INDIAN INSTITUTE OF SCIENCE
BANGALORE - 560012

ENTRANCE TEST FOR ADMISSIONS - 2008

Program : Research
Entrance Paper : Materials Science
Paper Code : MR

Day & Date
SUNDAY, 27TH APRIL 2008

Time
9.00 A.M. TO 12.00 NOON

General Instructions

1. This question paper has two parts (A&B). Answer all the questions from part A. Each question carries one mark. Answer any 10 questions from part B. Each question carries 5 marks.
2. Answers for part A have to be marked in the OMR sheet, while part B should be answered on the answer book provided.
3. For each question, darken the appropriate bubble in the OMR to indicate your answer.
4. Use only HB pencils for darkening the bubble.
5. Darken only one bubble per question. If you darken more than one, the answer will be evaluated as incorrect.
5. In case you wish to change your answer, erase the existing one completely before darkening another bubble.
7. There is no negative marking.

The following physical constants and conversion factors may be of some use:

Planck's constant (h),	=	6.626×10^{-34}	J.s
Electro rest mass (m_e),	=	9.108×10^{-31}	kg
Proton rest mass (m_p),	=	1.673×10^{-27}	kg
Electronic charge (e),	=	1.602×10^{-19}	C
Boltzmann's constant (k_B),	=	1.380×10^{-23}	J/K
Avagadro's number (N_A),	=	6.022×10^{23}	number per mol
Speed of light in vacuum (c),	=	2.998×10^{8}	m/s
Permittivity of free space (ε_o),	=	8.854×10^{-12}	F/m
Permeability of free space(μ_o)	=	$4\pi\times10^{-7}$	H/m
Bohr Magneton (μ_B)	=	9.274×10^{-24}	J/T
1 eV	=	1.602×10^{-19}	J

PART-A

Q1. Which of the following quantities is proportional to the electron density at a point?

(a) The wave function

(b) The square of the wave function

(c) The de Broglie wavelength

(d) The reciprocal of the de Broglie wavelength

Q2. The photoelectric effect is defined by the equation $E = h\nu - W$, where E is the kinetic energy of the electron emitted when electromagnetic radiation of frequency ν is incident on a metal whose work function is W. For metals, W is of the order of

(a) 0.05 eV (b) 0.5 eV (c) 5 eV (d) 50 eV

Q3. The nature of bond between Al (group III A) and N (group VA) in AlN is

(a) Van der Waals (b) ionic

(c) covalent (d) mixed ionic-covalent

Q4. The number of octahedral voids in a three dimensional close packing of spheres is equal to

(a) twice the number of spheres

(b) the number of spheres

(c) 3

(d) 4

Q5. Which one of the following oxides has a close-packed structure of anions with cations occupying all the octahedral voids?

(a) TiO_2 (b) Al_2O_3 (c) MgO (d) $MgAl_2O_4$

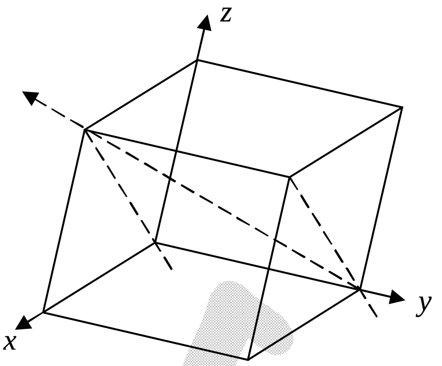
Q6. In the cubic unit cell shown below, the Miller indices of the plane and direction shown by the dashed lines are

(a) $(101)[1\bar{1}1]$

(b) $(\bar{1}01)[1\bar{1}1]$

(c) $(\bar{1}01)[111]$

(d) $(101)[1\bar{1}1]$



Q7. Which one of the following symmetry elements is not possible in crystalline solids exhibiting long range translational symmetry?

(a) Four fold rotational symmetry

(b) Five fold rotational symmetry

(c) Six fold rotational symmetry

(d) Mirror plane

Q8. A FCC material has a density of 8.91 g/cm^3. An amorphous thin film of the same material with a density of 8.55 g/cm^3 will have an average atomic packing factor of

(a) 0.77 (b) 0.74 (c) 0.71 (d) 0.67

Q9. The wavelength of an electron used in a transmission electron microscope is 0.037 ´. To achieve this wavelength the electron needs to be accelerated though a potential of

(a) 0.1 kV (b) 1 kV (c) 10 kV (d) 100 kV

Q10. The Bragg peaks in the powder diffraction pattern of nanocrystalline Cu are broader than that in microcrystalline Cu because

(a) of diffraction from surfaces of the nanocrystalline Cu

(b) destructive interference over a large range of non-Bragg angles is incomplete

(c) destructive interference over a larger range of non-Bragg angels is complete

(d) nanocrystalline Cu is more non-uniformly stressed than microcrystalline Cu

Q11. A material with a FCC unit cell of dimensions a = 0.404 nm is studied by X-ray diffraction using radiation of wavelength 0.154 nm. The Bragg angle in degrees at which the fourth order diffraction from the (100) planes will be observed is

(a) 48.0 (b) 51.1 (c) 50.4 (d) 49.7

Q12. Given the table below,

Characterization Technique	Problem
i. Atomic force microscopy	a. Studying fracture surfaces
ii. Scanning electron microscopy	b. Measuring residual stresses
iii. Transmission electron microscopy	c. Measuring thin film surface roughness
iv. Neutron diffraction	d. Studying dislocations

which one of the following sets best matches the characterization technique with the problem to be tackled?

(a) i-a, ii-b, iii-c, iv-d (b) i-c, ii-b, iii-d, iv-a

(c) i-c, ii-a, iii-d, iv-b (d) i-d, ii-a, iii-b, iv-d

Q13. Intrinsic point defects in crystalline solids

(a) are entropically stabilized

(b) are electrically neutral

(c) have a concentration that is temperature independent

(d) have a concentration that increased with formation energy

Q14. A pure edge dislocation

(a) has a burgers vector that is parallel to the dislocation line

(b) leads to the formation of growth spirals during crystal growth

(c) cannot cross slip

(d) can cross slip

Q15. The equilibrium shape of a single crystal is bound by a surface that has

(a) the least surface energy.
(b) the largest surface energy
(c) zero surface energy
(d) negative surface energy

Q16. For a given material system which of the following would be expected to have the largest specific energy?

(a) Solid-air interface
(b) Low angle grain boundary
(c) High angle grain boundary
(d) A coherent interface with another material

Q17. Diffusion in the direction of increasing concentration

(a) is a violation of Fick's laws.
(b) is a violation of the second law of thermodynamics
(c) can occur if there is an increase in chemical potential in the direction of increasing concentration
(d) can occur if there is a decrease in chemical potential in the direction of increasing concentration

Q18. The maximum number of phases that can co-exist in thermodynamic equilibrium in a ternary system at atmospheric pressure and only subjected to variations in temperature is

(a) 2
(b) 3
(c) 4
(d) 5

Q19. The martensitic transformation is an example of a

(a) massive phase transformation
(b) peritectic reaction
(c) eutectic reaction
(d) diffusionless phase transformation

Q20. Which one of the following is a peritectoid reaction?

(a) $L \rightarrow S_1 + S_2$ (b) $L + S_1 \rightarrow S_2$

(c) $S_3 \rightarrow S_1 + S_2$ (d) $S_3 + S_2 \rightarrow S_1$

Q21. For a solid with isotropic surface energy, supersaturation being the same, the critical radius for heterogenous nucleation is

(a) equal to that for homogenous nucleation

(b) less than that for homogenous nucleation

(c) greater than that for homogenous nucleation

(d) zero

Q22. The rate of heat that is produced per unit area of a liquid-solid growth interface for a solid growing at a rate 'f' and latent heat of fusion 'ΔH' per unit volume is

(a) $\dfrac{f}{\Delta H}$ (b) $f\Delta H$ (c) ΔH (d) $\dfrac{\Delta H}{f}$

Q23. Solid solution formation severely limited if the components

(a) have different crystal structures

(b) have no appreciate difference in electronegativity

(c) have atomic radii differing by more than 15%

(d) have different valency

Q24. For a given species, which one of the following four mechanisms would be expected to have the least activation energy for diffusion?

(a) Bulk diffusion (b) Grain boundary diffusion

(c) Diffusion along dislocations (d) Surface diffusion

Q25. If E_F is the Fermi energy, which statement is not appropriate for the Fermi function $f(E)$ in 0-1000 K range?

(a) $f(E)$ is essentially 1 for $E << E_F$

(b) $f(E)$ is essentially 0 for $E << E_F$

(c) $f(E)$ is 0.5 for $E = E_F$

(d) $f(E)$ is essentially independent of temperature

Q26. Metals are good electrical conductors because

(a) the valence band is partially filled

(b) the conduction band is partially filled

(c) the resistance decreases with decreasing temperature

(d) a small amount of impurity generates a large amount of free electrons

Q27. Which one of the following best describes a *p*-type semiconductor?

(a) A material with empty acceptor levels to which electrons from the valence band may be thermally promoted

(b) A material with electrons in donor levels which may be thermally promoted to the conduction band

(c) A material with no band gap which conducts with little resistance

(d) A material with a sizeable band gap

Q28. To increase the magnetic permeability of iron, it is necessary to

(a) purify it (b) add carbon (c) add cobalt (d) add nickel

Q29. The only element which is antiferromagnetic below the appropriate critical temperature is

(a) Fe (b) Ba (c) Mn (d) Cr

Q30. A transistor made of Si does not work properly above 300^{o} C. This is because

(a) doped Si becomes intrinsic above 300^{o}C

(b) the dopant added to Si evaporates above 300^{o} C

(c) doped Si gets fully oxidized above 300^{o} C

(d) the dopant added to fabricate the transistor lowers the melting point of Si to 300^{o} C

Q31. Diamond single crystal is fully transparent even for UV radiation because its energy gap is

(a) 3.0 eV (b) 4.2 eV (c) 5.6 eV (d) 1.6 eV

Q32. If atomic vibrations were to be harmonic, the heat flux by conduction across a perfect crystal of a dielectric would be

(a) zero

(b) infinite

(c) proportional to the temperature gradient across the crystal

(d) proportional to the temperature difference across the crystal

Q33. Every dipole is cancelled by an equal and opposite dipole in materials belonging to the point group

(a) m (b) 2/m (c) 2 (d) 4 mm

Q34. Electronic polarizability is the chief contributor to the observed dielectric constant in

(a) sodium chloride (b) barium titanate

(c) lithium sulfate (d) diamond

Q35. The number of independent piezoelectric coefficients in Zinc Blende which belongs to the $\bar{4}3m$ crystal class is

(a) 1 (b) 3 (c) 2 (d) 18

Q36. Brittle solids are observed to shatter when quenched from a higher to a lower temperature. This is due to

(a) tensile stresses on the surface (b) compressive stresses on the surface

(c) tensile stresses in the bulk (d) compressive stresses in the bulk

Q37. Slip by dislocation motion is preferred on relatively

(a) densely packed planes and along close packed directions

(b) rarely packed planes and along rarely packed directions

(c) densely packed planes and along rarely packed directions

(d) rarely packed planes and along densely packed directions

Q38. If A, B and C are principal stresses, then which one of the following stress matrices is correct?

(a) $\begin{vmatrix} A & 0 & 0 \\ 0 & B & 0 \\ 0 & 0 & C \end{vmatrix}$ (b) $\begin{vmatrix} A & \tau & \tau \\ \tau & B & \tau \\ \tau & \tau & C \end{vmatrix}$ (c) $\begin{vmatrix} A & \tau & \tau \\ 0 & B & \tau \\ 0 & 0 & C \end{vmatrix}$ (d) $\begin{vmatrix} A & \tau & \tau \\ -\tau & B & \tau \\ -\tau & -\tau & C \end{vmatrix}$

Q39. Beach marks on a fracture surface are a sign of failure by

(a) creep (b) fatigue (c) brittle fracture (d) ductile fracture

Q40. In the Hall-Petch model, hardness increases with a reduction in grain size because grain boundaries

(a) act as sources of dislocations

(b) aid dislocation motion

(c) act as barriers to dislocation motion

(d) act as sinks for dislocations

Q41. The Young's modulus of copper is

(a) 117 Pa (b) 11.7 MPa (c) 117 MPa (d) 117 GPa

Q42. The critical stress intensity factor, K_{IC} for a material is $(\pi)^{1/2}$ MPa-m$^{1/2}$. The critical flaw size when loaded in tension to a stress of 100 MPa is approximately,

(a) 1 mm (b) 100 mm (c) 1 μm (d) 100 μm

Q43. Given the table below,

Processing method	**Product**
i. Combustion synthesis	a. Oxide sputtering targets
ii. Molecular Beam Epitaxy	b. Bulk single crystals
iii. Pressing and sintering	c. Powders with nano sized particles
iv. Czochralski Process	d. Atomic monolayers

Which one of the following sets best matches the processing method with the product desired?

(a) i-c, ii-b, iii-a, iv-d

(b) i-a, ii-d, iii-c, iv-b

(c) i-c, ii-d, iii-a, iv-b

(d) i-c, ii-a, iii-b, iv-d

Q44. A protective oxide is one for which, R the ratio of specific volume of oxide to specific volume of metal is given by

(a) $R << 1$ (b) $2 > R > 3$ (c) $5 > R > 3$ (d) $R > 5$

Q45. The lowering of melting temperature of nanocrystals with reduction in size is due to

(a) quantum size effect

(b) imperfection in the crystal

(c) the coordination number of surface atoms is lower than the interior atoms

(d) surface area is small

Q46. The shape of a C_{60} molecule is

(a) truncated icosahedral

(b) decahedral

(c) either truncated icosahedral or decahedral

(d) neither truncated icosahedral nor decahedral

Q47. The transition from the normal metallic state to the superconducting state is a

(a) zeroth order phase transition

(b) first order phase transition

(c) second order phase transition

(d) metallic glass transition

Q48. Given that i is the square root of -1 ($i = \sqrt{-1}$), the value of i^i is

(a) $e^{i\pi/2}$ (b) $e^{-\pi/2}$ (c) i (d) 1

Q49. The shortest distance of the line $x + y + 1 = 0$ from the origin is

(a) 1 (b) $1/\sqrt{2}$ (c) $\sqrt{3}/2$ (d) 1/2

Q50. In a round robin tennis tournament involving eight players, each player plays every other player twice. The total number of matches played in the tournament is

(a) 48 (b) 56 (c) 49 (d) 64

Part B: answer any 10 questions. Each question carries 5 marks

Q1. The wavefunction (ψ) of an electron in a hydrogen atom can be determined as a function of its radial distance (r) of the electron from the nucleus, and ψ is different for different orbitals (1s, 2s, 2p, etc).

(a) Show a schematic plot of ψ vs. r for the 1s and 2s orbitals.

(b) Show a schematic plot of ψ^2 vs. r for the 2p orbital.

Q2. *Ge* has a diamond cubic structure with a cell constant of 0.565 nm. Its density at room temperature is 5.36×10^3 kg/m^3. Calculate its atomic volume and the nearest neighbour distance.

Q3. Derive expressions for the structure factor of a crystal with

(a) FCC structure

(b) BCC structure

(c) NaCl structure

Q4. Derive an expression for the critical radius for homogenous nucleation of a liquid from a vapour phase. What is the assumption made about the surface energy for this derivation? Briefly describe the geometrical method that one can use to arrive at the equilibrium shape of crystalline nuclei when such an assumption is not valid.

Q5. Write short notes on:

(a) Zone melting

(b) Kyropoulos method of crystal growth

Q6. Draw a schematic diagram to represent the temperature dependence of diffusivity “D”. Explain in brief the significance of the slope and the intercept on the diffusivity axis. Why would a doped oxide prone to forming Schottky defects, exhibit a kink in its oxygen ion diffusivity corresponding to an increase in slope with temperature?

Q7. The magnetization density (M) and the heat capacity (C_p) of a ferromagnetic material are found to vary with temperature (T) as it is raised from 0 K to the Curie temperature T_c and beyond.

(a) Draw a schematic diagram of

(i) M vs T and

(ii) Cp vs T.

(b) How does M vary with temperature in a ferromagnetic material?

Q8. How does the resistivity of a metal vary with temperature? If the resistivity is 25×10^{-9} Ωm at 20^o C and the temperature coefficient is 0.003 $(^oC)^{-1}$, what is the resistivity of the metal at 300^o C?

Q9. Justify why materials belonging to the following crystal classes are ferroelectric and linear electro-optic.

(a) *mm*2

(b) 4*mm*

Q10. Write short notes on:

(a) Electro-optic light modulators and

(b) Quantum well lasers.

Q11. A *Si* step junction maintained at room temperature under equilibrium conditions has a *p*-side doping density of $N_A = 2 \times 10^{15}$ / cm^3 and an *n*-side doping density of $N_D = 10^{15}$ / cm^3. Assuming $n_i = 10^{10}$ / cm^3 at 300 K, $\varepsilon_s = 1.04 \times 10^{-12}$ F/cm, compute:

(a) the barrier height and

(b) the total depletion width

Q12 *Si*-*Ge* alloys are used in current computer chips. If a *Si*-*Ge* alloy is deposited epitaxially on a single crystal *Si* substrate it is stressed.

(a) What is the source of this stress?

(b) Write down an expression for the lattice parameter of a $Si_xGe_{(I-x)}$ solid solution.

(c) Write down an expression for the strain in an unrelaxed thin $Si_xGe_{(I-x)}$ film on *Si*.

(d) The lattice parameters of *Si* and *Ge* are 0.54306 and 0.56574 nm respectively. Calculate the stress in an epitaxial thin film of $Si_{0.8}Ge_{0.2}$ alloy with a modulus of 173 GPa, deposited on *Si* in the absence of any relaxation.

(e) Will the stress be compressive or tensile?