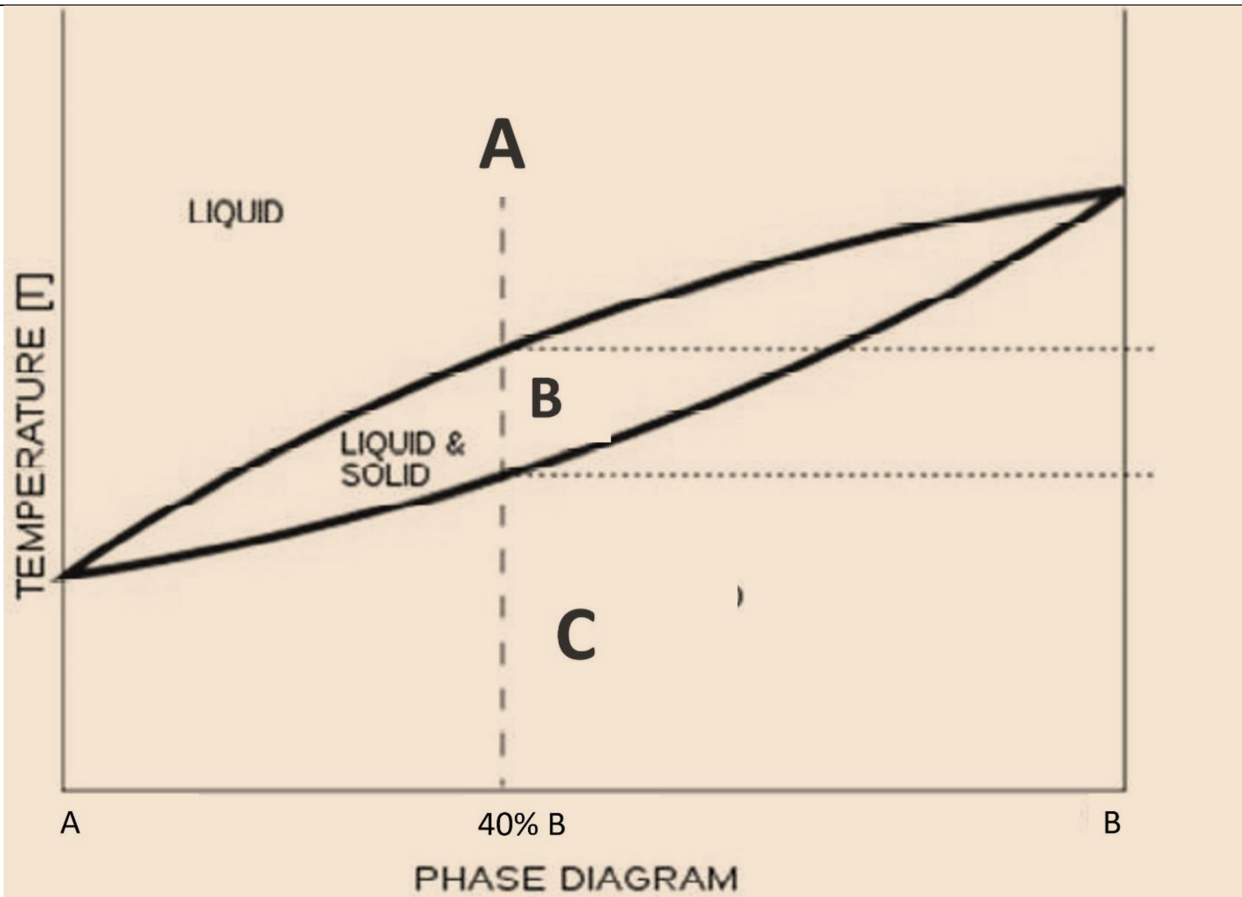

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