L-4/T-2/MME

Date: ~~17/04/2024~~ 18/05/2024

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2021-2022

Sub: **MME 447** (Industrial Metal Working Processes)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **EIGHT** questions in this section. Answer any **SIX**.

1. Envision a scenario where, post-graduation, you become part of a prominent aluminium extrusion facility. Upon observation, identify a significant surge in the force needed for extrusion towards the conclusion of ram travel, leading to the disposal of the remaining billet, resulting in economic inefficiency. In response, your company aims to establish a hydrostatic extrusion facility. However, if, for any reason, hydrostatic extrusion proves impractical, select an alternative extrusion process to eliminate material loss. **(17½)**

2. Instead of conventional assemblies, integral structures machined from thick aluminium plates are used in the airframe of the Airbus A380. In these aluminium alloys, a small amount of Zr is added to enhance the fracture toughness of the thick plates. With relevant microstructure, analyse the effect of heating rate during homogenization on fracture toughness in such Zr-added aluminium alloy plates. **(17½)**

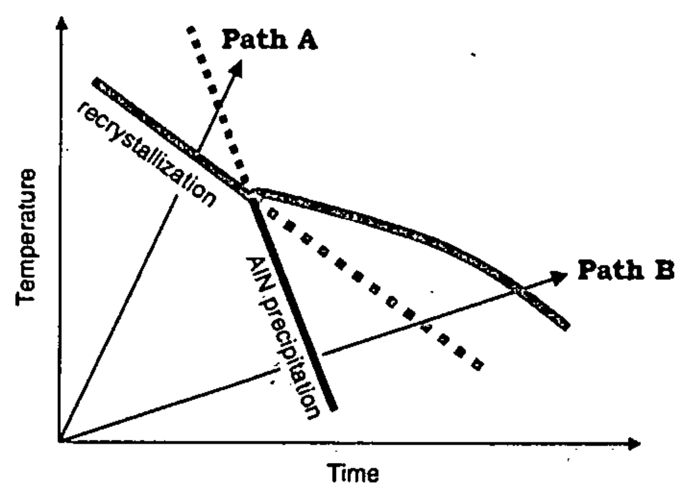
3. Choose an optimal final rolling temperature for the hot rolling process of a 0.2% carbon steel bar with the aim of achieving directional properties. Additionally, illustrate the anticipated final microstructure of the bar. **(17½)**

4. (a) A certain component is currently being hot forged successfully by a manufacturer using material provided by Company A. The manufacturer acquires a fresh batch of material from Company B, which has an identical nominal composition of major alloying elements as the material from Company A. Surprisingly, despite following the same forging procedure as before, the new forgings are experiencing cracks. Identify the probable cause of this issue. **(17½)**

5. Select an extrusion process for a critical part that will be under cyclic loading and explain how your selection will result in better performance under the condition compared to other extrusion processes. **(17½)**

Contd P/2

6. From the given figure, select the most suitable path for reheating towards the recrystallization temperature for texture development in Al-killed low carbon steel. Additionally, explain why the reheating rate is crucial for texture development. (17½)



7. A bloom of cross-sectional area b_1h_1 = 250×200mm is rolled to b_2h_2 = 262×150mm, included angle at neutral point is 20°. If the percentage of forward slip is 10%, determine entry and exit speed of the bloom. Also determine the percentage of backward slip. Other rolling conditions are: working roll dia. = 700mm, rotation of roller = 85rpm and the spread can be neglected. All the symbols have their usual meanings. (17½)

8. For a structural steel part, two rolling schedules are provided- (17½)

Hot rolling of a slab from 220 mm thick into a plate of 20 mm (0.12 wt% C, 1.4 wt% Mn, 0.025 wt% Nb)		
	Conventional	Controlled rolling
Reheating temperature	1200°C	1100°C
Number of passes in roughing mill	9	11
Temperature window for roughing	1100–1000°C	1050–950°C
Thickness after roughing	100 mm	67 mm
Time in between roughing and finishing mill	25 s	250 s
Start finishing rolling	1020–1000°C	800°C

Assuming a T_{NR} of 900°C for this steel, illustrate the final microstructure following both traditional and controlled rolling methods. Furthermore, elucidate the significance of a substantially greater reduction during the roughing pass in controlled rolling in comparison to conventional rolling.

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SECTION – B

There are **EIGHT** questions in this section. Answer any **SIX**.

9. In a tensile test, an annealed steel piece of 13mm diameter, 50mm gauge length, the following results were obtained. Determine the strength coefficient and strain-hardening exponent of the steel and calculate the total work done per unit volume during the tensile test. **(17½)**

Load kN	10	20	30	40	50	60	65
Length mm	50.019	50.0381	50.057	50.070	50.236	50.495	50.699
Load kN	67.5	70	72.1	70.4	68.0	62.3	61.1
Length mm	50.889	51.270	51.515	52.030	52.134	52.181	52.235

10. Analyse the roles that are played by dislocations during the four stages of work hardening of metallic materials. **(17½)**

11. Identify the controlling factors to resist failure during hydroforming and explain their effects on the strain mode and failure mechanism with proper diagram. **(17½)**

12. In case of rolling with smaller diameter rolls, larger diameter back-up rolls are essential- why? A steel strip 185 mm wide, 2.5 mm thick is reduced 25% in a cold rolling mill with 600 mm diameter rolls. Given that the coefficient of friction of the rolls is 0.15 and the mean yield stress of the steel for the reduction is 675 N/mm^2. If the mill runs at 200 rpm, calculate the theoretical power required. Assume reasonable value for any missing data. **(17½)**

13. Distinguish between Recovery and Recrystallization. A steel sample containing 0.2% carbon (C), 0.3% silicon (Si) and 0.6% manganese (Mn) was rolled at 700°C. Was it hot worked or cold worked? Justify your answer and draw the microstructure of the sample after rolling. **(17½)**

14. Design SPD/DB process for a titanium alloy and briefly describe the mechanism of the process. Assess the changes required to design this process for aluminium. **(17½)**

15. What do you understand by Bauschinger Effect? Explain the reasons of this effect. Analyse the influence of the precipitate phase on this effect. **(17½)**

Contd P/4

16. Compare deep drawing and fluid forming. In sheet metal forming processes, various defects as shown in "Figure for Question No. 16" were observed. Discuss possible reasons of formation of these defects. (17½)

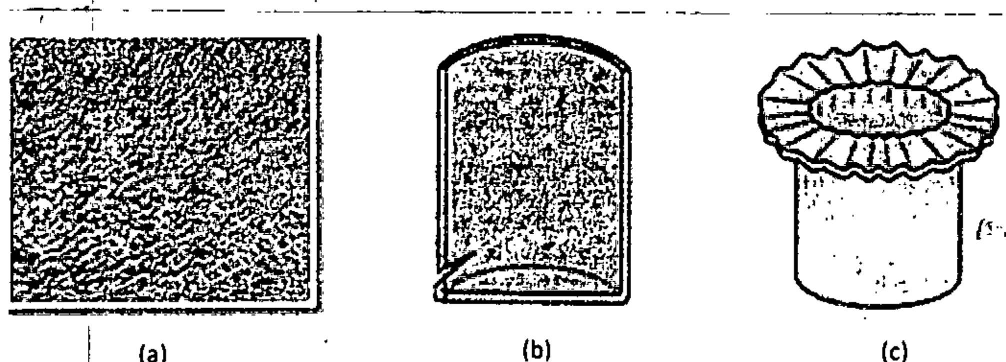

Figure for Question No 16

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BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B.Sc. Engineering Examinations 2021-2022

Sub: **MME 457 (Powder Metallurgy)**

Full Marks: 140 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

1. Suppose for an electronic-mechanical application, you require a magnetic ferrite embedded in a nonferrous, highly conductive metal matrix, surrounded by a metallic/intermetallic hard and wear resistant surface (like tool materials, also called 'hard metal'). The geometry of the hard surface layer and ferrite-metal matrix would be such that, the diffusion of atoms between ferrite and the matrix of hard metal can be considered negligible.

(a) Which conductor metal and which ferrite would you choose, considering electronic configuration for magnetism of ferrite, and reduced tendency of the metal to react with metallic icons in the ferrite? Justify your choice. **$(3\frac{1}{2}+3\frac{1}{2}=7)$**

(b) How would you prepare the ferrite, combine with it conductive metal, and join with the 'hard metal' coating? Justify your choice. What precautions would be required for (presintering, if needed, and) sintering as well as final processing of this material? **$(6+3\frac{1}{3}=9\frac{1}{3})$**

(c) Which would be the matrix of hard metal and hard carbide that would surround the ferrite-metal composite? Remember to keep the matrix of hard metal metallurgically compatible with ferrite-conductive metal matrix. Explain your choice. **$(3\frac{1}{2}\text{ x } 2=7)$**

2. (a) Explain your choice for a possible cermet(s) for high intensity optical and electron emission in a moderate-temperature, slightly oxidizing environment. How can even a slight rise of oxidation in environment can catastrophically destroy metallic component of that cermet? **(5+3=8)**

(b) To prepare a binary amorphous alloy by ball milling, explain the possible science behind picking up the metals from the periodic table. If you are told to prepare such an alloy of readily available metals, which two metals would you choose, and why? What are some contamination and time limitation of your processing, and what can possibly go wrong if you do not pay heed to these limitations? **$(4+3\frac{1}{3}+2\text{x}4 = 15\frac{1}{3})$**

Contd........... P/2

3. For preparing a porous fine-grained tungsten bearing material -

(a) Would you choose sintering processes that enhance surface diffusion, or bulk diffusion? Explain your choice. **($5\frac{1}{3}$)**

(b) Would you resort to any specialized (e.g. liquid-phase) sintering process? Which would be such process and additive (s), if any, and why would you choose that? **(3x2=6)**

(c) What would be your process to prepare such bearing? (Do mention, with proper reason, whether you are using any backing, hard wear-resistant phases or self-lubrication) **(6)**

(d) What would be your choice of sintering atmosphere, and why would you disregard all other choices, including those that are industrially relevant but not suitable for this particular purpose? You may take help form the table below. **(6)**

Iron	Hydrogen, Argon, Exothermic Endothermic gas.	Molybdenum	Hydrogen.
Nickel	Hydrogen, Argon, Exothermic Endothermic gas.	Alnico magnets	Hydrogen.
Copper, Brass, Bronze	Hydrogen, Argon, Exothermic Endothermic gas.	Aluminium	Vacuum.
Cobalt, Tungsten carbide	Hydrogen, Vacuum.	Chromium	Vacuum.
Tungsten	Hydrogen, Argon, Vacuum.	Tantalum	Vacuum, Argon, Helium
Stainless steel	Hydrogen, Argon, Vacuum.	Vanadium	Vacuum
		Gold	Air
		Platinum	Air
		Silver	Air, Hydrogen.

4. Suppose you need to prepare specially grooved rollers through powder metallurgy route for roller hearth of sintering furnace intended to sinter high surface-finish products. The roller would have cylindrical symmetry, locally almost circularly round surface, but variable cross-section to accommodate the shape of product put into furnace. There would be a central symmetric-polygon shaped hole to fit the roller into the axle. The central part of the axle would be polygonal shaped, yet axle edges would be cylindrical-shaped to fit into hearth bearing system.

(a) How would you address tradeoff between hot hardness and thermal shock resistance properties of this roller, if you are told to prefer only one of these properties? Briefly explain your choice. **(5)**

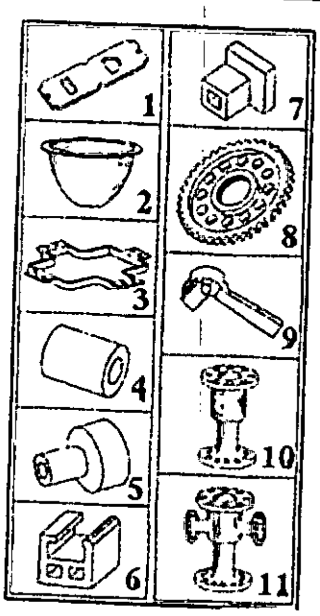
(b) Roughly sketch a longitudinal and a transverse cross-sectional view of the roller as the roller would be used in service, and also sketch these two views as the roller would be shaped for sintering. These two sketches would not be necessarily identical, as there are some shape limitations of PM tooling. Explain the tooling limitations of PM products that you have explicitly taken into account for preparing these sketches. (At least three limitations are sought to be taken into account while drawing the sketches) **(2+2+3=7)**

Contd............ P/3

(c) Considering size-shape, mass, surface finish/tolerance, mechanical properties, environmental impact, what would be production method of your choice? Explain. Also mention proper batch size for this technique. You may use the following tables attached. $(6x1\frac{1}{2}+2\frac{1}{3}=11\frac{1}{3})$

TABLE · Size Range of P/M² Shaping Technologies

shaping process	size range, mm	mass range, g	characteristics
die compaction	1 to 200	1 to 5,000	squat, multiple levels
powder forging	4 to 200	100 to 4,500	chunky, rounded, squat
injection molding	0.1 to 300	0.1 to 200	slender, complex, small
extrusion	1 to 400	10 to 50,000	constant cross-section
slip casting	1 to 500	50 to 50,000	hollow, low precision
tape casting	1 to 300	1 to 300	simple, thin, flat
cold isostatic pressing	5 to 600	100 to 250,000	long, low precision
hot pressing	5 to 300	5 to 10,000	thin, hard to sinter
hot isostatic pressing	5 to 3000	100 to 1,000,000	large, chunky, dense
spray forming	5 to 8000	150 to 120,000	large, thin, imprecise
freeform fabrication	1 to 400	100 to 20,000	complex, low precision



-die compaction, lowest cost: 1 , 7, 8
-powder forged shapes chunky, rounded and squat: 5
-injection moulded shapes, slender, three-dimensional, small and complicated: 3, 9
-extruded shapes, constant cross-section: 4, 6
-slip cast shapes, hollow, large, rounded: 2
-tape cast shapes, flat, thin, constant wall thickness: 1
-cold isostatic pressed and sintered shapes, tubes: 4, 10
-hot pressed components, single-level shapes
-hot isostatically pressed shapes, chunky, poor edge and corner definition: 11
-spray formed shapes, large, hollow, thin-walled: 4
-freeform components produced by laser sintering process, complex shape, low in precision: 6, 7, 9, 10 and 11

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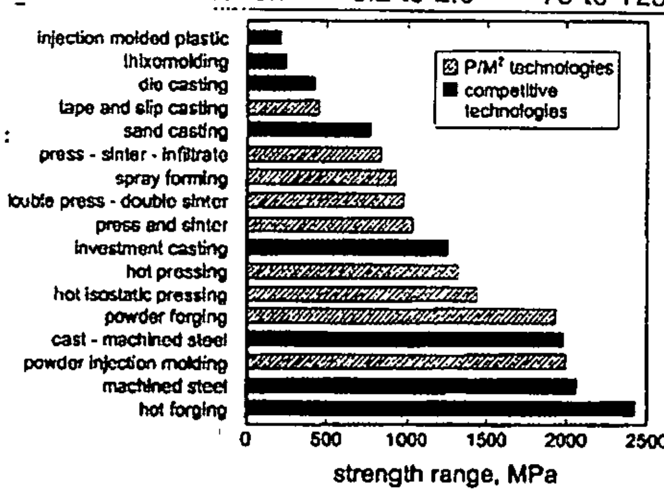
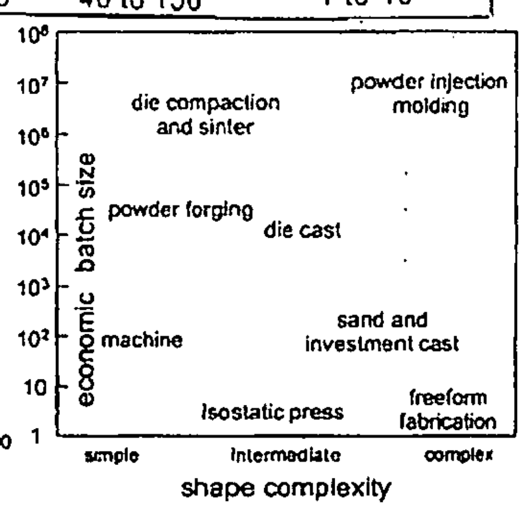
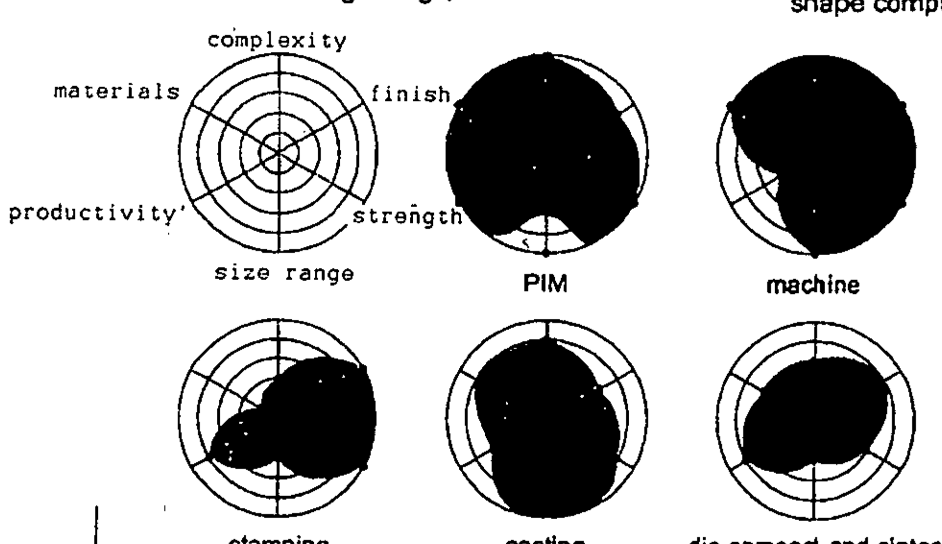
TABLE 2. Tolerances, Surface Finish, Complexity, and Batch Size Ranges

shaping process	tolerance range, %	finish range, μm	complexity range	production quantity range
die compaction	0.1 to 0.3	0.1 to 6	20 to 100	10,000 to 1 billion
powder forging	0.1 to 0.6	0.8 to 3	20 to 50	20,000 to millions
injection molding	0.2 to 0.5	0.4 to 3	20 to 130	20,000 to millions
extrusion	0.5 to 1.0	0.8 to 3	5 to 300	200 to 2 million
slip casting	0.2 to 5.0	10 to 25	20 to 100	10 to 1,000
tape casting	0.1 to 2.0	10 to 25	3 to 10	100 to 1 million
cold isostatic pressing	0.2 to 2.0	2 to 6	10 to 50	1 to 1 million
hot pressing	0.1 to 0.5	1 to 6	5 to 40	100 to 1 million
hot isostatic pressing	0.1 to 2.0	2 to 6	6 to 50	1 to 10,000
spray forming	0.5 to 3.0	10 to 25	5 to 60	1 to 1,000
freeform fabrication	0.2 to 2.0	75 to 125	40 to 150	1 to 10







SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) Mention the basic steps of powder metallurgy. Discuss the applications of this manufacturing technology. **(12)**

   (b) How is the size distribution of powders ranging from 0μm to 300 μm measured? **($5\frac{1}{3}$)**

   (c) Differentiate between apparent density and tap density of powders. **(6)**

6. (a) What is atomization? Mention its advantages. Compare gas atomization and water atomization in respect of atomizing media, powder characteristics, economy and process energy efficiency. **(12)**

   (b) Explain the components shape design for obtaining better quality finished product. **($8\frac{1}{3}$)**

   (c) Suggest a pressing process that is suitable for the compaction of alumina powder. **(3)**

7. (a) What are the major functions of powder compaction? Is it necessary to add binder to the metal/ceramic powder? Explain. **(11)**

   (b) Why is preliminary heat treatment of powder needed before mixing of metallic powders? **($5\frac{1}{3}$)**

   (c) What are the problems associated with mixing? **(7)**

8. With appropriate diagrams, discuss radial and vertical density gradients of isostatically and triaxially compacted iron powder at different levels of confining pressure. **($23\frac{1}{3}$)**

L-4/T-2/MME **Date: 24/03/2024**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2021-2022

Sub: **MME 467** (Ceramics for Advanced Applications)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. We have an oxide with two different types of cation sites, A and B. The A-O-B bonds are 180° degrees. The A-O-A bonds are 90°. There are no B-O-B bonds.

(a) How would you expect the A and B sites to be coupled magnetically? The material has a formula of ABO_2 and a cubic unit cell containing 4 formula units, with a lattice parameter of 0.6 nm. If A is Fe^{2+} and B is Co^{2+}, what would the saturation magnetization be? **(20)**

(b) If the Co^{2+} is replaced with Cu^{2+}, what saturation magnetization would you expect? If the Co^{2+} is replaced with Zn^{2+}, what saturation magnetization would you expect? **(15)**

2. (a) Explain with the help of diagrams what material is used as the storage layer in hard disks? Using sketches, distinguish between a bit in hard discs versus a bit in MRAM. **(15)**

(b) Seagate has recently introduced its first commercial HAMR hard drives allowing capacities of 50TB and beyond. What is the trilemma of ultrahigh density recording media and how does HAMR help solve it? **(15)**

(c) Why do oxides containing Gd have very low anisotropy K_u whereas oxides containing Tb and Dy have high anisotropy? **(5)**

3. (a) You are given a substrate of $Nd_3Ga_5O_{12}$ with orientation (111) that has a lattice parameter of 12.505 Å. With the help of the lattice parameters and the strain data provided in table provided below, design a RE iron garnet thin film that is MOST likely to have out-of-plane magnetic anisotropy. **(20)**

Contd P/2

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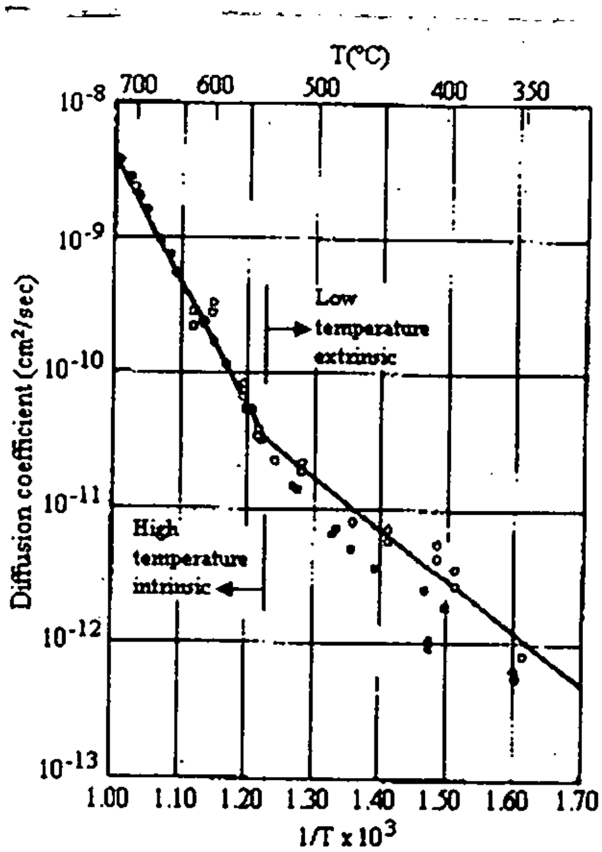
Contd ... Q. No. 3 (a)

RE Element	Lattice parameter Å	λ_{100}@ 300K, 10^{-6}	λ_{111}@ 300K, 10^{-6}
Y	12.376	−1.25	−2.73
Sm	12.530	+21	−8.5
Eu	12.498	+21	+1.8
Gd	12.470	+0.2	−2.9
Tb	12.436	−3.3	+12
Dy	12.405	−12.5	−5.9
Ho	12.375	−4.0	−3.4
Er	12.349	+2	−4.9
Tm	12.325	+1.4	−5.2
Yb	12.302	+1.4	−4.5
Lu	12.283		

(b) How will defect density during film growth by evaporation depend on T_{sor}, T_{sub} and P_{back}? **(15)**

4. The attached figure shows the Arrhenius plot of the diffusion coefficient of Na in NaCl containing a small quantity of $CuCl_2$ (solute). Answer the following questions using data on the fitted line.
[Use $R = 8.314/96500 = 8.615 \times 10^{-5}$ eV/K, $N = 6.02 \times 10^{23}$ atoms/mole, $k = 1.38 \times 10^{-23}$ J/K, density and molecular weight of NaCl are 2.16 g/cm^3 and 58.44 g/mole, respectively, $D_0 = 10^{-2}$ cm^2/s.



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Contd ... Q. No. 4

(a) Write a defect equilibrium reaction for incorporation of $CuCl_2$ as a solute in NaCl. Write general expressions for the diffusion coefficient of Na in the intrinsic and extrinsic regimes. **(15)**

(b) Determine the migration energy from the data. **(10)**

(c) Determine the Schottky defect formation energy from the data. **(10)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Differentiate between sputter deposition and evaporative deposition in terms of the quality of the film. **(15)**

(b) What are the benefits associated with RF sputtering for thin film deposition over DC sputtering? **(10)**

(c) There are some concerns regarding the sputter deposition technique. Illuminate them. **(10)**

6. (a) Interpret the applications of polycrystalline thin films in microsystems. **(15)**

(b) Explain the concept of pseudomorphic strain in film growth and also show the relationship of film thickness with pseudomorphic growth. **(10)**

(c) Schematically illustrate the significance of critical transition temperature of superconductivity. **(10)**

7. (a) Describe the possible polarization mechanisms in a dielectric ceramic material. **(25)**

(b) Mention some device applications utilizing direct and indirect effects of piezoelectric ceramics. **(10)**

8. (a) Compose the defect reactions for the following incidents: **(15)**

(i) Metal loss from ZnO.

(ii) For dissolution of Nb_2O_5 in TiO_2.

(b) A non-stoichiometric oxide $Fe_{1-y}O$ has a lattice parameter of 429 pm and a density of 5.63 g/cm^3. Moreover, $Fe_{1-y}O$ has rock salt structure. **(10)**

(i) Determine the composition of the oxides? (ii) Calculate the density of defects (no. per unit volume). Assume any missing data.

(c) Clarify how defect concentrations are influenced by temperature. **(10)**

Periodic Table, with the Outer Electron Configurations of Neutral Atoms in Their Ground States

The notation used to describe the electronic configuration of atoms and ions is discussed in all textbooks of introductory atomic physics. The letters *s, p, d*, . . . signify electrons having orbital angular momentum 0, 1, 2, . . . in units ħ; the number to the left of the letter denotes the principal quantum number of one orbit, and the superscript to the right denotes the number of electrons in the orbit.

H^{1} $1s$																	He^{2} $1s^2$
Li^{3} $2s$	Be^{4} $2s^2$											B^{5} $2s^22p$	C^{6} $2s^22p^2$	N^{7} $2s^22p^3$	O^{8} $2s^22p^4$	F^{9} $2s^22p^5$	Ne^{10} $2s^22p^6$
Na^{11} $3s$	Mg^{12} $3s^2$											Al^{13} $3s^23p$	Si^{14} $3s^23p^2$	P^{15} $3s^23p^3$	S^{16} $3s^23p^4$	Cl^{17} $3s^23p^5$	Ar^{18} $3s^23p^6$
K^{19} $4s$	Ca^{20} $4s^2$	Sc^{21} $3d$ $4s^2$	Ti^{22} $3d^2$ $4s^2$	V^{23} $3d^3$ $4s^2$	Cr^{24} $3d^5$ $4s$	Mn^{25} $3d^5$ $4s^2$	Fe^{26} $3d^6$ $4s^2$	Co^{27} $3d^7$ $4s^2$	Ni^{28} $3d^8$ $4s^2$	Cu^{29} $3d^{10}$ $4s$	Zn^{30} $3d^{10}$ $4s^2$	Ga^{31} $4s^24p$	Ge^{32} $4s^24p^2$	As^{33} $4s^24p^3$	Se^{34} $4s^24p^4$	Br^{35} $4s^24p^5$	Kr^{36} $4s^24p^6$
Rb^{37} $5s$	Sr^{38} $5s^2$	Y^{39} $4d$ $5s^2$	Zr^{40} $4d^2$ $5s^2$	Nb^{41} $4d^4$ $5s$	Mo^{42} $4d^5$ $5s$	Tc^{43} $4d^6$ $5s$	Ru^{44} $4d^7$ $5s$	Rh^{45} $4d^8$ $5s$	Pd^{46} $4d^{10}$ –	Ag^{47} $4d^{10}$ $5s$	Cd^{48} $4d^{10}$ $5s^2$	In^{49} $5s^25p$	Sn^{50} $5s^25p^2$	Sb^{51} $5s^25p^3$	Te^{52} $5s^25p^4$	I^{53} $5s^25p^5$	Xe^{54} $5s^25p^6$
Cs^{55} $6s$	Ba^{56} $6s^2$	La^{57} $5d$ $6s^2$	Hf^{72} $4f^{14}$ $5d^2$ $6s^2$	Ta^{73} $5d^3$ $6s^2$	W^{74} $5d^4$ $6s^2$	Re^{75} $5d^5$ $6s^2$	Os^{76} $5d^6$ $6s^2$	Ir^{77} $5d^9$ –	Pt^{78} $5d^9$ $6s$	Au^{79} $5d^{10}$ $6s$	Hg^{80} $5d^{10}$ $6s^2$	Tl^{81} $6s^26p$	Pb^{82} $6s^26p^2$	Bi^{83} $6s^26p^3$	Po^{84} $6s^26p^4$	At^{85} $6s^26p^5$	Rn^{86} $6s^26p^6$
Fr^{87} $7s$	Ra^{88} $7s^2$	Ac^{89} $6d$ $7s^2$															

Ce^{58} $4f^2$ $6s^2$	Pr^{59} $4f^3$ $6s^2$	Nd^{60} $4f^4$ $6s^2$	Pm^{61} $4f^5$ $6s^2$	Sm^{62} $4f^6$ $6s^2$	Eu^{63} $4f^7$ $6s^2$	Gd^{64} $4f^7$ $5d$ $6s^2$	Tb^{65} $4f^8$ $5d$ $6s^2$	Dy^{66} $4f^{10}$ $6s^2$	Ho^{67} $4f^{11}$ $6s^2$	Er^{68} $4f^{12}$ $6s^2$	Tm^{69} $4f^{13}$ $6s^2$	Yb^{70} $4f^{14}$ $6s^2$	Lu^{71} $4f^{14}$ $5d$ $6s^2$
Th^{90} – $6d^2$ $7s^2$	Pa^{91} $5f^2$ $6d$ $7s^2$	U^{92} $5f^3$ $6d$ $7s^2$	Np^{93} $5f^4$ $7s^2$	Pu^{94} $5f^6$ $7s^2$	Am^{95} $5f^7$ $7s^2$	Cm^{96} $5f^7$ $6d$ $7s^2$	Bk^{97}	Cf^{98}	Es^{99}	Fm^{100}	Md^{101}	No^{102}	Lr^{103}

Physical Constants, Conversions, and Useful Combinations

Physical Constants	
Avogadro constant	$N_A = 6.022 \times 10^{23}$ particles/mole
Boltzmann constant	$k = 8.617 \times 10^{-5}$ eV/K $= 1.38 \times 10^{-23}$ J/K
Elementary charge	$e = 1.602 \times 10^{-19}$ coulomb
Planck constant	$h = 4.136 \times 10^{-15}$ eV · s
	$= 6.626 \times 10^{-34}$ joule · s
Speed of light	$c = 2.998 \times 10^{10}$ cm/s
Permittivity (free space)	$\epsilon_0 = 8.85 \times 10^{-14}$ farad/cm
Electron mass	$m = 9.1095 \times 10^{-31}$ kg
Coulomb constant	$k_c = 8.988 \times 10^9$ newton-m^2/(coulomb)^2
Atomic mass unit	$u = 1.6606 \times 10^{-27}$ kg
Permeability of space	$\mu_o = 4\pi\ 10^{-7}$ Henry/m
Useful Combinations	1 μ_B (Bohr magneton) = 9.27 10^{-24} Am^2
Thermal energy (300 K)	$kT = 0.0258$ eV $\simeq 1$ eV/40
Photon energy	$E = 1.24$ eV at $\lambda = 1$ μm
Coulomb constant	$k_c e^2 = 1.44$ eV · nm
Permittivity (Si)	$\epsilon = \epsilon_r \epsilon_0 = 1.05 \times 10^{-12}$ farad/cm
Permittivity (free space)	$\epsilon_0 = 55.3e$/V · μm