D PHYSICS

CSIR-NET, GATE, SET, JEST, IIT-JAM, BARC, TIFR

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PHYSICAL SCIENCE

SOLID STATE PHYSICS

Previous Year Questions [Topic-Wise]

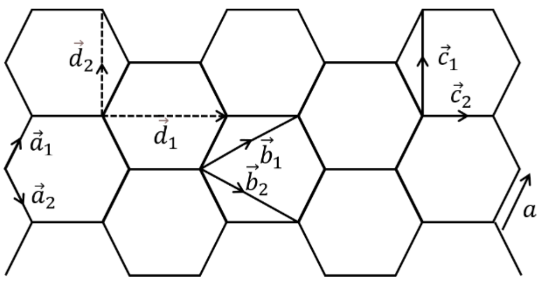
With Answer Key

CSIR-NET/JRF, GATE, JEST, TIFR

❖ **CSIR-NET PYQ's**

1. The two-dimensional lattice of graphene is an arrangement of Carbon atoms forming a honeycomb lattice of lattice spacing a, as shown below. The carbon atoms occupy the vertices.

[CSIR – JUNE 2011]



(A) The Wigner-Seitz cell has an area of

(a) $2a^2$

(b) $\frac{\sqrt{3}}{2}a^2$

(c) $6\sqrt{3}a^2$

(d) $\frac{3\sqrt{3}}{2}a^2$

(B) The Bravais lattice for this array is a

(a) Rectangular lattice with basis vectors $\vec{d}_1$ and $\vec{d}_2$

(b) Rectangular lattice with basis vectors $\vec{c}_1$ and $\vec{c}_2$

(c) Hexagonal lattice with basis vectors $\vec{a}_1$ and $\vec{a}_2$

(d) Hexagonal lattice with basis vectors $\vec{b}_1$ and $\vec{b}_2$

2. Consider the crystal structure of sodium chloride which is modeled as a set of touching spheres. Each sodium atom has a radius r_1 and each chlorine atom has a radius r_2. The centres of the spheres form a simple cubic lattice. The packing fraction of this system is

[CSIR – DEC 2014]

(a) $\pi\left[\left(\frac{r_1}{r_1+r_2}\right)^3+\left(\frac{r_2}{r_1+r_2}\right)^3\right]$

(b) $\frac{2\pi}{3}\frac{r_1^3+r_2^3}{(r_1+r_2)^3}$

(c) $\frac{r_1^3+r_2^3}{(r_1+r_2)^3}$

(d) $\pi\frac{r_1^3+r_2^3}{2(r_1+r_2)^3}$

3. The first order diffraction peak of a crystalline solid occurs at a scattering angle of 30° when the diffraction pattern is recorded using an x-ray beam of wavelength 0.15 nm. If the error in measurements of the wavelength and the angle are 0.01 nm and 1° respectively, then the error in calculating the inter-planar spacing will approximately be

[CSIR – DEC 2015]

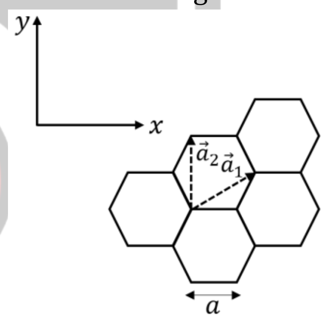
(a) 1.1×10^{-2} nm

(b) 1.3×10^{-4} nm

(c) 2.5×10^{-2} nm

(d) 2.0×10^{-3} nm

4. Consider a hexagonal lattice with basis vectors as shown in the figure below.



If the lattice spacing is $a=1$, the reciprocal lattice vectors are **[CSIR – DEC 2016]**

(a) $\left(\frac{4\pi}{3},0\right),\left(-\frac{2\pi}{3},\frac{2\pi}{\sqrt{3}}\right)$

(b) $\left(\frac{4\pi}{3},0\right),\left(\frac{2\pi}{3},\frac{2\pi}{\sqrt{3}}\right)$

(c) $\left(0,\frac{4\pi}{\sqrt{3}}\right),\left(\pi,\frac{2\pi}{\sqrt{3}}\right)$

(d) $\left(\frac{2\pi}{3},\frac{2\pi}{\sqrt{3}}\right),\left(-2\pi,\frac{2\pi}{\sqrt{3}}\right)$

5. A crystal of MnO has NaCl structure. It has a paramagnetic to anti-ferromagnetic transition at 120 K. Below 120 K, the spins within a single [111] plane are parallel but the spins in adjacent [111] planes are anti-parallel. If neutron scattering is used to determine the lattice constants, respectively, d and d', below and above the transition temperature of MnO then

[CSIR – DEC 2017]

(a) $d = \frac{d'}{2}$

(b) $d = \frac{d'}{\sqrt{2}}$

(c) $d = 2d'$

(d) $d = \sqrt{2}d'$

6. Sodium Chloride (NaCl) crystal is a face centred cubic lattice, with a basis consisting of $Na^+$and Cl ions separated by half the body diagonal of a unit cube. Which of the planes corresponding to the Miller indices given below will not give rise to Bragg reflection of X-rays?

[CSIR – JUNE 2018]

(a) (2 2 0)

(b) (2 4 2)

(c) (2 2 1)

(d) (3 1 1)

7. Hard discs of radius R are arranged in a two-dimensional triangular lattice. What is the fractional area occupied by the discs in the closests possible packing?

[CSIR – JUNE 2018]

(a) $\frac{\pi\sqrt{3}}{6}$

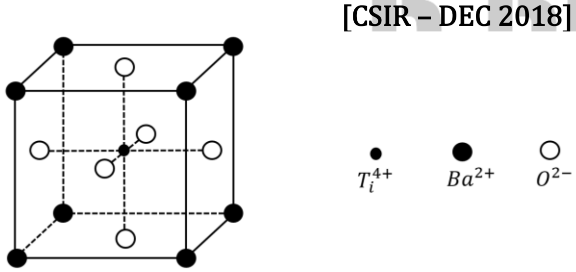
(b) $\frac{\pi}{3\sqrt{2}}$

(c) $\frac{\pi\sqrt{2}}{5}$

(d) $\frac{2\pi}{7}$

8. Barium Titanate ($BaTiO_3$) crystal has a cubic perovskite structure, where the Ba^{2+} ions are at the vertices of a unit cube, the O^{2-} ions are at the centres of the faces while the T^{2+} is at the centre. The number of optical phonon modes of the crystal is

[CSIR – DEC 2018]



(a) 12

(b) 15

(c) 5

(d) 18

9. The third-nearest neighbor distance in a BCC (Body Centered Cubic) crystal with lattice constant a_0 is

[CSIR – JUNE 2019]

(a) a_0

(b) $3a_0/2$

(c) $\sqrt{3}a_0$

(d) $\sqrt{2}a_0$

10. A lattice is defined by the unit vectors

$$\vec{a}_1 = a\hat{\imath}, \vec{a}_2 = -\frac{a}{2}\hat{\imath} + \frac{a\sqrt{3}}{2}\hat{\jmath}$$

and $\vec{a}_3 = a\hat{k}$, where $a > 0$ is a constant. The spacing between the (100) planes of the lattice is

[CSIR – JUNE 2020]

(a) $\sqrt{3}a/2$

(b) $a/2$

(c) a

(d) $\sqrt{2}a$

11. Potassium chloride forms an FCC lattice, in which K and Cl occupy alternating sites. The density of KCl is 1.98 g/cm^3 and the atomic weights of K and Cl are 39.1 and 35.5, respectively. The angles of incidence (in degrees) for which Bragg peaks will appear when X-ray of wavelength 0.4 nm is shone on a KCl crystal are [CSIR – JUNE 2021]

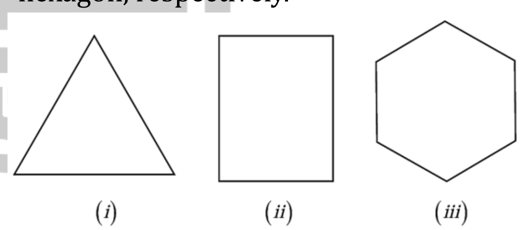
(a) 18.5,39.4 and 72.2

(b) 19.5 and 41.9

(c) 12.5,25.7,40.5 and 60.0

(d)13.5,27.8,44.5 and 69.0

12. The Figures (i), (ii) and (iii) below represent an equilateral triangle, a rectangle and a regular hexagon, respectively.



Which of these can be primitive unit cells of a Bravais lattice in two dimensions?

[CSIR – JUNE 2022]

(a)Only (i) and (iii) but not (ii),

(b)Only (i) and (ii) but not (iii),

(c)Only (ii) and (iii) but not (i),

(d)All of them

13. A lattice A consists of all points in three-dimensional space with coordinates (n_x, n_y, n_z) where n_x, n_y and n_z are integers with $n_x + n_y + n_z$

being odd integers. In another lattice B, $n_x + n_y + n_z$ are even integers. The lattices A and B are

[CSIR – JUNE 2023]

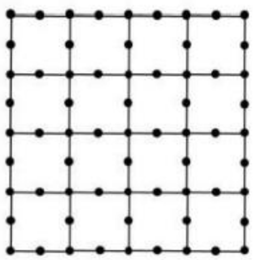
(a) Both BCC

(b) Both FCC

(c) BCC and FCC respectively

(d) FCC and BCC respectively

14. In the section of an infinite lattice shown in the figure below, all sites are occupied by identical hard circular discs so that the resulting structure is tightly packed.



The packing fraction is **[CSIR – DEC 2023]**

(a) $\frac{3\pi}{4}$ (b) $\frac{\pi}{4}$

(c) $\frac{3\pi}{16}$ (d) $\frac{9\pi}{16}$

15. Consider a body-centered tetragonal lattice with lattice constants $a = b = a_0$ and $c = \frac{a_0}{2}$.

The number of nearest neighbors, the nearest neighbor distance, the number of next nearest neighbors and the next nearest neighbor distance, respectively, are

[CSIR JUNE 2024]

(a) $6, \frac{1}{2}a_0, 8, \frac{\sqrt{3}}{2}a_0$ (b) $8, \frac{\sqrt{3}}{2}a_0, 6, a_0$

(c) $2, \frac{1}{2}a_0, 8, \frac{3}{4}a_0$ (d) $8, a_0, 6, \frac{4}{3}a_0$

❖ **GATE PYQ's**

1. The probability that a state which is 0.2eV above the Fermi energy in a metal atom at 700 K is

[GATE 2001]

(a) 96.2% (b) 62.3%

(c) 3.5% (d) 37.7%

2. A narrow beam of electrons, accelerated under a potential difference, incident on a crystal whose grating space is 0.3 nm. If the first diffraction ring is produced at an angle 5.8° from the incident beam, find the momentum of the electrons and the potential difference applied.

[GATE 2001]

3. For an NaCl crystal, the cell-edge $a = 0.563$ nm. The smallest angle at which Bragg reflection can occur corresponds to a set of planes whose incides are

[GATE 2002]

(a) 100 (b) 110

(c) 111 (d) 200

4. Silicon has diamond structure with unit-cell-edge $a = 0.563$ nm. The interatomic separation is

[GATE 2002]

(a) 0.122 nm (b) 0.234 nm

(c) 0.383 nm (d) 0.542 nm

5. If the ionic radii of Mn and S are 0.80 and 0.184 nm respectively, the structure of MnS will be

[GATE 2003]

(a) cubic closed packed

(b) body centered cubic

(c) NaCl type

(d) primitive cubic cell

Data for Q. No. 6 to 7

A crystal belongs to a face centered cubic lattice with four atoms in the unit cell. The size of the crystal is 1 cm and its unit cell dimension is 1 nm. f is the scattering factor of the atom.

6. The number of atoms in the crystal is

[GATE 2003]

(a) 2×10^{21} (b) 4×10^{21}

(c) 2×10^{23} (d) 4×10^{24}

7. The structure factors for $(0 \quad 1 \quad 0)$ and (200) reflections respectively are **[GATE 2003]**

(a) $2f$ and zero (b) zero and $4f$

(c) $2f$ and $2f$ (d) zero and zero

8. The c/a ratio for an ideal hexagonal closed packed structure is

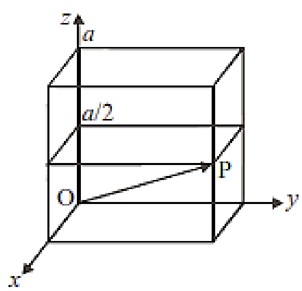
[GATE 2004]

(a) $\frac{2}{\sqrt{3}}$ (b) $\sqrt{8}$

(c) $\sqrt{5}$ (d) $\sqrt{\frac{8}{3}}$

9. In crystallographic notations the vector $\overline{OP}$ in the cubic cell shown in the figure is

[GATE 2005]



(a) [221] (b) [122]

(c) [121] (d) [112]

10. For a closed packed BCC structure of hard spheres, the lattice constant a is related to the sphere radius R as

[GATE 2005]

(a) $a = \frac{4R}{\sqrt{3}}$ (b) $a = 4R\sqrt{3}$

(c) $a = 4R\sqrt{2}$ (d) $a = 2R\sqrt{2}$

11. Which one of the following axes of rotational symmetry is NOT permissible in single crystals?

[GATE 2006]

(a) two-fold axis (b) three-fold axis

(c) four-fold axis (d) five-fold axis

Statement for Linked Answer Q. 12and Q. 13:
The powder diffraction pattern of a body centred cubic crystal is recorded by using CuK_αX-rays of wavelength 1.54Å.

12. If the (002) planes diffract at 60°, then lattice parameter is

[GATE 2006]

(a) 2.67Å (b) 3.08Å

(c) 3.56Å (d) 5.34Å

13. Assuming the atomic mass of the constituent atoms to be 50.94amu, then density of the crystal in units of kg m^{-3} is

[GATE 2006]

(a) 3.75×10^3 (b) 4.45×10^3

(c) 5.79×10^3 (d) 8.89×10^3

14. Consider the atomic packing factor (APF) of the following crystal structures:
P. Simple Cubic
Q. Body Centered Cubic
R. Face Centered Cubic
S. Diamond
T. Hexagonal Close Packed
Which two of the above structures have equal APF? **[GATE 2007]**

(a) P and Q (b) S and T

(c) R and S (d) R and T

15. In a powder diffraction pattern recorded from a face-centered cubic sample using X-rays, the first peak appears at 30°. The second peak will appear at **[GATE 2007]**

(a) 32.8° (b) 33.7°

(c) 34.8° (d) 35.3°

16. The primitive translation vectors of the body Centered cubic lattice are

$$\vec{a} = \frac{a}{2}(\hat{x} + \hat{y} - \hat{z}),$$

$$\vec{b} = \frac{a}{2}(-\hat{x} + \hat{y} + \hat{z})$$

and

$$\vec{c} = \frac{a}{2}(\hat{x} - \hat{y} + \hat{z})$$

The primitive translation vectors $\vec{A}, \vec{B}$ and $\vec{C}$ of the reciprocal lattice are **[GATE 2008]**

(a) $\vec{A} = \frac{2\pi}{a}(\hat{x} - \hat{y}); \vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z}); \vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$

(b) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y}); \vec{B} = \frac{2\pi}{a}(\hat{y} - \hat{z}); \vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$

(c) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y}); \vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z}); \vec{C} = \frac{2\pi}{a}(\hat{x} - \hat{z})$

(d) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y}); \vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z}); \vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$

17. The primitive translation vectors of the fcc reciprocal lattice are **[GATE 2009]**

(a) $\hat{b}_1 = \left(\frac{2\pi}{a}\right)(-\hat{\imath} + \hat{\jmath} + \hat{k}); \hat{b}_2 = \left(\frac{2\pi}{a}\right)(\hat{\imath} - \hat{\jmath} + \hat{k}); \vec{b}_3 = \left(\frac{2\pi}{a}\right)(\hat{\imath} + \hat{\jmath} - \hat{k})$

(b) $\hat{b}_1 = \left(\frac{\pi}{a}\right)(-\hat{\imath} + \hat{\jmath} + \hat{k}); \hat{b}_2 = \left(\frac{\pi}{a}\right)(\hat{\imath} - \hat{\jmath} + \hat{k}); \vec{b}_3 = \left(\frac{\pi}{a}\right)(\hat{\imath} + \hat{\jmath} - \hat{k})$

(c) $\hat{b}_1 = \left(\frac{\pi}{a}\right)(-\hat{\imath} + \hat{\jmath} + \hat{k}); \hat{b}_2 = \left(\frac{2\pi}{a}\right)(\hat{\imath} - \hat{\jmath} + \hat{k}); \vec{b}_3 = \left(\frac{\pi}{a}\right)(\hat{\imath} + \hat{\jmath} - \hat{k})$

(d) $\hat{b}_1 = \left(\frac{3\pi}{a}\right)(-\hat{\imath} + \hat{\jmath} + \hat{k}); \hat{b}_2 = \left(\frac{3\pi}{a}\right)(\hat{\imath} - \hat{\jmath} + \hat{k}); \vec{b}_3 = \left(\frac{3\pi}{a}\right)(\hat{\imath} + \hat{\jmath} - \hat{k})$

18. The volume of the primitive cell of the fcc reciprocal lattice is **[GATE 2009]**

(a) $4\left(\frac{2\pi}{a}\right)^3$ (b) $4\left(\frac{\pi}{a}\right)^3$

(c) $4\left(\frac{\pi}{2a}\right)^3$ (d) $4\left(\frac{3\pi}{a}\right)^3$

19. Consider X-ray diffraction from a crystal with a face-centered-cubic (fcc) lattice. The lattice plane for which there is NO diffraction peak is **[GATE 2010]**

(a) (2,1,2) (b) (1,1,1)

(c) (2,0,0) (d) (3,1,1)

20. A lattice has the following primitive vectors (in $\dot{A}$): $\vec{a} = 2(\hat{\jmath} + \hat{k}), \vec{b} = 2(\hat{k} + \hat{\imath}), \vec{c} = 2(\hat{\imath} + \hat{\jmath})$. The reciprocal lattice corresponding to the above lattice is **[GATE 2013]**

(a) BCC lattice with cube edge of $\left(\frac{\pi}{2}\right)\dot{A}^{-1}$

(b) BCC lattice with cube edge of $(2\pi)\dot{A}^{-1}$

(c) FCC lattice with cube edge of $\left(\frac{\pi}{2}\right)\dot{A}^{-1}$

(d) FCC lattice with cube edge of $(2\pi)\dot{A}^{-1}$

21. The Miller indices of a plane passing through the three points having coordinates

$$(0,0,1), (1,0,0), \left(\frac{1}{2}, \frac{1}{2}, \frac{1}{4}\right)$$

are **[GATE 2014]**

(a) (212) (b) (111)

(c) (121) (d) (211)

22. Neutrons moving with speed 10^3 m/s are used for the determination of crystal structure. If the Bragg angle for the first order diffraction is 30°, the inter-planar spacing of the crystal is_____________ $\dot{A}$. **[GATE 2014]**

23. Atoms, which can be assumed to be hard spheres of radius R, are arranged in an FCC lattice with lattice constant a, such that each atom touches its nearest neighbours. Take the center of one of the atoms as the origin. Another atom of radius r (assumed to be hard sphere) is to be accommodated at a position $(0, a/2, 0)$ without distorting the lattice. The maximum value of r/R is________ (Give your answer upto two decimal places) **[GATE 2016]**

24. The real space primitive lattice vectors are $\vec{a}_1 = a\hat{x}$ and

$$\vec{a}_2 = \frac{a}{2}(\hat{x} + \sqrt{3}\hat{y})$$

. The reciprocal space unit $\vec{b}_1$ and $\vec{b}_2$ for this lattice are, respectively

[GATE 2017]

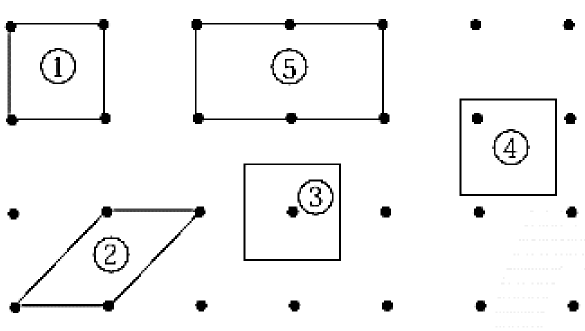
(a) $\frac{2\pi}{a}\left(\hat{x} - \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$

(b) $\frac{2\pi}{a}\left(\hat{x} + \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$

(c) $\frac{2\pi}{a\sqrt{3}}\hat{x}$and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} + \hat{y}\right)$

(d) $\frac{2\pi}{a\sqrt{3}}\hat{x}$and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} - \hat{y}\right)$

25. For the given unit cells of a two dimensional square lattice, which option lists all the primitive cells? **[GATE 2018]**



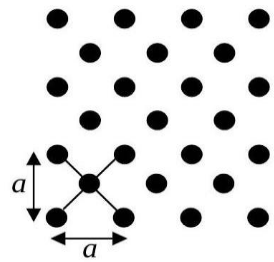
(a) (1) and (2)

(b) (1), (2) and (3)

(c) (1), (2), (3) and (4)

(d) (1), (2), (3), (4) and (5)

26. The number of distinct ways the primitive unit cell can be constructed for the two-dimensional lattice as shown in the figure is



[GATE 2020]

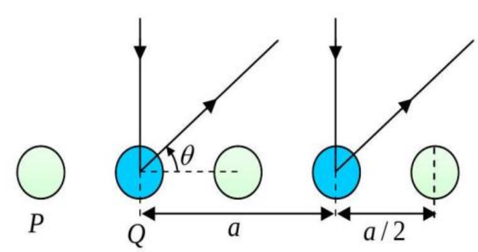
27. Consider a simple cubic monoatomic Bravais lattice which has a basis with vectors

$$\vec{r}_1 = 0, \vec{r}_2 = \frac{a}{4}(\hat{x} + \hat{y} + \hat{z}), a$$

is the lattice parameter. The Bragg reflection is observed due to the change in the wave vector between the incident and the scattered beam as given by $\vec{K} = n_1\vec{G}_1 + n_2\vec{G}_2 + n_3\vec{G}_3$, where $\vec{G}_1, \vec{G}_2$ and $\vec{G}_3$ are primitive reciprocal lattice vectors. For $n_1 = 3, n_2 = 3$ and $n_3 = 2$, the geometrical structure factor is

[GATE 2020]

28. As shown in the figure, X - ray diffraction pattern is obtained from a diatomic chain of atoms P and Q. The diffraction condition is given by $a\cos\theta = n\lambda$, where n is the order of the diffraction peak. Here, a is the lattice constant and λ is the wavelength of the X - rays. Assume that atomic form factors and resolution of the instrument do not depend on θ. Then, the intensity of the diffraction peaks is **[GATE 2021]**



(a) Lower for even values of n, when compared to odd values of n

(b) Lower for odd values of n, when compared to even values of n

(d) Zero for odd values of n

(a) Zero for even values of n

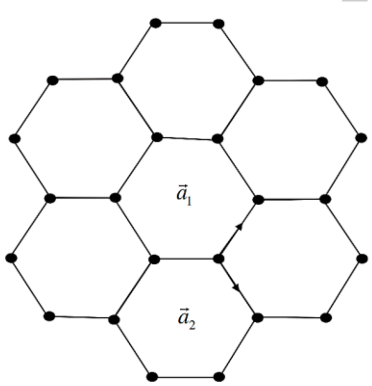
29. In an X-Ray diffraction experiment on a solid with FCC structure, five diffraction peaks corresponding to (111), (200), (220), (311) and (222) planes are observed using $1.54 \mathring{A} X$ rays. On using $3 \mathring{A}^{\circ} X$-rays on the same solid, the number of observed peaks will be **[GATE 2022]**

30. A compound consists of three ions X, Y and Z. The Z ions are arranged in an FCC arrangement. The X ions occupy $\frac{1}{6}$ of the tetrahedral voids and the Y ions occupy $\frac{1}{3}$ of the octahedral voids. Which one of the following is the CORRECT chemical formula of the compound? **[GATE 2023]**

(a) XY_2Z_4 (b) XYZ_3

(c) XYZ_2 (d) XYZ_4

31. Graphene is a two dimensional material, in which carbon atoms are arranged in a honeycomb lattice with lattice constant a. As shown in the figure, $\vec{a}_1$ and $\vec{a}_2$ are two lattice vectors. Which one of the following is the area of the first Brillouin zone for this lattice? **[GATE 2023]**



(a) $\frac{8\pi^2}{3\sqrt{3}a^2}$ (b) $\frac{4\pi^2}{3\sqrt{3}a^2}$

(c) $\frac{8\pi^2}{\sqrt{3}a^2}$ (d) $\frac{4\pi^2}{\sqrt{3}a^2}$

32. A neutron beam with a wave vector $\vec{k}$ and an energy 20.4meV diffracts from a crystal with an outgoing wave vector $\vec{k}'$. One of the diffraction peaks is observed for the reciprocal lattice vector $\vec{G}$ of magnitude $3 \cdot 14 \mathring{A}^{-1}$. What is the diffraction angle in degrees (rounded off to the nearest integer) that $\vec{k}$ makes with the plane? (Use mass of neutron $= 1.67 \times 10^{-27}$Kg) **[GATE 2023]**

(a) 15 (b) 30

(c) 45 (d) 60

33. The X-ray diffraction pattern of a monatomic cubic crystal with rigid spherical atoms of radius 1.56£ shows several Bragg reflections of which the reflection appearing at the lowest 2θ value in from (111) plane. If the wavelength of X -ray used is $0.78\mathring{A}$, Bragg angle (in 2θ, rounded off to one decimal place) corresponding to this reflection and the crystal structure, respectively, are **[GATE 2024]**

(a) 21.6° and body centered cubic

(b) 17.6° and face centered cubic

(c) 10.8° and body centered cubic

(d) 8.8° and face centered cubic

❖ **JEST PYQ's**

1. A beam of **X**-rays is incident on a BCC crystal. If the difference between the incident and scattered wavevectors is $\vec{K} = hx + ky + \hat{z}$ where $x, y, \hat{z}$ are the unit vectors of the associated cubic lattice, the necessary condition for the scattered beam to give a Laue maximum is **[JEST 2012]**

(a) $h + k + l =$ even (b) $h = k = l$

(c) h, k, l are all distinct (d) $h + k + l =$ odd

2. The second order maximum in the diffraction of X-rays of 0.20 nanometer wavelength from a simple cubic crystal is found to occur at an angle of thirty degrees of the crystal plane. The distance between the lattice planes is **[JEST 2012]**

(a) 1 Angstrom (b) 2 Angstrom

(c) 4 Angstrom (d) 8 Angstrom

3. A metal suffers a structural phase transition form face-centred cubic (FCC) to the simple cubic (SC) structure. It is observed that this phase transition does not involve any change of volume. The nearest neighbor distances d_{fc} and d_{SC} for the FCC and the SC structures respectively are in the ratio (d_{fc}/d_{SC}) [Given $2^{1/3} = 1.26$]

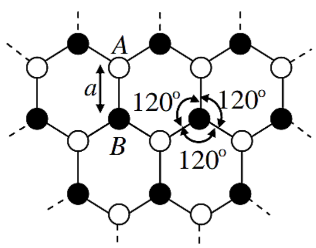
[JEST 2013]

(a) 1.029 (b) 1.122

(c) 1.374 (d) 1.130

4. For a 2-dimensional honeycomb lattice as shown in the figure 3, the first Bragg spot occurs for the grazing angle θ_1 while sweeping the angle from 0°. The next Bragg spot is obtained at θ_2 given by

[JEST 2015]



(a) $\sin^{-1}(3\sin\theta_1)$ (b) $\sin^{-1}\left(\frac{3}{2}\sin\theta_1\right)$

(c) $\sin^{-1}\left(\frac{\sqrt{3}}{2}\sin\theta_1\right)$ (d) $\sin^{-1}(\sqrt{3}\sin\theta_1)$

5. The total number of Na + and Cl-ions per unit cell of NaCl is,

[JEST 2015]

(a) 2 (b) 4

(c) 6 (d) 8

6. The number of different Bravais lattices possible in two dimension is: **[JEST 2016]**

(a) 2 (b) 3

(c) 5 (d) 6

7. If $\vec{k}$ is the wave vector of incident light (

$$|\vec{k}| = \frac{2\pi}{\lambda}, \lambda$$

is the wave length of light) and $\vec{G}$ is a reciprocal lattice vector, then Bragg's law can be written as:

[JEST 2016]

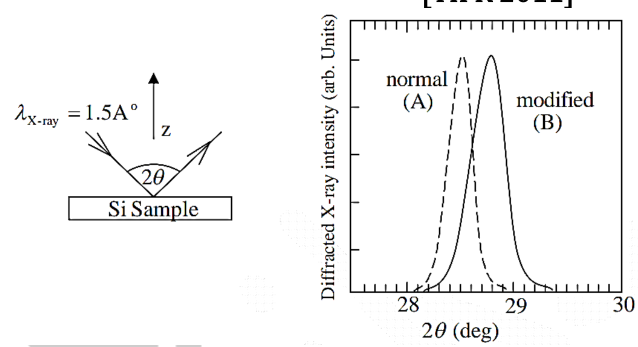
(a) $\vec{k} + \vec{G} = 0$ (b) $2\vec{k}\cdot\vec{G} + G^2 = 0$

(c) $2\vec{k}\cdot\vec{G} + k^2 = 0$ (d) $\vec{k}\cdot\vec{G} = 0$

❖ TIFR PYQ's

1. The figure below shows the Bragg diffraction pattern for X-rays of wavelength 1.54Å incident on two crystalline Silicon thin film Samples A and B. The dashed line corresponds to a normal Sample A and the continuous line corresponds to another Sample B, which is modified due to differences in the growth conditions.

[TIFR 2011]



These plots suggest that the modified sample B is

(a) stretched in all directions by 3%

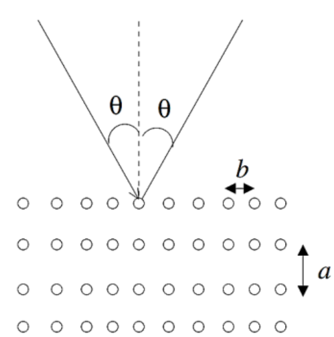
(b) compressed in all directions by 3%

(c) stretched in the z direction by 1% and possibly compressed in $x\&y$ directions

(d) compressed in the z direction by 1% and possibly stretched out in $x\&y$ directions

2. A monochromatic beam of X-rays with wavelength λ is incident at an angle θ on a crystal with lattice spacings a and b as sketched in the figure below. A condition for there to be a maximum in the diffracted X-ray intensity is

[TIFR 2012]



(a) $2\sqrt{a^2+b^2}\sin\theta = \lambda$ (b) $2b\cos\theta = \lambda$

(c) $2a\cos\theta = \lambda$ (d) $(a+b)\sin\theta = \lambda$

3. Metallic Copper is known to form cubic crystals and the lattice constant is measured from X-ray diffraction studies to be about 0.36 nm. If the specific gravity of Copper is 8.96 and its atomic weight is 63.5, one can conclude that

[TIFR 2012]

(a) the crystals are of simple cubic type

(b) the crystals are of b.c.c. type

(c) the crystals are of f.c.c. type

(d) the crystals are a mixture of f.c.c. and b.c.c. types

(e) there is insufficient data to distinguish between the previous options

4. In a simple cubic lattice of lattice constant 0.287 nm, the number of atoms per mm^2 along the 111 plane is

[TIFR 2016]

(a) 2.11×10^{13} (b) 1.73×10^{13}

(c) 1.29×10^{13} (d) 1.21×10^{13}

5. The lattice constant of a material is of the order of a μm, and its bond energies are of the order of an eV. The bulk modulus of such a material, in Pascals, is of the order of

[TIFR 2016]

(a) 10^{-1} (b) 10^{-3}

(c) 10^{-6} (d) 10^{9}

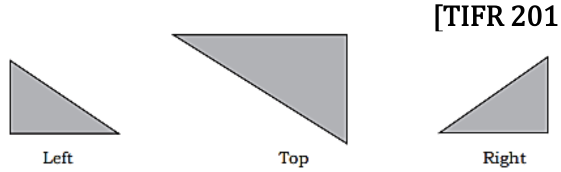
6. Consider a 2-D square lattice. The ratio of the kinetic energy of a free electron at a corner of the first Brillouin zone (E_c) to that of an electron at the midpoint of a side face of the same zone (E_m) is $E_c/E_m =$ **[TIFR 2017]**

(a) 1/2 (b) 2

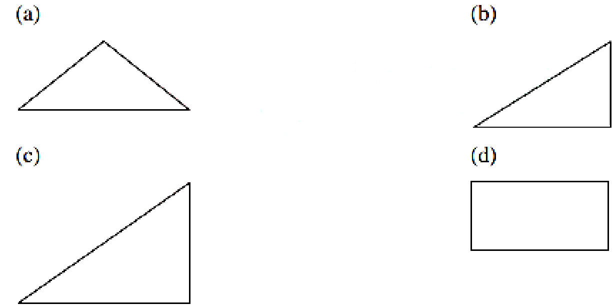
(c) $\sqrt{2}$ (d) 1

7. A solid tetrahedron (solid with four plane sides) has the following projections (drawn to scale) when seen from three different sides:

[TIFR 2017]



When viewed from the front, its projection will be



8. A beam of X-rays is incident upon a powder sample of a material which forms simple cubic crystals of lattice constant 5.5Å. The maximum wavelength of the X-rays which can produce diffraction from the planes with Miller indices (0,0,5) is

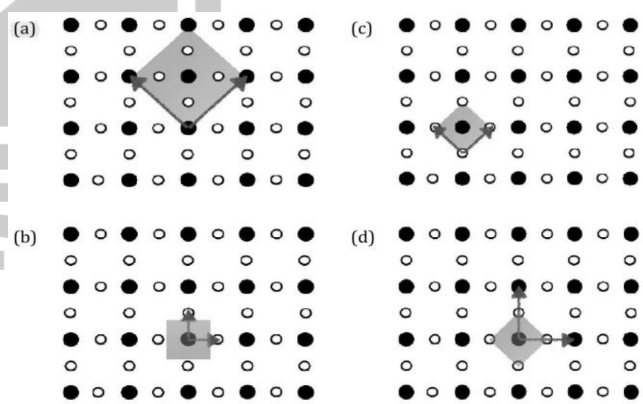
[TIFR 2020]

(a) 2.2Å (b) 55.0Å

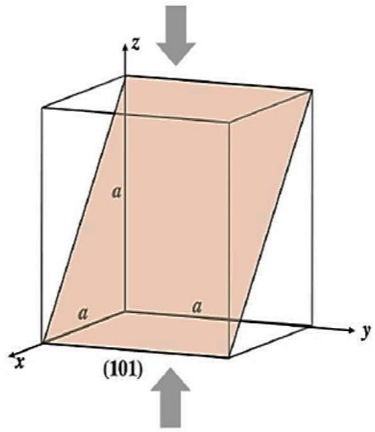
(c) 1.1Å (d) 27.5Å

9. The pictures below are intended to denote a two-dimensional lattice with primitive vectors indicated by arrows and with the unit cell shaded. Which of the following pictures is correct?

[TIFR 2021]



10. An X-ray of wavelength λ, when incident on the (101) plane of a cubic lattice with lattice constant a produces a first-order Bragg's reflection at $\theta = 30°$ (θ is measured from the lattice plane).
Suppose this cubic lattice is compressed along the z axis such that its lattice parameters along the x and y axes remain the same while that along the z axis becomes $\frac{1}{\sqrt{3}}a$ (see figure).

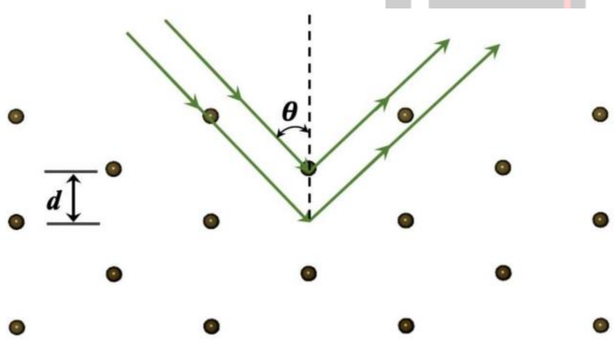


The first-order reflection for the (101) plane of the compressed lattice occurs at: **[TIFR 2023]**

(a) $\theta = 60°$ (b) $\theta = 15°$

(c) $\theta = 30°$ (d) $\theta = 45°$

11. An X-ray of wavelength 3.1Å incident on the (110) plane of a cubic lattice with lattice constant a produces a second-order Bragg reflection at $\theta = 30°$ (θ is the angle measured from normal to the plane as shown in the figure).



What is the value of a ? **[TIFR 2024]**

(a) 5.06Å (b) 8.77Å

(c) 3.58Å (d) 5.46Å

Answer Key				
CSIR-NET				
1. d, c	2. b	3. a	4. a	5. c
6. c	7. a	8. a	9. d	10. a
11. a	12. c	13. b	14. c	15. c
GATE				
1. c	2.	3. a	4. c	5. c
6. b	7. b	8. d	9. a	10. a
11. d	12. c	13. a	14. d	15. d
16. d	17. a	18. a	19. a	20. a
21. a	22. 3.96	23. 0.41	24. a	25. c
26. 5	27.	28. b	29. 1	30. b
31. a	32. b	33. b		
JEST				
1. a	2. c	3. c	4. d	5. d
6. c	7. b			
TIFR				
1. d	2. c	3. c	4. a	5. a
6. b	7. b	8. a	9. a	10. d
11. a				

❖ CSIR -NET PYQ's

1. The potential of a diatomic molecule as a function of the distance r between the atoms is given by

$$V(r) = -\frac{a}{r^6} + \frac{b}{r^{12}}$$

. The value of the potential at equilibrium separation between the atoms is:

[CSIR DEC 2011]

(a) $-4a^2/b$ (b) $-2a^2/b$

(c) $-a^2/2\,b$ (d) $-a^2/4b$

❖ GATE PYQ's

1. The binding energy per molecule of NaCl (lattice parameter is 0.563 nm) is 7.95eV. The repulsive term of the potential is of the form $\frac{K}{r^9}$, where K is a constant. The value of the Madelung constant is______________ (upto three decimal places)

[GATE 2015]

2. Consider a three-dimensional crystal of N inert gas atoms. The total energy is given by $U(R)$

$$= 2N\epsilon\left[p\left(\frac{\sigma}{R}\right)^{12} - q\left(\frac{\sigma}{R}\right)^{6}\right]$$

, where $p = 12.13, q = 14.45$, and R is the nearest neighbour distance between two atoms. The two constants, ϵ and R, have the dimensions of energy and length, respectively. The equilibrium separation between two nearest neighbour atoms in units of σ (rounded off to two decimal places) is **[GATE 2019]**

3. For a covalently bonded solid consisting of ions of mass m, the binding potential can be assumed to

be given by

$$U(r) = -\epsilon\left(\frac{r}{r_0}\right)e^{-\frac{r}{r_0}}$$

, where $\in$ and r_0 are positive constants.

What is the Einstein frequency of the solid in Hz ?

[GATE 2023]

(a) $\frac{1}{2\pi}\sqrt{\frac{\epsilon e}{m r_0^2}}$ (b) $\frac{1}{2\pi}\sqrt{\frac{\epsilon}{m e r_0^2}}$

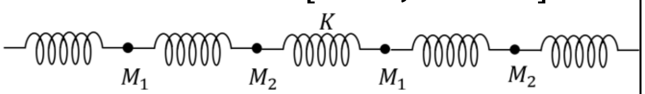
(c) $\frac{1}{2\pi}\sqrt{\frac{2\epsilon}{m e r_0^2}}$ (d) $\frac{1}{2\pi}\sqrt{\frac{\epsilon e}{2 m r_0^2}}$

❖ Answer Key		
CSIR-NET PYQ		
1. d		
GATE PYQ		
1. -1.750	2. 1.07 to 21.11	3. b

❖ CSIR-NET PYQ's

1. The phonon dispersion for the following one-dimensional diatomic lattice with masses M_1 and M_2 (as shown in the figure) is given by where a is the lattice parameter and K is spring constant. The velocity of sound is

[CSIR – JUNE 2013]



(a) $\sqrt{\frac{\mathrm{K}(\mathrm{M}_1+\mathrm{M}_2)}{2\mathrm{M}_1\mathrm{M}_2}}\mathrm{a}$ (b) $\sqrt{\frac{K}{2(M_1+M_2)}}a$

(c) $\sqrt{\frac{K(M_1+M_2)}{M_1M_2}}a$ (d) $\sqrt{\frac{K_1M_1}{2(M_1+M_2)^3}}\mathrm{a}$

2. A uniform linear monoatomic chain is modeled by a spring-mass system of masses m separated by nearest neighbor distance a and spring constant $m\omega_0^2$. The dispersion relation for this system is

[CSIR – DEC 2013]

(a) $\omega(k) = 2\omega_0\left(1-\cos\left(\frac{ka}{2}\right)\right)$

(b) $\omega(k) = 2\omega_0\sin^2\left(\frac{ka}{2}\right)$

(c) $\omega(k) = 2\omega_0\sin\left(\frac{ka}{2}\right)$

(d) $\omega(k) = 2\omega_0\tan\left(\frac{ka}{2}\right)$

❖ GATE PYQ's

1. A cubic cell consists of two atoms of masses m_1 and $m_2(m_1 > m_2)$ with m_1 and m_2 atoms situated on alternate planes. Assuming only nearest neighbor interactions, the centre of mass of the two atoms

[GATE 2003]

(a) moves with the atoms in the optical mode and remains fixed in the acoustic mode

(b) remains fixed in the optical mode and moves with the atoms in the acoustic mode

(c) remains fixed in both optical and acoustic modes

(d) moves with the atoms in both optical and acoustic modes

2. A linear diatomic lattice of lattice constant a with masses M and $m(M > m)$ are coupled by a force constant C. The dispersion relation is given by

$$\omega_{\pm}^2 = C\left(\frac{M+m}{Mm}\right) \pm \left[C^2\left(\frac{M+m}{Mm}\right)^2 - \frac{4C^2}{Mm}\sin^2\frac{ka}{2}\right]^{1/2}$$

Which one of the following statements is incorrect?

[GATE 2008]

(a) The atoms vibrating in transverse mode correspond to the optical branch

(b) The maximum frequency of the acoustic branch depends on the mass of the lighter atom m

(c) The dispersion of frequency in the optical branch is smaller than that in the acoustic branch

(d) No normal modes exist in the acoustic branch for any frequency greater than the maximum frequency at $k = k/a$.

3. The group velocity at the boundary of the first Brillion zone is

[GATE 2012]

(a) 0 (b) 1

(c) $\sqrt{\frac{Aa^2}{2}}$ (d) $\frac{1}{2}\sqrt{\frac{Aa^2}{2}}$

4. The force constant between the nearest neighbor of the lattice is (M is the mass of the atom

[GATE 2012]

(a) $\frac{MA^2}{4}$ (b) $\frac{MA^2}{2}$

(c) MA^2 (d) $2MA^2$

5. A one-dimensional linear chain of atoms contains two types of atoms of masses m_1 and m_2 (where $m_2 > m_1$), arranged alternately. The distance between successive atoms is the same. Assume that the harmonic approximation is valid. At the first Brillouin zone boundary, which of the following statement is correct?

[GATE 2016]

(a) The atoms of mass m_2 are at rest in the optical mode, while they vibrate in the acoustical mod

(b) The atoms of mass m_1 are at rest in the optical mode, while they vibrate in the acoustical mode

(c) Both types of atoms vibrate with equal amplitudes in the optical as well as in the acoustical modes

(d) Both types of atoms vibrate, but with unequal non-zero amplitudes in the optical as well as in the acoustical modes

6. Consider a two-dimensional crystal with 3 atoms in the basis. The number of allowed optical branches (n) and acoustic branches (m) due to the lattice vibrations are

[GATE 2020]

(a) $(n, m) = (2,4)$ (b) $(n, m) = (3,3)$

(c) $(n, m) = (4,2)$ (d) $(n, m) = (1,5)$

7. Apart from the acoustic modes, 9 optical modes are identified from the measurements of photon dispersions of a solid with chemical formula A_nB_m, where A and B denote the atomic species, and n and m are integers. Which of the following combination of n and m is/are possible?

[GATE 2024]

(a) $n = 1, m = 1$ (b) $n = 2, m = 2$

(c) $n = 3, m = 1$ (d) $n = 4, m = 4$

Answer Key

CSIR-NET				
1. b	2. c			
GATE				
1. b	2. b	3. a	4. a	5. a
6. c	7. b,c			

❖ CSIR-NET PYQ's

1. The excitation of a three-dimensional solid are bosonic in nature with their frequency ω and wavenumber k are related by $\omega \propto k^2$ in the large wavelength limit. If the chemical potential is zero, the behaviour of the specific heat of the system at low temperature is proportional to

[CSIR – DEC 2011]

(a) $T^{1/2}$ (b) T

(c) $T^{3/2}$ (d) T^3

2. Consider two crystalline solids, one of which has a simple cubic structure, and the other has a tetragonal structure. The effective spring constant between atoms in the c-direction is half the effective spring constant between atoms in the a and b directions. At low temperatures, the behaviour of the lattice contribution to the specific heat will depend as a function of temperature T aS

[CSIR – DEC 2014]

(a) T^2 for the tetragonal solid, but as T^3 for the simple cubic solid

(b) T for the tetragonal solid and as T^3 for the simple cubic solid

(c) T for both solids

(d) T^3 for both solids

3. The total number of phonon modes in a solid of volume V is $\int_0^{\omega_D} g(\omega)d\omega = 3N$, where N is the number of primitive cells, ω_3 is the Debye frequency and density of photon modes is $g(\omega) = AV\omega^2$ (with $A > 0$ a constant). If the density of the solid doubles in a phase transition, the Debye temperature θ_D will

[CSIR – JUNE 2021]

(a) increase by a factor of $2^{2/3}$

(b) increase by a factor of $2^{1/3}$

(c) decrease by a factor of $2^{2/3}$

(d) decrease by a factor of $2^{1/3}$

❖ GATE PYQ's

1. In simple metals the phonon contribution to the electrical resistivity at temperature T is

[GATE 2003]

(a) directly proportional to T above Debye temperature and to T^3 below it

(b) inversely proportional to T for all temperatures

(c) independent of T for all temperatures

(d) directly proportional to T above Debye temperature and to T^5 below it

2. The number of independent elastic constants in an isotropic cubic solid is

[GATE 2004]

(a) 1 (b) 2

(c) 3 (d) 4

3. The lattice specific heat C of a crystalline solid can be obtained using the Dulong Petit model, Einstein model and Debye model. At low temperature $\hbar\omega > k_B T$, which one of the following statements is true (a and A are constants)

[GATE 2008]

(a) Dulong Petit : $C \propto \exp(-a/T)$; Einstein : C = constant : Debye : $C \propto \left(\frac{T}{A}\right)^3$

(b) Dulong Petit : $C =$ constant ; Einstein : $C \propto \left(\frac{T}{A}\right)^3$; Debye : $C \propto \left(\frac{T}{A}\right)^3$

(c) Dulong Petit : $C =$ constant ; Einstein : $C \propto \frac{e^{-a/T}}{T^2}$; Debye : $C \propto \left(\frac{T}{A}\right)^3$

(d) Dulong Petit : $C \propto \left(\frac{T}{A}\right)^3$; Einstein : $C \propto \frac{e^{-a/T}}{T^2}$; Debye : $C =$ constant

4. A Ge semiconductor is doped with acceptor impurity concentration of 10^{15} atoms $/\text{cm}^3$. For the given hole mobility of $1800\ \text{cm}^2/\text{V}-\text{s}$, the resistivity of this material is

[GATE 2012]

(a) 0.288Ωcm (b) 0.694Ωcm

(c) 3.472Ωcm (d) 6.944Ωcm

5. The energy vs. wave vector $(E-k)$ relationship near the bottom of a band for a solid can be approximated as $E = A(ka)^2 + B(ka)^4$, where the lattice constant $a = 2.1$ A. The values of A and B are $6.3 \times 10^{-19} J$ and $3.2 \times 10^{-20} J$, respectively. At the bottom of the conduction band, the ratio of the effective mass of the electron to the mass of free electron is________ (Give your answer upto two decimal places)
(Take $h = 1.05 \times 10^{-34}$ J − s, mass of free electron $= 9.1 \times 10^{-31}$ kg)

[GATE 2016]

6. In order to estimate the specific heat of phonons, the appropriate method to apply would be

[GATE 2019]

(a) Einstein model for acoustic phonons and Debye model for optical phonons

(b) Einstein model for optical phonons and Debye model for acoustic phonons

(c) Einstein model for both optical and acoustic phonons

(d) Debye model for both optical and acoustic phonons

❖ **JEST PYQ's**

1. The Dulong-Petit law fails near room temperature (300 K) for many light elements (such as boron and beryllium) because their Debye temperature is

[JEST 2012]

(a) $\gg 300$ K (b) ~ 300 K

(c) $\ll 300$ K (d) 0 K

Answer Key				
CSIR-NET				
1. c	2. d	3. b		
GATE				
1. d	2. c	3. c	4. c	5. 0.22
6. b				
JEST				
1. a				

❖ **CSIR-NET PYQ's**

1. Consider electrons in graphene, which is a planar monatomic layer of carbon atoms. If the dispersion relation of the electrons is taken to be $\varepsilon(k) = ck$ (where c is constant). over the entire k-space, then the Fermi energy ε_F depends on the number density of electrons ρ as

[CSIR JUNE 2016]

(a) $\varepsilon_F \propto \rho^{1/2}$ (b) $\varepsilon_F \propto \rho$

(c) $\varepsilon_F \propto \rho^{2/3}$ (d) $\varepsilon_F \propto \rho^{1/3}$

2. The electrons in graphene can be thought of as a two-dimensional gas with a linear energy-momentum relation $E = |\vec{p}|v$, where $\vec{p} = (p_x, p_y)$ and v is a constant. If ρ is the number of electrons per unit area, the energy per unit area is proportional to

[CSIR DEC 2016]

(a) $\rho^{3/2}$ (b) ρ

(c) $\rho^{1/3}$ (d) p^2

3. A metallic nanowire of length l is approximated as a one-dimensional lattice of N atoms with lattice spacing a. If the dispersion of electrons in the lattice is given as $E(k) = E_0 - 2t\cos\, ka$, where E_0 and t are constants, then the density of states inside the nanowire depends on E as

[CSIR DEC 2017]

(a) $N^3\sqrt{\frac{t^2}{E-E_0}}$ (b) $\sqrt{\left(\frac{E-E_0}{2t}\right)^2 - 1}$

(c) $N^3\sqrt{\frac{E-E_0}{t^2}}$ (d) $\frac{N}{\sqrt{(2t)^2-(E-E_0)^2}}$

4. The dispersion relation of optical phonons in a cubic crystal is given by $\omega(k) = \omega_0 - ak^2$, where ω_0 and a are positive constants. The contribution to the density of states due to these phonons with frequencies just below ω_0 is proportional to

[CSIR DEC 2018]

(a) $(\omega_0 - \omega)^{1/2}$ (b) $(\omega_0 - \omega)^{3/2}$

(c) $(\omega_0 - \omega)^2$ (d) $(\omega_0 - \omega)$

5. A tight binding model of electrons in one dimension has the dispersion relation

$\varepsilon(k) = -2t(1 - \cos\, ka)$, where $t > 0, a$ is the lattice constant and

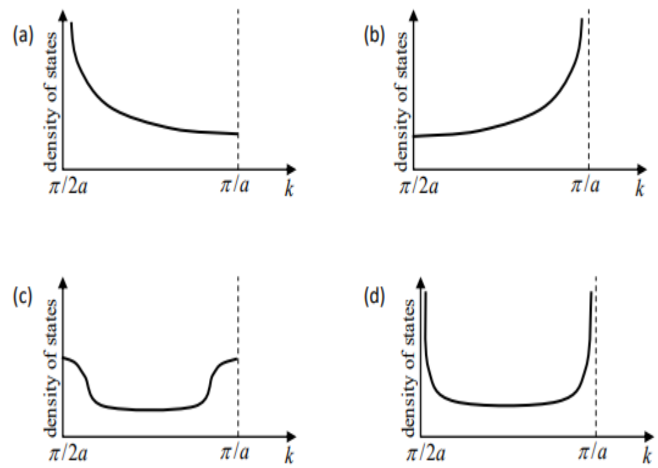
$$-\frac{\pi}{a} < k < \frac{\pi}{a}$$

. Which of the following figures best represents the density of states over the range

$$\frac{\pi}{2a} \le k < \frac{\pi}{a}$$

?

[CSIR JUNE 2020]



❖ **GATE PYQ's**

1. For an energy state E of a photon gas, the density of states is proportional to

[GATE 2001]

(a) $\sqrt{E}$ (b) E

(c) $E^{3/2}$ (d) E^2

2. The energy density of states of an electron in a one-dimensional potential well of infinitely high walls is (the symbols have their usual meaning)

[GATE 2003]

(a) $L\sqrt{m}/[\pi\hbar\sqrt{(2E)}]$ (b) Lm $/(\pi\hbar\sqrt{E})$

(c) Lm $/[\pi\hbar\sqrt{(2E)}]$ (d) $L\sqrt{m}/(2\pi hE)$

3. Density of states of free electrons in a solid moving with an energy 0.1eV is given by $2.15 \times 10^{21}\mathrm{eV}^{-1}\,\mathrm{cm}^{-3}$. The density of states (in $\mathrm{eV}^{-1}\,\mathrm{cm}^{-3}$) for electrons moving with an energy of 0.4eV will be

[GATE 2005]

(a) 1.07×10^{21} (b) 1.52×10^{21}

(c) 3.04×10^{21} (d) 4.30×10^{21}

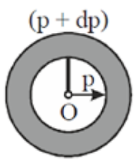
4. The density of states of electrons (including spin degeneracy) in the band is given by **[GATE 2011]**

(a) $\dfrac{L}{\pi\gamma a \sin(ka)}$ (b) $\dfrac{L}{2\pi\gamma a \sin(ka)}$

(c) $\dfrac{L}{2\pi\gamma a \cos(ka)}$ (d) $\dfrac{L}{\pi\gamma a \cos(ka)}$

5. For a free electron gas in two dimensions, the variation of the density of states, $N(E)$ as a function of energy E, is best represented by **[GATE 2014]**

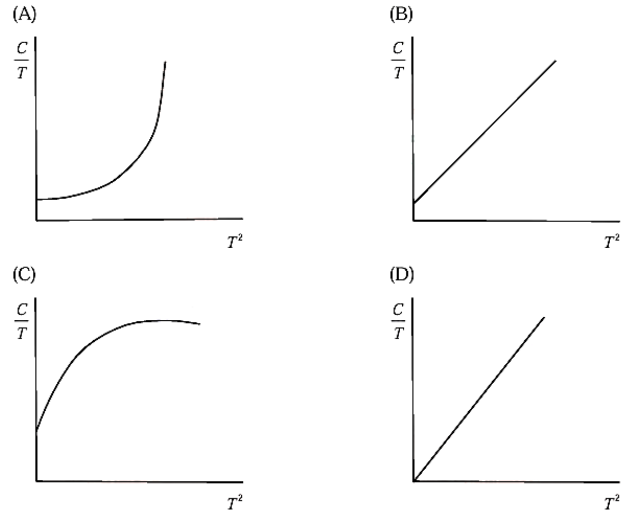
6. The energy dependence of the density of states for a two dimensional non-relativistic electron gas is given by $g(E) = CE^n$, where C is constant. The value of n is___________. **[GATE 2015]**



7. Doubt X is the dimensionality of a free electron gas, the energy (E) dependence of density of states is given by $E^{\frac{1}{2}X-Y}$, where Y is _. **[GATE 2018]**

8. The energy-wavevector $(E-k)$ dispersion relation for a particle in two dimensions is $E = Ck$, where C is a constant. If its density of states $D(E)$ is proportional to E^p then the value of p is **[GATE 2019]**

9. For a non-magnetic metal, which one of the following graphs best represents the behaviour of $\frac{C}{T}$ vs. T^2, where C is the heat capacity and T is the temperature? **[GATE 2023]**



❖ JEST PYQ

1. The ratio of specific heat of electrons in a heated copper wire at two temperatures 200°C and 100°C is **[JEST 2022]**

(a) 1.61 (b) 2

(c) 1.41 (d) 1.27

❖ TIFR PYQ

1. At low temperatures, the measured specific heat C_V of a solid sample is found to depend on temperature as

$$C_V = aT^{3/2} + bT^3$$

where a and b are constants. This material has

(a) one fermionic excitation with dispersion relation $\omega \propto k^4$; another bosonic excitation with dispersion relation $\omega \propto k$

(b) one fermionic excitation with dispersion relation $\omega \propto k^2$; another bosonic excitation with dispersion relation $\omega \propto k^4$

(c) one bosonic excitation with dispersion relation $\omega \propto k^2$; another bosonic excitation with dispersion relation $\omega \propto k$

(d) one fermionic excitation with dispersion relation $\omega \propto k^2$; another fermionic excitation with dispersion relation $\omega \propto k$

Answer Key				
CSIR-NET PYQ				
1. a	2. a	3. d	4. a	5. b
GATE PYQ				
1. d	2. a	3. d	4. b	5. c
6. 0	7. 1	8. 1	9. b	
JEST PYQ				
1. d				
TIFR PYQ				
1. c				

- **CSIR-NET PYQ's**

1. The radius of the Fermi sphere of free electrons in a monovalent metal with an fcc structure, in which the volume of the unit cell is a^3, is

[CSIR – DEC 2012]

(a) $\left(\frac{12\pi^2}{a^3}\right)^{1/3}$ (b) $\left(\frac{3\pi^2}{a^3}\right)^{1/3}$

(c) $\left(\frac{\pi^2}{a^3}\right)^{1/3}$ (d) $\frac{1}{a}$

2. Using the frequency-dependent Drude formula, what is the effective kinetic inductance of a metallic wire that is to be used as a transmission line? [In the following, the electron mass is m, density of electrons is n, and the length and cross-sectional area of the wire are ℓ and A respectively

[CSIR – JUNE 2013]

(a) $\mathrm{mA}/(\mathrm{ne}^2\ell)$ (b) zero

(c) $\mathrm{m}\ell/(\mathrm{ne}^2\,\mathrm{A})$ (d) $\mathrm{m}\sqrt{\mathrm{A}}/(\mathrm{ne}^2\ell^2)$

3. A thin metal film of dimension $2\text{ mm} \times 2\text{ mm}$ contains 4×10^{12} electrons. The magnitude of the Fermi wavevector of the system, in the free electron approximation, is

[CSIR – DEC 2015]

(a) $2\sqrt{\pi} \times 10^7\text{ cm}^{-1}$ (b) $\sqrt{2\pi} \times 10^7\text{ cm}^{-1}$

(c) $\sqrt{\pi} \times 10^7\text{ cm}^{-1}$ (d) $2\pi \times 10^7\text{ cm}^{-1}$

4. Consider electrons in graphene, which is a planar monatomic layer of carbon atoms. If the dispersion relation of the electrons is taken to be $\varepsilon(k) = ck$ (where c is constant). over the entire k-space, then the Fermi energy ε_F depends on the number density of electrons ρ as

[CSIR – JUNE 2016]

(a) $\varepsilon_F \propto \rho^{1/2}$ (b) $\varepsilon_F \propto \rho$

(c) $\varepsilon_F \propto \rho^{2/3}$ (d) $\varepsilon_F \propto \rho^{1/3}$

5. Suppose the frequency of phonons in a one-dimensional chain of atoms is proportional to the wavevector. If n is the number density of atoms and c is the speed of the phonons, then the Debye frequency is

[CSIR – JUNE 2016]

(a) $2\pi cn$ (b) $\sqrt{2}\pi cn$

(c) $\sqrt{3}\pi cn$ (d) $\frac{\pi cn}{2}$

6. Suppose that free charges are present in a material of dielectric constant $\varepsilon = 10$ and resistivity $\rho = 10^{11}\Omega - \text{m}$. Using Ohm's law and the equation of continuity for charge, the time required for the charge density inside the material to decay by $1/e$ is closest to

[CSIR – DEC 2016]

(a) 10^{-6} s (b) 10^6 s

(c) 10^{12} s (d) 10 s

7. The electrical conductivity of copper is approximately 95% of the electrical conductivity of silver, while the electron density in silver is approximately 70% of the electron density in copper. In Drude's model, the approximate ratio $\tau_{\mathrm{Cu}}/\tau_{\mathrm{Ag}}$ of the mean collision time in copper (τ_{Cl}) to the mean collision time in silver (τ_{Ag}) is

[CSIR – JUNE 2017]

(a) 0.44 (b) 1.50

(c) 0.33 (d) 0.66

8. The dispersion relation of a gas of spin $-\frac{1}{2}$ fermions in two dimensions is $E = \hbar v|\vec{k}|$, where E is the energy, $\vec{k}$ is the wave vector and v is a constant with the dimension of velocity. If the Fermi energy at zero temperature is ε_F, the number of particles per unit area is

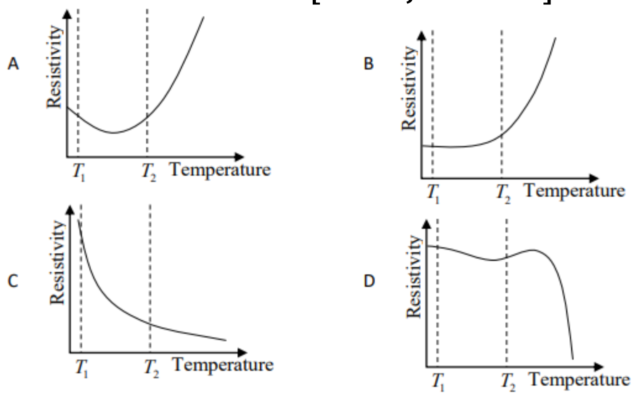
[CSIR – DEC 2017]

(a) $\frac{\varepsilon_F}{(4\pi v\hbar)}$ (b) $\frac{\varepsilon_F^3}{(6\pi^2 v^3\hbar^2)}$

(c) $\frac{\pi\varepsilon_F^{3/2}}{(3v^3\hbar^3)}$ (d) $\frac{\varepsilon_F^2}{(2\pi v^2\hbar^2)}$

9. The temperature variation of the resistivity of four materials are shown in the following graphs.

[CSIR – JUNE 2020]



10. A certain two-dimensional solid crystallizes to a square monoatomic lattice with lattice constant a. Each atom can contribute an integer number of free conduction electrons. The minimum number of electrons each atom must contribute such that the free electron Fermi circle at zero temperature encloses the first Brillouin zone completely, is

[CSIR – JUNE 2020]

(a) 3 (b) 1

(c) 4 (d) 2

11. The lattice constant of the bcc structure of sodium metal is 4.22Å. Assuming the mass of the electron inside the metal to be the same as free electron mass, the free electron Fermi energy is closest to

[CSIR – DEC 2023]

(a)3.2eV (b)2.9Ev

(c)3.5eV (d)2.5eV

❖ **GATE PYQ's**

1. The probability that a state which is 0.2eV above the Fermi energy in a metal atom at 700 K is

[GATE 2001]

(a) 96.2% (b) 62.3%

(c) 3.5% (d) 37.7%

2. The drift mobility (in $m^2\,V^{-1}\,s^{-1}$) of the conduction electrons is

[GATE 2007]

(a) 6.67×10^{-3} (b) 6.67×10^{-6}

(c) 7.63×10^{-3} (d) 7.63×10^{-6}

3. The relaxation time (mean free time), in seconds, of the conduction electrons is

[GATE 2007]

(a) 3.98×10^{-15} (b) 3.79×10^{-14}

(c) 2.84×10^{-12} (d) 2.64×10^{-11}

4. Metallic monovalent sodium crystallizes in body centred cubic structure. If the length of the unit cell is 4×10^{-8} cm, the concentration of conduction electrons in metallic sodium is

[GATE 2008]

(a) $6.022 \times 10^{23}\ \mathrm{cm^{-3}}$ (b) $3.125 \times 10^{22}\ \mathrm{cm^{-3}}$

(c) $2.562 \times 10^{21}\ \mathrm{cm^{-3}}$ (d) $1.250 \times 10^{20}\ \mathrm{cm^{-3}}$

5. The valence electrons do not directly determine the following property of a metal

[GATE 2010]

(a) Electrical conductivity

(b) Thermal conductivity

(c) Shear modulus

(d) Metallic Luster

6. Given that the Fermi energy of gold is 5.54eV, the number density of electrons is (upto one decimal place)

[GATE 2015]

(Mass of electron $= 9.11 \times 10^{-31}$ kg; $h = 6.626 \times 10^{-34}$ J = s; leV $= 1.6 \times 10^{-19}$ J)

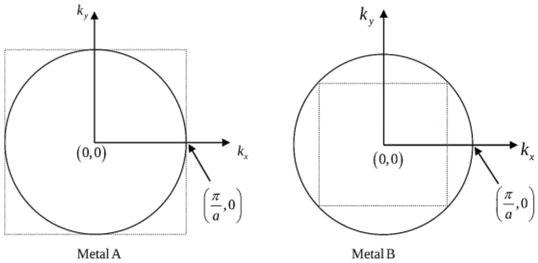
7. Consider a metal which obeys the Sommerfeld model exactly. If E_F is the Fermi energy of the metal at $T = 0K$ and R_H is the Hall coefficient which of the following statements is correct?

[GATE 2016]

8. Consider a 2-dimensional electron gas with a density of $10^{19}\ \mathrm{m^{-2}}$. The Fermi energy of the system is____ eV (up to two decimal places).
($m_e = 9.31 \times 10^{-31}$ kg. $h = 6.626 \times 10^{-34}$Js, $e = 1.602 \times 10^{-19}$C) **[GATE 2017]**

9. The atomic mass and mass density of sodium are 23 and $0.968\ \mathrm{g\,cm^{-3}}$, respectively. The number density of valence electrons is $\times\ 10^{22}\ \text{cm}^{-3}$. (up to two decimal places.) (Avogadro number, $N_A = 6.022 \times 10^{23}$). **[GATE 2017]**

10. Crystal structures of two metals A and B are two-dimensional square lattices with same lattice constant a. Electrons in metals behave as free electrons. The Fermi surfaces corresponding to A and B are shown by solid circles in figures.



The electron concentrations in A and B are n_A and n_B, respectively. The value of $\left(\frac{n_B}{n_A}\right)$ is **[GATE 2024]**

(a) 3 (b) 2

(c) $3\sqrt{3}$ (d) $\sqrt{2}$

❖ **TIFR PYQ**

1. In two dimensions, two metals A and B, have the number density of free electrons in the ratio

$$n_A : n_B = 1 : 2$$

The ratio of their Fermi energies is

[TIFR 2017]

(a) $2:3$ (b) $1:2$

(c) $1:4$ (d) $1:8$

2. Assume that the crystal structure of metallic copper (Cu) results in a density of atoms $\rho_{\text{Cu}} = 8.46 \times 10^{28}\ \text{m}^{-3}$. Each Cu atom in the crystal donates one electron to the conduction band, which leads, for the 3-D Fermi gas, to a density of states

$$g(\varepsilon) = \frac{1}{2\pi^2}\left(\frac{2m^x}{\hbar^2}\right)^{3/2} \varepsilon^{1/2}$$

where m^* is the effective mass of the conduction electrons. In the low temperature limit (i.e. $T = 0\ \text{K}$), find the Fermi energy E_F, in units of eV. You may assume m^* to be equal to the free electron mass m_e.

[TIFR 2017]

Answer Key

CSIR-NET PYQ					
1. a	2. c	3. b	4. a	5. a	6. d
7. d	8. d	9. c	10. c	11. a	
GATE PYQ					
1. c	2. a	3. b	4. b	5. c	6. 1.2
7. 1.2	8. 2.34	9.	10. b		
TIFR PYQ					
1. b	2. 6.87				

GATE Q.9. $2.53 \times 10^{22}\ \text{cm}^{-3}$

❖ **CSIR-NET PYQ's**

1. In a band structure calculation, the dispersion relation for electrons is found to be

$$\varepsilon_k = \beta(\cos k_x a + \cos k_y a + \cos k_z a)$$

where β is a constant and a is the lattice constant. The effective mass at the boundary of the first Brillioun zone is

[CSIR – DEC 2012]

(a) $\frac{2\hbar^2}{5\beta a^2}$ (b) $\frac{4\hbar^2}{5\beta a^2}$

(c) $\frac{\hbar^2}{2\beta a^2}$ (d) $\frac{\hbar^2}{3\beta a^2}$

2. The energy of an electron in a band as a function of its wave vector k is given by $E(k) = E_0 - B(\cos k_x a + \cos k_y a + \cos k_z a)$, where E_0, B and a are constants. The effective mass of the electron near the bottom of the band is

[CSIR – DEC 2013]

(a) $\frac{2\hbar^2}{3Ba^2}$ (b) $\frac{\hbar^2}{3Ba^2}$

(c) $\frac{\hbar^2}{2Ba^2}$ (d) $\frac{\hbar^2}{Ba^2}$

3. The dispersion relation of electrons in a 3-dimensional lattice in the tight binding approximation is given by, $\varepsilon_k = \alpha\cos k_x a + \beta\cos k_y a + \gamma\cos k_z a$ where a is the lattice constant and α, β, γ are constants with dimension of energy. The effective mass tensor at the corner of the first Brillouin zone $\left(\frac{\pi}{a}, \frac{\pi}{a}, \frac{\pi}{a}\right)$ is

[CSIR – DEC 2015]

(a) $\frac{\hbar^2}{a^2}\begin{pmatrix} -\frac{1}{\alpha} & 0 & 0 \\ 0 & -\frac{1}{\beta} & 0 \\ 0 & 0 & \frac{1}{\gamma} \end{pmatrix}$

(b) $\frac{\hbar^2}{a^2}\begin{pmatrix} -\frac{1}{a} & 0 & 0 \\ 0 & -\frac{1}{\beta} & 0 \\ 0 & 0 & -\frac{1}{\gamma} \end{pmatrix}$

(c) $\frac{\hbar^2}{a^2}\begin{pmatrix} \frac{1}{\alpha} & 0 & 0 \\ 0 & \frac{1}{\beta} & 0 \\ 0 & 0 & \frac{1}{\gamma} \end{pmatrix}$

(d) $\frac{\hbar^2}{a^2}\begin{pmatrix} \frac{1}{\alpha} & 0 & 0 \\ 0 & \frac{1}{\beta} & 0 \\ 0 & 0 & -\frac{1}{r} \end{pmatrix}$

4. or an electron moving through a one-dimensional periodic lattice of periodicity a, which of the following corresponds to an energy eigenfunction consistent with Bloch's theorem?

[CSIR – DEC 2015]

(a)$\psi(x) = A\exp\left(i\left[\frac{\pi x}{a} + \cos\left(\frac{\pi x}{2a}\right)\right]\right)$

(b)$\psi(x) = A\exp\left(\left[\frac{\pi x}{a} + \cos\left(\frac{2\pi x}{a}\right)\right]\right)$

(c)$\psi(x) = A\exp\left(i\left[\frac{2\pi x}{a} + i\cosh\left(\frac{2\pi x}{a}\right)\right]\right)$

(d)$\psi(x) = A\exp\left(i\left[\frac{\pi x}{2a} + i\left|\frac{\pi x}{2a}\right|\right]\right)$

5. Consider a one-dimensional chain of atoms with lattice constant a. The energy of an electron with wave-vector k is $\varepsilon(k) = \mu - \gamma\cos(ka)$, where μ and γ are constants. If an electric field E is applied in the positive x-direction, the time dependent velocity of an electron is (in the following B is the constant)

[CSIR – DEC 2016]

(a) proportional to $\cos\left(B - \frac{eE}{\hbar}at\right)$

(b) proportional to E

(c) independent of E

(d) proportional to sin $\left(B - \frac{eE}{\hbar}at\right)$

6. The energy gap and lattice constant of an indirect band gap semiconductor are 1.875eV; 0.52 nm, respectively. For simplicity take the dielectric constant of the material to be unity. When it is excited by broadband radiation, an electron initially in the valence band at $k = 0$ makes a transition to the conduction band. The wavevector of the electron in the conduction band, in terms of the wavevector $k_{\max}$ at the edge of the Brillouin zone, after the transition is closest to

[CSIR – JUNE 2017]

(a) $k_{\max}/10$ (b) $k_{\max}/100$

(c) $k_{\max}^t 1000$ (d) 0

7. The dispersion relation for the electrons in the conduction band of a semiconductor is given by $E = E_0 + \alpha k^2$, where α and E_0 are constants. If ω_c is the cyclotron resonance frequency of the conduction band electrons in a magnetic field B, the value of α is

[CSIR – JUNE 2018]

(a) $\frac{\hbar^2\omega_c}{4eB}$ (b) $\frac{2\hbar^2\omega_c}{eB}$

(c) $\frac{\hbar^2\omega_c}{eB}$ (d) $\frac{\hbar^2\omega_c}{2eB}$

8. The electron cloud (of the outermost electrons) of an ensemble of atoms of atomic number Z is described by a continuous charge density $\rho(r)$ that adjusts itself so that the electrons at the Fermi level have zero energy. If $V(r)$ is the local electrostatic potential, then $\rho(r)$ is

[CSIR – JUNE 2023]

(a) $\frac{e}{3\pi^2\hbar^3}[2m_e eV(r)]^{3/2}$

(b) $\frac{Ze}{3\pi^2\hbar^3}[2m_e eV(r)]^{3/2}$

(c) $\frac{Ze}{3\pi^2\hbar^3}[Zm_e eV(r)]^{3/2}$

(d) $\frac{e}{3\pi^2\hbar^3}[m_e eV(r)]^{3/2}$

❖ **GATE PYQ's**

1. In a one-dimensional Kronig Penny model, the total number of possible wave functions is equal to

[GATE 2002]

(a) twice the number of unit cells

(b) number of unit cells

(c) half the number of unit cells

(d) independent of the number of unit cells

2. Consider the energy E in the first Brillouin zone as a function of the magnitude of the wave vector k for a crystal of lattice constant a. Then

[GATE 2003]

(a) the slope of E versus k is proportional to the group velocity

(b) the slope of E versus k has its maximum value at $|k| = \pi/a$

(c) the plot of E versus k will be parabolic in the interval $(-\pi/a) < k < (\pi/a)$

(d) the slope of E versus k is non-zero for all k the interval $(-\pi/a) < k < (\pi/a)$

3. Which one of the following axes of rotational symmetry is NOT permissible in single crystals?

[GATE 2006]

(a) two-fold axis (b) three-fold axis

(c) four-fold axis (d) five-fold axis

4. The energy $E(\vec{k})$ of electrons of wavevector $\vec{k}$ in a solid is given by $E(\vec{k}) = Ak^2 + Bk^4$, where A and B are constants. The effective mass of the electron at $|\vec{k}| = k_0$ is

[GATE 2006]

(a) Ak_0^2 (b) $\dfrac{\hbar^2}{2A}$

(c) $\dfrac{\hbar^2}{2A+12Bk_0^2}$ (d) $\dfrac{\hbar^2}{Bk_0^2}$

5. Which one of the following statements is NOT correct about the Brillouin zones (BZ) of a square lattices with constant a ?

[GATE 2006]

(a) The first BZ is a square of side $2\pi/a$ in $k_x - k_y$ plane

(b) The areas of the first BZ and third BZ are the same

(c) The k-points are equidistant in k_x as well as in k_y directions

(d) The area of the second BZ is twice that of the first BZ

6. The kinetic energy of a free electron at a corner of the first Brillion zone of a two-dimensional square lattice is larger than that of an electron at the mid-point of a side of the zone by a factor b. The value of b is

[GATE 2008]

(a) $b = \sqrt{2}$ (b) $b = 2$

(c) $b = 4$ (d) $b = 8$

7. The Bloch theorem states that within a crystal, the wave function, $\Psi(\vec{r})$, of an electron has the form

[GATE 2010]

(a) $\Psi(\vec{r}) = u(\vec{r})e^{\vec{k}\cdot\vec{r}}$ where $u(\vec{r})$ is an arbitrary function and $\vec{k}$ is an arbitrary vector

(b) $\Psi(\vec{r}) = u(\vec{r})e^{i\vec{k}\cdot\vec{r}}$ where $u(\vec{r})$ is an arbitrary function and $\vec{G}$ is a reciprocal lattice vector

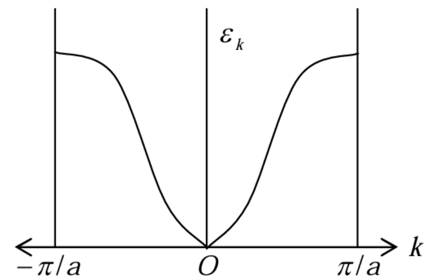
(c) $\Psi(\vec{r}) = u(\vec{r})e^{i\vec{k}\cdot\vec{r}}$ where $u(\vec{r}) = u(\vec{r}+\vec{\Lambda})$, $\vec{\Lambda}$ is a lattice vector and $\vec{G}$ is a reciprocal lattice vector

(d) $\Psi(\vec{r}) = u(\vec{r})e^{i\vec{k}\cdot\vec{r}}$ where $u(\vec{r}) = u(\vec{r}+\vec{\Lambda})$, $\vec{\Lambda}$ is a lattice vector and $\vec{k}$ is an arbitrary vector

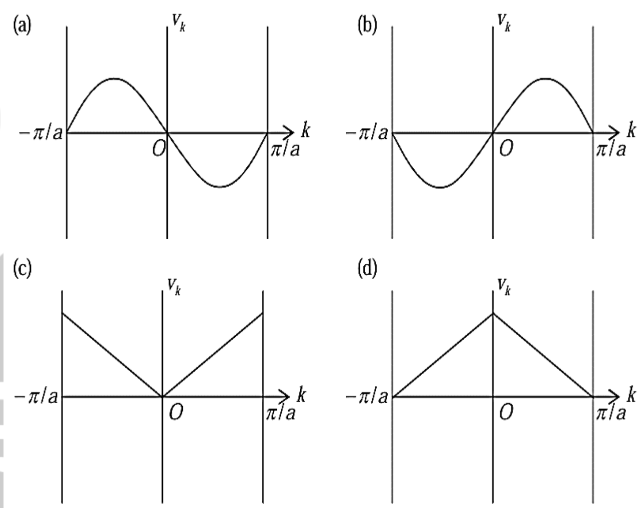
8. The energy, ε_k for band electrons as a function of the wave vector, k in the first Brillouin zone

$$\left(-\frac{\pi}{a} \le k \le \frac{\pi}{a}\right)$$

of a one dimensional monatomic lattice is shown as (a is lattice constant)



The variation of the group velocity v_k is most appropriately represented by **[GATE 2014]**



9. The Fermi energies of two metals X and Y are 5eV and 7eV and their Debye temperatures are 170 K and 340 K. respectively. The molar specific heats of theses metals at constant volume at low temperature can be written as $(C_V)_x = \gamma_x T + A_x T^3$ and $(C_V)_y = \gamma_y T + A_y T^3$, where γ and A are constants. Assuming that the thermal effective mass of the electrons in the two metals are same which of the following is correct?

[GATE 2016]

(a) $\dfrac{\gamma_x}{\gamma_y} = \dfrac{7}{5}, \dfrac{A_x}{A_y} = 8$ (b) $\dfrac{\gamma_x}{\gamma_y} = \dfrac{7}{5}, \dfrac{A_x}{A_y} = \dfrac{1}{8}$

(c) $\frac{\gamma_x}{\gamma_y}=\frac{5}{7},\frac{A_x}{A_y}=\frac{1}{8}$ (d) $\frac{\gamma_x}{\gamma_y}=\frac{5}{7},\frac{A_x}{A_y}=8$

10. The energy vs. wave vector $(E-k)$ relationship near the bottom of a band for a solid can be approximated as $E=A(ka)^2+B(ka)^4$, where the lattice constant $a=2.1$ A. The values of A and B are $6.3\times10^{-19}J$ and $3.2\times10^{-20}J$, respectively. At the bottom of the conduction band, the ratio of the effective mass of the electron to the mass of free electron is_________ (Give your answer upto two decimal places)
(Take $h=1.05\times10^{-34}$ J − s, mass of free electron $=9.1\times10^{-31}$ kg) **[GATE 2016]**

11. Consider a one-dimensional lattice with a weak periodic potential

$$U(x)=U_0\cos\left(\frac{2\pi x}{a}\right)$$

. The gap at the edge of the Brillouin zone $\left(k=\frac{\pi}{a}\right)$ is:

[GATE 2017]

(a) U_0 (b) $\frac{U_0}{2}$

(c) $2U_0$ (d) $\frac{U_0}{4}$

12. The energy dispersion for electrons in one dimensional lattice with lattice parameter a is given by

$$E(k)=E_0-\frac{1}{2}W\cos\,ka$$

, where W and E_0 are constants. The effective mass of the electron near the bottom of the band is

[GATE 2018]

(a) $\frac{2\hbar^2}{Wa^2}$ (b) $\frac{\hbar^2}{Wa^2}$

(c) $\frac{\hbar^2}{2Wa^2}$ (d) $\frac{\hbar^2}{4Wa^2}$

13. A particle of mass m moves in a lattice along the x-axis in a periodic potential $V(x)=V(x+d)$ with periodicity d. The corresponding Brillouin zone extends from $-k_0$ to k_0 with these two k-points being equivalent. If a weak force F in the x-direction is applied to the particle, it starts a periodic motion with time period T. Using the equation of motion

$$F=\frac{dp_{\text{crystal}}}{dt}$$

for a particle moving in a band, where p_{crystal} is the crystal momentum of the particle, the period T is found to be (h is Planck constant)

[GATE 2019]

(a) $\sqrt{\frac{2md}{F}}$ (b) $2\sqrt{\frac{2md}{F}}$

(c) $\frac{2h}{Fd}$ (d) $\frac{h}{Fd}$

14. In a certain two-dimensional lattice, the energy dispersion of the electrons is

$$\varepsilon(\vec{k})=-2t\left[\cos\,k_xa+2\cos\,\frac{1}{2}k_xa\cos\,\frac{\sqrt{3}}{2}k_ya\right]$$

where $\vec{k}=(k_x,k_y)$ denotes the wave vector, a is the lattice constant and t is a constant in units of eV. In this lattice the effective mass tensor m_{ij} of electrons calculated at the center of the Brillouin zone has the form

$$m_{ij}=\frac{\hbar^2}{ta^2}\begin{pmatrix}\alpha & 0\\ 0 & \alpha\end{pmatrix}$$

The value of α (rounded off to three decimal places) is

[GATE 2019]

15. A two-dimensional square lattice has lattice constant $a.k$ represents the wavevector in reciprocal space. The coordinates (k_x,k_y) of reciprocal space where band gap(s) can occur are

[GATE 2021]

(a) (0,0) (b) $\left(\pm\frac{\pi}{a},\pm\frac{\pi}{a}\right)$

(c) $\left(\pm\frac{\pi}{a},\pm\frac{\pi}{1.3a}\right)$ (d) $\left(\pm\frac{\pi}{3a},\pm\frac{\pi}{a}\right)$

❖ **JEST PYQ's**

1. Given that tight binding dispersion relation

$$E(k)=E_0+A\sin^2\left(\frac{ka}{2}\right)$$

. where E_0 and A are constants and a is the lattice parameter. What is the group velocity of an electron at the second Brillion zone boundary?

[JEST 2015]

(a) 0 (b) $\frac{a}{h}$

(c) $\frac{2a}{h}$ (d) $\frac{a}{2h}$

❖ **TIFR PYQ's**

1. Consider a 2-D square lattice. The ratio of the kinetic energy of a free electron at a corner of the first Brillouin zone (E_c) to that of an electron at the midpoint of a side face of the same zone (E_m) is $E_c/E_m =$

[TIFR 2017]

(a) 1/2 (b) 2

(c) $\sqrt{2}$ (d) 1

2. A particle is confined to a one-dimensional lattice with a lattice spacing δ. In the position space, the Hamiltonian operator for this particle is given by the matrix

$$\mathcal{H} = E_0 \begin{pmatrix} \ddots & & & & & & \\ & \dots & \dots & 0 & 0 & 0 & 0 \\ & \dots & 2 & -1 & 0 & 0 & 0 \\ 0 & -1 & 2 & -1 & 0 & 0 & \\ 0 & 0 & -1 & 2 & -1 & 0 & \\ 0 & 0 & 0 & -1 & 2 & \cdots & \\ 0 & 0 & 0 & 0 & \cdots & \cdots & \\ & & & & & & \ddots \end{pmatrix}$$

Noting that it commutes with the generator T of translations

$$\mathcal{T} = \begin{pmatrix} \ddots & & & & & & \\ & \dots & \dots & 0 & 0 & 0 & 0 \\ & \dots & 0 & 1 & 0 & 0 & 0 \\ & 0 & 0 & 0 & 1 & 0 & 0 \\ & 0 & 0 & 0 & 0 & 1 & 0 \\ & 0 & 0 & 0 & 0 & 0 & \dots \\ & 0 & 0 & 0 & 0 & \dots & \dots \\ & & & & & & \ddots \end{pmatrix}$$

where $T = e^{i\mathcal{P}\delta/\hbar}$ in terms of the momentum operator $\mathcal{P}$, the energy of a state with momentum p will be

[TIFR 2022]

(a) $E_0 \sin(p\delta/\hbar)$ (b) $E_0 \cos(p\delta/\hbar)$

(c) $4E_0 \sin^2(p\delta/2\hbar)$ (d) $E_0(p\delta/2\hbar)^2$

3. A student designed a new semiconductor with lattice constant a that crystallizes in the face-centered cubic (fcc) structure. The conduction band minimum of this semiconductor lies at all momentum points equivalent to $\vec{k} = (0.5,0,0)\pi/a$. How many conductions band minimum points are inside the first Brillouin zone? **[TIFR 2024]**

(a) 3 (b) 4

(c) 6 (d) 1

❖ Answer Key				
CSIR-NET				
1. d	2. d	3. c	4. b	5. d
6. c	7. d	8. b		
GATE				
1. b	2. c	3. d	4. c	5. d
6. b	7. d	8. b	9. a	10. 0.22
11. a	12. ab	13. d	14. 0.33,	15. b,d
JEST				
1. a				
TIFR				
1. b	2. c	3. c	4.	5.

❖ **GATE PYQ's**

1. In a cubic system with cell edge a, two phonons with wave vectors $\vec{q}_1$ and $\vec{q}_2$ collide and produce a third phonon with a wave vector $\vec{q}_3$ such that
$\vec{q}_1 + \vec{q}_2 = \vec{q}_3 + \vec{R}$,
where $\vec{R}$ is a lattice vector. Such a collision process will lead to

[GATE 2002]

(a) finite thermal resistance

(b) zero thermal resistance

(c) an infinite thermal resistance

(d) a finite thermal resistance for certain $|\vec{R}|$ only

2. Group I contain elementary excitations in solids. Group II gives the associated fields with these excitations. Match the excitations with their associated field and select your answer as per codes given below.

[GATE 2013]

Group I

(P) phonon
(Q) plasmon
(R) polaron
(S) polariton

Group II

(i) photon + lattice vibration
(ii) electron + elastic deformation
(iii) collective electron oscillations
(iv) elastic wave

Codes

(a) (P-iv), (Q-iii), (R-i), (S-ii)

(b) (P-iv), (Q-iii), (R-ii), (S-i)

(c) (P-i), (Q-iii), (R-ii), (S-iv)

(d) (P-iii), (Q-iv), (R-ii), (S-i)

3. In the first Brillouin zone of a rectangular lattice (lattice constants $a = 6$Å and $b = 4$Å), three incoming phonons with the same wave vector $\langle 1.2\text{Å}^{-1}, 0.6\text{Å}^{-1}\rangle$ interact to give one phonon. Which one of the following is the CORRECT wave vector of the resulting phonon? **[GATE 2023]**

(a) $\langle 2.56\text{Å}^{-1}, 0.23\text{Å}^{-1}\rangle$

(b) $\langle 3.60\text{Å}^{-1}, 1.80\text{Å}^{-1}\rangle$

(c) $\langle 0.48\text{Å}^{-1}, 0.23\text{Å}^{-1}\rangle$

(d) $\langle 3.60\text{Å}^{-1}, 0.80\text{Å}^{-1}\rangle$

Answer key		
GATE PYQ		
1. - a	2. - b	3. c

❖ CSIR-NET PYQ's

1. A sample of Si has electron and hole mobilities of 0.13 and 0.05 $m^2/V-s$ respectively at 300 K. It is doped with P and Al with doping densities of $1.5 \times 10^{21}/m^3$ and $2.5 \times 10^{21}/m^3$ respectively. The conductivity of the doped Si sample at 300 K is

[CSIR – DEC 2013]

(a) $8\Omega^{-1}m^{-1}$ (b) $32\Omega^{-1}m^{-1}$

(c) $20.8\Omega^{-1}m^{-1}$ (d) $83.2\Omega^{-1}m^{-1}$

2. The concentration of electrons, n and holes, p for an intrinsic semiconductor at a temperature T can be expressed as

$$n = p = AT^{3/2}\exp\left(-\frac{E_g}{2k_BT}\right)$$

, where E_g is the band gap and A is a constant. If the mobility of both types of carries is proportional to $T^{-3/2}$, then the log of the conductivity is a linear function of T^{-1} with slope

[CSIR – JUNE 2015]

(a) $\frac{E_g}{(2k_B)}$ (b) $\frac{E_g}{k_g}$

(c) $\frac{-E_g}{(2k_B)}$ (d) $\frac{-E_g}{k_B}$

3. A silicon crystal is doped with phosphorus atoms. (The binding energy of a **H** atom is 13.6eV, the dielectric constant of silicon is 12 and the effective mass of electron in the crystal is $0.4m_e$). The gap between the donor energy level and the bottom of the conduction band is nearest to

[CSIR – DEC 2018]

(a) 0.01eV (b) 0.08eV

(c) 0.02eV (d) 0.04Ev

4. A bound electron and hole pair interacting via Coulomb interaction in a semiconductor is called an exciton. The effective masses of an electron and a hole are about $0.1m_e$ and $0.5m_e$ respectively,
where m_e is the rest mass of the electron. The dielectric constant of the semiconductor is 10. Assuming that the energy levels of the excitons are hydrogen like, the binding energy of an exciton (in units of the Rydberg constant) is closest
to

[CSIR – JUNE 2019]

(a) 2×10^{-3} (b) 2×10^{-4}

(c) 8×10^{-4} (d) 3×10^{-3}

❖ GATE PYQ's

1. The potential in a divalent solid at a particular temperature is represented by a one-dimensional periodic model. The solid should behave electrically as

[GATE 2002]

(a) a semiconductor

(b) a conductor

(c) an insulator

(d) a superconductor

2. Consider the Fermi-Dirac distribution function f(E) at room temperature (300 K) where E refers to energy. If E_F is the Fermi energy, which of the following is true?

[GATE 2003]

(a) f(E) is a step function

(b) $f(E_F)$ has a value of ½

(c) States with $E < E_F$ are filled completely

(d) f(E) is large and tends to infinity as E decreases much below E_F

3. The effective mass of an electron in a semiconductor can be

[GATE 2003]

(a) negative near the bottom of the band

(b) a scalar quantity with a small magnitude

(c) zero at the center of the band

(d) negative near the top of the band

4. The effective mass of an electron in a semiconductor

[GATE 2004]

(a) can never be positive

(b) can never be negative

(c) can be positive or negative

(d) depends on its spin

5. An n-type semiconductor has an electron concentration of $3 \times 10^{20}\ \mathrm{m}^{-3}$. If the electron drift velocity is $100\ \mathrm{ms}^{-1}$ in an electric field of $200\mathrm{Vm}^{-1}$, the conductivity (in $\Omega^{-1}\ \mathrm{m}^{-1}$) of this material is

[GATE 2005]

(a) 24 (b) 36

(c) 48 (d) 96

6. The effective density of states at the conduction band edge of Ge is $1.04 \times 10^{19}\ \mathrm{cm}^{-3}$ at room temperature (300 K). Ge has an optical bandgap of 0.66eV. The intrinsic carrier concentration (in cm^{-3}) in Ge at room temperature (300 K) is approximately

[GATE 2005]

(a) 3×10^{10} (b) 3×10^{13}

(c) 3×10^{16} (d) 3×10^{16}

7. An extrinsic semiconductor sample of cross-section A and length L is doped in such a way that the doping concentration varies as $N_D(x) = N_0 \exp\left(-\frac{x}{L}\right)$, where N_0 is a constant. Assume that the mobility μ of the majority carriers remains constant. The resistance R of the sample is given by

[GATE 2007]

(a)$R = \frac{L}{A\mu e N_0}[\exp(1.0) - 1]$

(b)$R = \frac{L}{\mu e N_0}[\exp(1.0) - 1]$

(c)$R = \frac{L}{A\mu e N_0}[\exp(-1.0) - 1]$

(d)$R = \frac{L}{A\mu e N_0}$

8. The order of magnitude of the energy gap of a typical superconductor is

[GATE 2011]

(a) 1MeV (b) 1KeV

(c) 1eV (d) 1meV

9. For an intrinsic semiconductor, m_e^* and m_h^* are respectively the effective masses of electrons and holes near the corresponding band edges. At a finite temperature, the position of the Fermi leve

[GATE 2011]

(a) depends on m_e^* but not on m_h^*

(b) depends on m_h^* but not on m_e^*

(c) depends on both m_e^* and m_h^*

(d) depends neither on m_e^* nor on m_h^*

10. A Ge semiconductor is doped with acceptor impurity concentration of 10^{15} atoms $/\mathrm{cm}^3$. For the given hole mobility of $1800\ \mathrm{cm}^2/\mathrm{V-s}$, the resistivity of this material is

[GATE 2012]

(a) $0.288\Omega\mathrm{cm}$ (b) $0.694\Omega\mathrm{cm}$

(c) $3.472\Omega\mathrm{cm}$ (d) $6.944\Omega\mathrm{cm}$

11. The donor concentration in a sample of n-type silicon is increased by a factor 100. The shift in the position of the Fermi level at $300K$, assuming the sample to be non-degenerate is_________ MeV. ($k_BT = 25meV$ at 300 K)

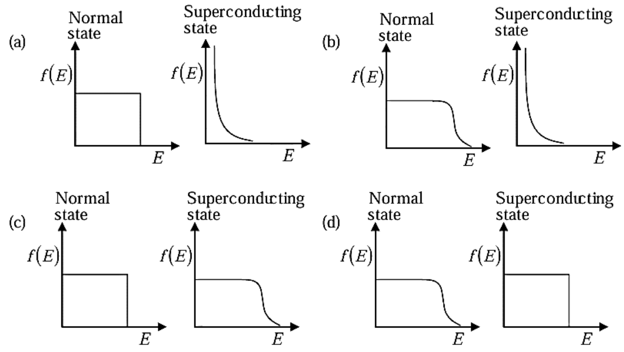
[GATE 2014]

12. The hand gap of an intrinsic semiconductor is $F_g = 0.72\mathrm{eV}$ and $m_h^* = 6m_e^*$. At 300 K, the Fermi level with respect to the edge of the valence band (in eV) is at_______________ (upto three decimal places) $k_B = 1.38 \times 10^{-23} JK^{-1}$

[GATE 2015]

13. Which one of the following represents the electron occupancy for a superconductor in its normal and superconducting states?

[GATE 2015]



14. The number density of electron in the conduction band of a semiconductor at a given temperature is $2 \times 10^{19}\ \mathrm{m}^{-3}$. Upon lightly doping this semiconductor with donor impurities, the number density of conduction electrons at the same temperature becomes $4 \times 10^{20}\ \mathrm{m}^{-3}$. The ratio of majority to minority charge carrier concentration is______________.

[GATE 2016]

15. Consider a one-dimensional non-magnetic crystal with one atom per unit cell. Assume that the valence electrons (i) do not interact with each other and (ii) interact weakly with the ions. If n is the number of valence electrons per unit cell, then at 0 K,

[GATE 2020]

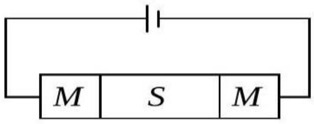
(a) the crystal is metallic for any value of n

(b) the crystal is non-metallic for any value of n

(c) the crystal is metallic for even values of n

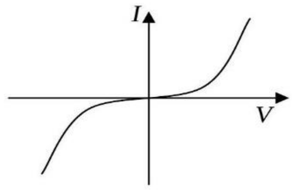
(d) the crystal is metallic for odd values of n

16. As shown in the figure, two metal-semiconductor junctions are formed between an n type semiconductor S and metal M. The work functions of S and M are φ_S and φ_M, respectively

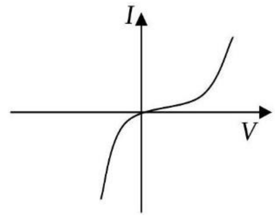


with $\varphi_M > \varphi_S$.
The $I - V$ characteristics (on linear scale) of the junctions is best represented by **[GATE 2021]**

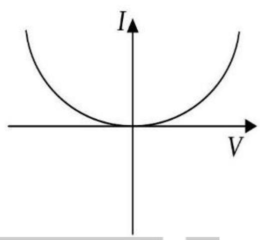
(a)



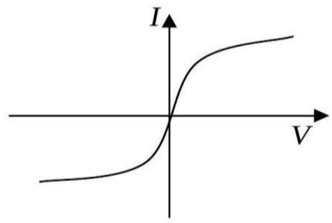
(b)



(c)



(d)



17. Choose the correct statement from the following:

[GATE 2021]

(a) Silicon is a direct band gap semiconductor.
(b) Conductivity of metals decreases with increase in temperature.
(c) Conductivity of semiconductor decreases with increase in temperature.
(d) Gallium Arsenide is an indirect band gap semiconductor.

18. The donor concentration in a sample of n - type silicon is increased by a factor of 100. Assuming the sample to be non-degenerate, the shift in the Fermi level (in meV) at 300 K (rounded off to the nearest integer) is
(Given: $k_B T = 25\text{meV}$ at 300 K)

[GATE 2021]

19. In a semiconductor, the ratio of the effective mass of hole to electron is 2: 11 and the ratio of average relaxation time for hole to electron is 1: 2. The ratio of the mobility of the hole to electron is

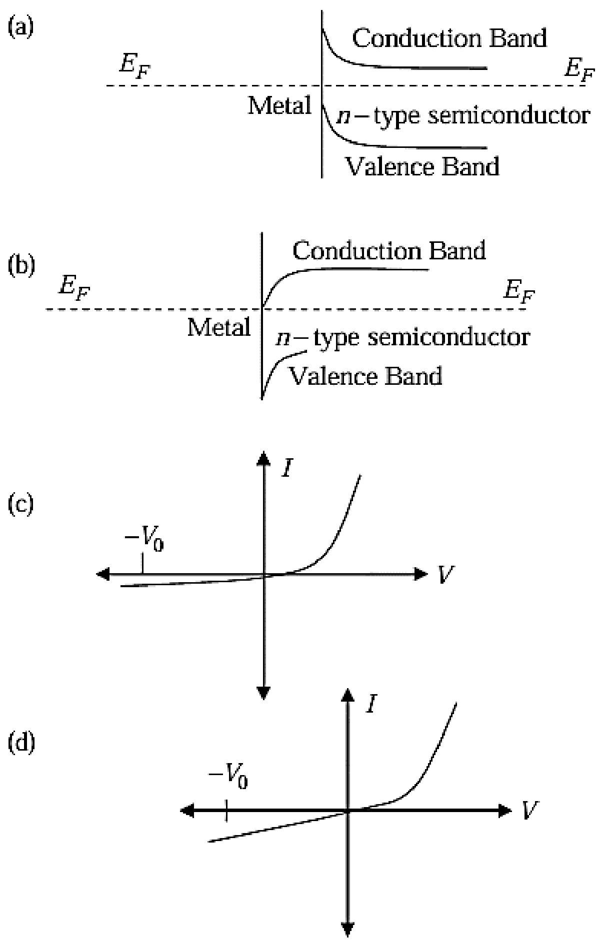
[GATE 2021]

(a) 4: 9 (b) 4: 11

(c) 9: 4 (d) 11: 4

20. A junction is formed between a metal on the left and an n-type semiconductor on the right. Before forming the junction, the Fermi level E_F of the metal lies below that of the semiconductor. Then which of the following schematics are correct for the bands and the $I - V$ characteristics of the junction?

[GATE 2022]



❖ **JEST PYQ's**

1. The net charge of an n-type semiconductor is

[JEST 2012]

(a) Positive

(b) zero

(c) negative

(d) dependent on the dopant density

2. Where does the Fermi level of an n-type semiconductor lie?

[JEST 2024]

(a) Inside the valence band

(b) Near the valence band maximum.

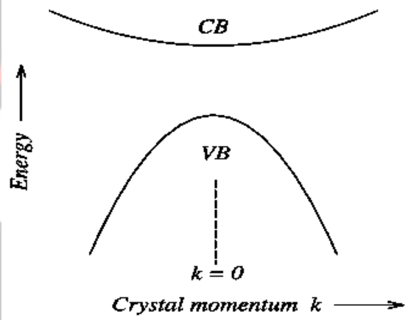
(c) At the middle of the energy gap.

(d) Near the conduction band minimum.

3. In an intrinsic semiconductor at 300 K, the number density of electrons is $n_e = 2.5 \times 10^{20}\ \mathrm{m^{-3}}$. If the mobility of electrons is $\mu_e = 0.4\ \mathrm{m^2\ V^{-1}\ s^{-1}}$ and the mobility of holes is $\mu_h = 0.2\ \mathrm{m^2\ V^{-1}\ s^{-1}}$, find the conductivity in units of mho /m. Charge of a proton $e = 1.6 \times 10^{-19}$ Coulom(b) **[JEST 2024]**

❖ **TIFR PYQ's**

1. Suppose the energy band diagram of a certain pure crystalline solid is as shown in the figure below, where the energy (E) varies with crystal momentum (k) as $E \propto k^2$.



At finite temperatures the bottom of the conduction band (CB) is partially filled with electrons (e) and the top of the valence band (VB) is partially filled with holes (h). If an electric field is applied to this solid, both e and h will start moving. If the time between collisions is the same for both e and h, then

[TIFR 2012]

(a) e and h will move with the same speed in opposite directions

(b) h will on an average achieve higher speed than e

(c) e will on an average achieve higher speed than h

(d) e and h will recombine and after a while there will be no flow of charges

2. An electron makes a transition from the valence band to the conduction band in an indirect band gap semiconductor. Which of the following is NOT true?

[TIFR 2015]

(a) The energy of the electron increases.

(b) A phonon is involved in the process.

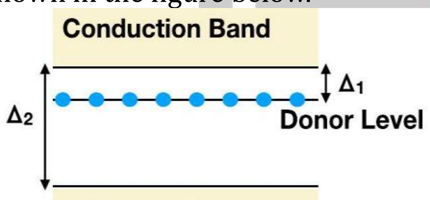
(c) A photon is absorbed in the process.

(d) There is no momentum change in the electron.

3. Electrons in a metal are scattered by both impurities and phonons. The impurity scattering time is 8×10^{-12} s and the phonon scattering time is 2×10^{-12} s. Taking the density of electrons to be 3×10^{14} m^3, find the conductivity of the metal in units of AV^{-1} m^{-1}. [Assume that the effective mass of the electrons is the same as that of a free electron.

[TIFR 2017]

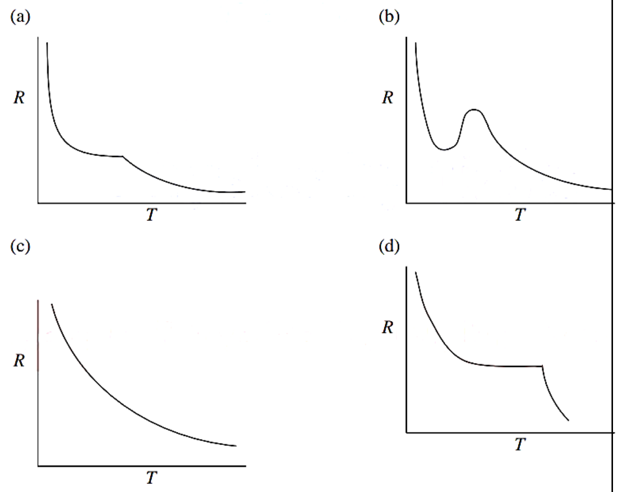
4. A semiconductor with donor impurities can be thought in terms of a filled valence band, a filled donor level and an empty valence band at $T = 0$, as shown in the figure below.



Valence Band

If the band gap between donor level and conduction band is Δ_1 and that between conduction and valence band is Δ_2 where $\Delta_2 \gg \Delta_1$, which of the following figures depict the qualitative features of the resistance (R)-vs-temperature (T) graph of the semi-conductor? (Assume temperature-independent scattering rates and a flat density of states for the bands.)

[TIFR 2020]



5. For a pure germanium semiconductor, cooled in liquid nitrogen, the average density of conduction electrons is about $n = 10^{12}$ cm^{-3}. At this temperature, the electron and hole mobilities are equal and have the common value $\mu = 5.0 \times 10^3$ cm^2 V^{-1} s^{-1}.
If a potential of 100 V is applied across opposite faces of a cube of this cooled germanium sample having side 1 cm, the current through the sample can be estimated as

[TIFR 2021]

(a) 8 mA (b) 16 Ma

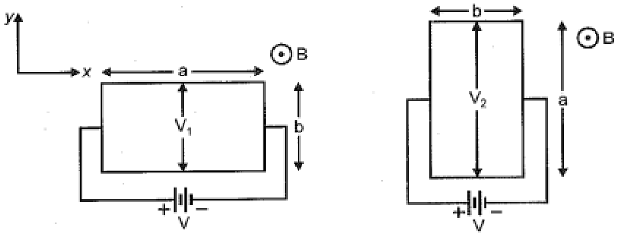
(c) 160 mA (d) 80 mA

Answer Key				
CSIR-NET				
1. a	2. c	3. d	4. c	
GATE				
1. b	2. b	3. a	4. c	5. a
6. b	7. b	8. d	9. c	10. c
11. 115	12. 0.395	13. b	14.	15. d
16. a	17. b	18. 115.15	19. d	20. ac
JEST				
1. b	2. b	3. 24		
TIFR				
1. b	2. d	3.	4. a	5. c

3. 13.5 x10-6 (TIFR)

❖ CSIR-NET PYQ's

1. A thin rectangular conducting plate of length a and width b is placed in the xy-plane in two different orientations, as shown in the figures below. In both cases a magnetic field B is applied in the z direction and a current flow in the x-direction due to the applied voltage V.



If the Hall voltage across the y-direction in the two cases satisfy $V_2 = 2V_1$, the ratio $a:b$ must be

[CSIR – DEC 2016]

(a) $1:2$ (b) $1:\sqrt{2}$

(c) $2:1$ (d) $\sqrt{2}:1$

2. Consider a two-dimensional material of length l and width w subjected to a constant magnetic field B applied perpendicular to it. The number of charge carriers per unit area may be expressed as

$$n = \frac{k|q|B}{(2\pi\hbar)},$$

where k is a positive real number and q is the carrier charge. Then the Hall resistivity ρ_{xy} is

[CSIR – DEC 2017]

(a) $\frac{2\pi hk}{q^2}\sqrt{\frac{l}{w}}$ (b) $\frac{2\pi\hbar}{kq^2}\sqrt{\frac{w}{l}}$

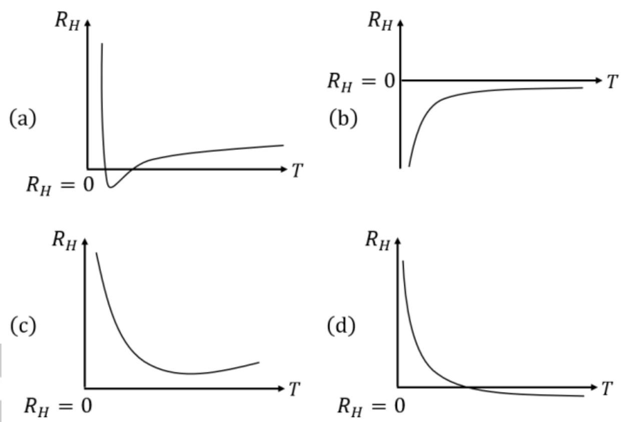
(c) $\frac{2\pi\hbar}{kq^2}$ (d) $\frac{2\pi\hbar k}{q^2}$

3. The Hall co-efficient for a semiconductor having both types of carriers is given as:

$$R_H = \frac{p\mu_p^2 - n\mu_n^2}{|e|(p\mu_p + n\mu_n)^2}$$

where p and n are the carrier densities of the holes and electrons, μ_p and μ_n are their respective mobilities. For a p-type semiconductor in which the mobility of holes is less than that of electrons, which of the following graphs best describes the variation of the Hall coefficient with temperature?

[CSIR – DEC 2019]



4. The Hall coefficient R_H of a sample can be determined from the measured Hall voltage $V_H = \frac{1}{d}R_H BI + RI$ where d is the thickness of the sample, B is the applied magnetic field, I is the current passing through the sample and R is an unwanted offset resistance. A lock-in detection technique is used by keeping I constant with the applied magnetic field being modulated as $B = B_0 \sin\Omega t$, where B_0 is the amplitude of the magnetic field and Ω is frequency of the reference signal. The measured V_H is

[CSIR JUNE 2023]

(a) $B_0\frac{R_H I}{d}$ (b) $\frac{B_0}{\sqrt{2}}\frac{R_H I}{d}$

(c) $\frac{I}{\sqrt{2}}\left(\frac{B_0 R_H I}{d} + R\right)$ (d) $I\left(\frac{B_0 R_H}{d} + R\right)$

❖ GATE PYQ's

1. A sample of Silicon of thickness 200μm is doped with 10^{23} Phosphorous atoms per m^3. If the sample is kept in a magnetic field of 0.2 Wb/m^2 and a current of 1 mA is passed through the sample, the Hall voltage produced is

[GATE 2001]

(a) 62.5μV (b) -6.25μV

(c) $+6.25\mu$V (d) -62.5μV

2. In a Hall effect experiment, the Hall voltage for an intrinsic semiconductor is negative. This is because(symbols carry usual meaning)

[GATE 2001]

(a) $n \approx p$ (b) $n > p$

(c) $\mu_e > \mu_h$ (d) $m_e^* > m_h^*$

3. Consider a metal which obeys the Sommerfeld model exactly. If E_F is the Fermi energy of the metal at $T = 0K$ and R_H is the Hall coefficient which of the following statements is correct?

[GATE 2016]

(a) $R_H \propto E_F^{3/2}$

(b) $R_H \propto E_F^{2/3}$

(c) $R_H \propto E_F^{-3/2}$

(d) R_H is independent of E_F

4. Amongst electrical resistivity (ρ), thermal conductivity (κ), specific heat (C), Young's modulus (Y) and magnetic susceptibility (χ), which quantities show a sharp change at the superconducting transition temperature?

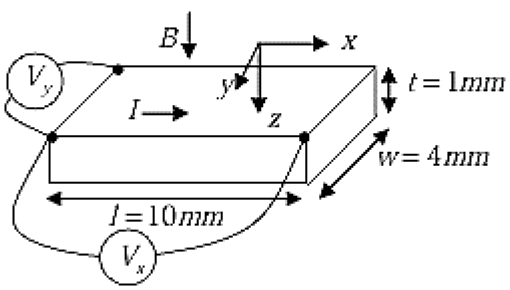
[GATE 2018]

(a) ρ, κ, C, Y (b) ρ, C, χ

(c) ρ, κ, C, χ (d) κ, Y, χ

5. A p - doped semiconductor slab carries a current $I = 100$ mA in a magnetic field $B = 0.2T$ as shown. One measures $V_y = 0.25$mV and $V_x = 2$mV. The mobility of holes in the semiconductor is $m^2V^{-1}s^{-1}$ (up to two decimal places)

[GATE 2018]



6. In a Hall effect experiment on an intrinsic semiconductor, which of the following statements are correct?

[GATE 2022]

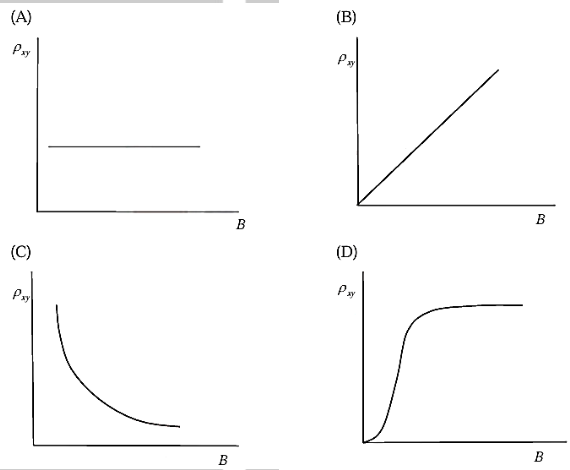
(a) Hall voltage is always zero

(b) Hall voltage is negative if the effective mass of holes is larger than those of electrons

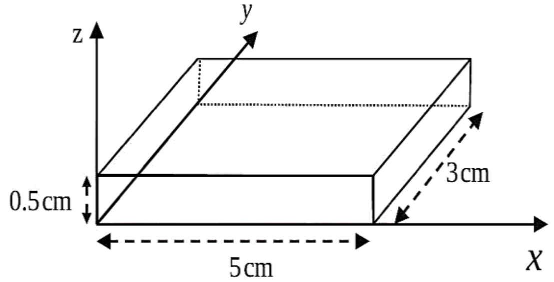
(c) Hall coefficient can be used to estimate the carrier concentration in the semiconductor

(d) Hall voltage depends on the mobility of the carriers

7. The Hall experiment is carried out with a non-magnetic semiconductor. The current I is along the x-axis and the magnetic field B is along the z-axis. Which one of the following is the CORRECT representation of the variation of the magnitude of the Hall resistivity ρ_{xy} as a function of the magnetic field? **[GATE 2023]**



8. An extrinsic semiconductor shown in figure carries a current of 2 mA along its length parallel to $+x$ axis. When the majority charge carrier concentration is 12.5×10^{13} cm^{-3} and the sample is exposed to a constant magnetic field applied along the $+z$ direction, a Hall voltage of 20 mV is measured with the negative polarity at $y = 0$



plane. Take the electric charge as 1.6×10^{-19}C. The concentration of minority charge carrier is negligible. Which of the following statement is/are true? **[GATE 2024]**

(a) The majority charge carrier is electron

(b) The magnitude of the applied magnetic field is 1 Tesla

(c) The electric field corresponding to the Hall voltage is in the $+y$ direction

(d) The magnitude of Hall coefficient is $50{,}000\ \mathrm{m^3C^{-1}}$

Answer Key				
CSIR-NET PYQ				
1. d	2. c	3. d	4. b	5.
GATE PYQ				
1. d	2. c	3. c	4. b	5.
6. bcd	7. b	8. ab	9.	10.

❖ CSIR-NET PYQ's

1. Assume that the free energy of a magnetic system has an expansion in the order parameter M of the form $F(M,T) = a(T-T_C)M^2 + bM^4 + cM^6$, with a, b and $c > 0$. As the temperature is lowered below T_C, the system undergoes a phase transition. The behaviour of the order parameter just below the transition, where $(T - T_C)$ is very small, is best described by

[CSIR – DEC 2011]

(a) $M \propto (T_C - T)^{-1/2}$ (b) $M \propto (T_C - T)^{1/2}$

(c) $M \propto (T_C - T)$ (d) $M \propto (T_C - T)^3$

2. The free energy difference between the superconducting and the normal states of a material is given by

$$\Delta F = F_S - F_N = \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4$$

, where ψ is an order parameter and α and β are constants such that $\alpha > 0$ in the normal and $\alpha < 0$ in the superconducting state, while $\beta > 0$ always. The minimum value of ΔF in the superconducting state is

[CSIR – DEC 2012]

(a) $-\alpha^2/\beta$ (b) $-\alpha^2/2\beta$

(c) $-3\alpha^2/2\beta$ (d) $-5\alpha^2/2\beta$

❖ GATE PYQ's

1. A ferromagnetic material has a Curie temperature 100 K. Then

[GATE 2003]

(a) its susceptibility is doubled when it is cooled from 300 K to 200 K

(b) all the atomic magnets in it get oriented in the same direction above 100 K

(c) the plot of inverse susceptibility versus temperature is linear with a slope T_C

(d) the plot of its susceptibility versus temperature is linear with an intercept T_C

2. The energy of a ferromagnet as a function of magnetization M is given by $F(M) = F_0 + 2(T - T_c)M^2 + M^4$, $F_0 > 0$.

The number of minima in the function $F(M)$ for $T > T_c$ is

[GATE 2005]

(a) 0 (b) 1

(c) 3 (d) 4

3. A ferromagnetic mixture of iron and copper having 75% atoms of Fe exhibits a saturation magnetization of $1.3 \times 10^6 \text{Am}^{-1}$. Assume that the total number of atoms per unit volume is $8 \times 10^{28}\ \text{m}^{-3}$. The magnetic moment of an iron atom, in terms of the Bohr Magneton, is

[GATE 2007]

(a) 1.7 (b) 2.3

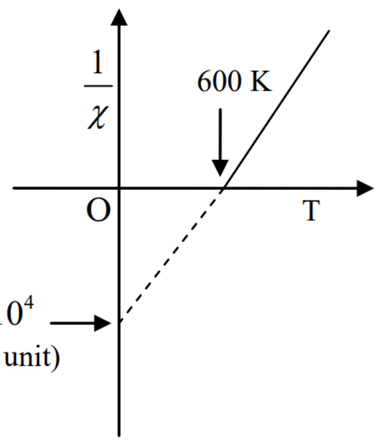
(c) 2.9 (d) 3.8

4. The plot of inverse magnetic susceptibility $1/\chi$ versus temperature T of an anti-ferromagnetic sample corresponds to **[GATE 2008]**

5. In an experiment involving a ferromagnetic medium, the following observations were made. Which one of the plots does not correctly represent the property of the medium (T_C is the Curie temperature) **[GATE 2010]**

6. Inverse susceptibility $(1/\chi)$ as a function of temperature T for a material undergoing paramagnetic to ferromagnetic transition is given in the figure. Where O is the origin. The values of the Curie constant C and the Weiss molecular field constant λ in CGS units are

[GATE 2012]



(a) $C = 5 \times 10^{-5}, \lambda = 3 \times 10^{-2}$

(b) $C = 3 \times 10^{-2}, \lambda = 5 \times 10^{-5}$

(c) $C = 3 \times 10^{-2}, \lambda = 2 \times 10^{4}$

(d) $C = 2 \times 10^{4}, \lambda = 3 \times 10^{-2}$

7. A simple cubic crystal with lattice parameter a_c undergoes transition into a tetragonal structure with lattice parameters $a_t = b_t = \sqrt{2}a_c$ and $c_t = 2a_c$, below a certain temperature. The ratio of the interplanar spacing of (1 0 1) planes for the cubic and the tetragonal structures is

[GATE 2012]

(a) $\sqrt{\frac{1}{6}}$ (b) $\frac{1}{6}$

(c) $\sqrt{\frac{3}{8}}$ (d) $\frac{3}{8}$

8. A solid material is found to have a temperature independent magnetic susceptibility, $\chi = C$, which of the following statements is correct?

[GATE 2016]

(a) If C is positive, the material is a diamagnet

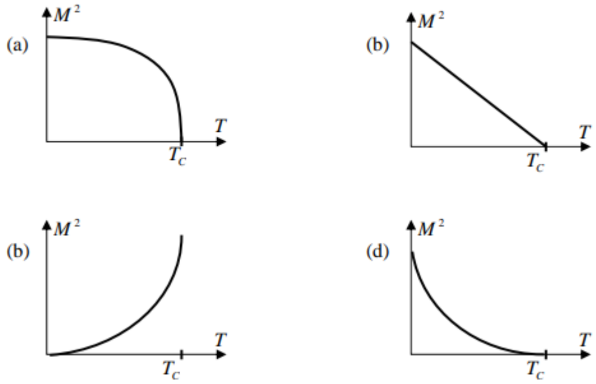
(b) If C is positive, the material is a ferromagnet

(c) If C is negative, the material could be a type I superconductor

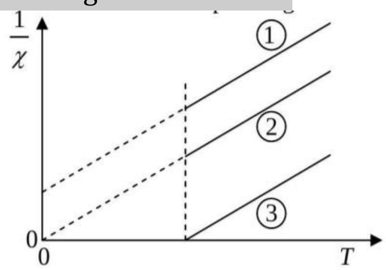
(d) If C is positive, the material could be a type I superconductor

9. The free energy of a ferromagnet is given by $F = F_0 + a_0(T - T_C)M^2 + bM^4$, where F_0, a_0, and b are positive constants, M is the magnetization, T is the temperature, and T_C is the Curie temperature. The relation between M^2 and T is best depicted by

[GATE 2021]



10. As shown in the figure, inverse magnetic susceptibility $(1/\chi)$ is plotted as a function of temperature (T) for three different materials in paramagnetic states.



(Curie temperature of ferromagnetic material = T_C
Neel temperature of antiferromagnetic material = T_N)
Choose the correct statement from the following

[GATE 2021]

(a) Material 1 is paramagnetic, 2 is antiferromagnetic $(T < T_N)$, and 3 is ferromagnetic $(T < T_C)$

(b)Material 1 is antiferromagnetic $(T < T_N)$, 2 is paramagnetic, and 3 is ferromagnetic $(T < T_C)$

(c) Material 1 is ferromagnetic $(T < T_C)$, 2 is antiferromagnetic $(T < T_N)$, and 3 is paramagnetic

(d) Material 1 is ferromagnetic $(T < T_C)$, 2 is paramagnetic, and 3 is antiferromagnetic $(T < T_N)$

11. Consider an atomic gas with number density $n = 10^{20}\ \mathrm{m}^{-3}$, in the ground state at 300 K. The valence electronic configuration of atoms is f^7. The paramagnetic susceptibility of the gas $\chi = m \times 10^{-11}$. The value of m (rounded off to two decimal places) is

(Given: Magnetic permeability of free space
$\mu_0 = 4\pi \times 10^{-7}\text{Hm}^{-1}$
Bohr magneton $\mu_B = 9.274 \times 10^{-24}\text{Am}^2$
Boltzmann constant $k_\text{B} = 1.3807 \times 10^{-23}\text{JK}^{-1}$
)

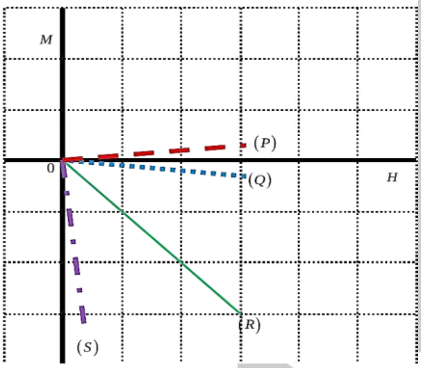
[GATE 2021]

12. Potassium metal has electron concentration of 1.4×10^{28} m^{-3} and the corresponding density of states at Fermi level is 6.2×10^{46}Joule^{-1} m^{-3}. If the Pauli paramagnetic susceptibility of Potassium is $n \times 10^{-k}$ in standard scientific form, then the value of k (an integer) is

(Magnetic moment of electron is 9.3×10^{-24} Joule T^{-1}; permeability of free space is $4\pi \times 10^{-7}\text{TmA}^{-1}$)

[GATE 2022]

13. The figure schematically shows the M (magnetization) - H (magnetic field) plots for certain types of materials. Here M and H are plotted in the same scale and units. Which one of the following is the most appropriate combination? **[GATE 2023]**



(a) (Q) - Paramagnet; (R) - Type-I Superconductor; (S) - Antiferromagnet

(b) (P) - Paramagnet; (Q) - Diamagnet; (R) - Type-I Superconductor

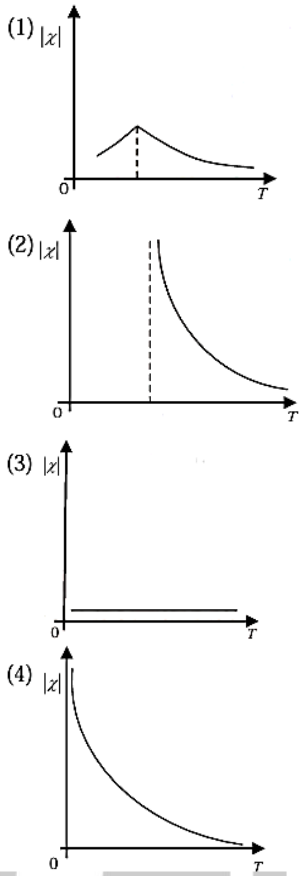
(c) (P) - Paramagnet; (Q) - Antiferromagnet; (R) - Type-I Superconductor

(d) (P) - Diamagnet; (R) - Paramagnet; (S) - Type-I Superconductor

14. The temperature T dependence of magnetic susceptibility χ (Column I) of certain magnetic materials (Column II) are given below. Which of the following option is/are correct?

[GATE 2024]

Column I | **Column II**



(P) Diamagnetic

(Q) Paramagnetic

(R) Ferromagnetic

(S) Antiferromagnetic

(a) 2 – P, 4 – Q, 3 – S

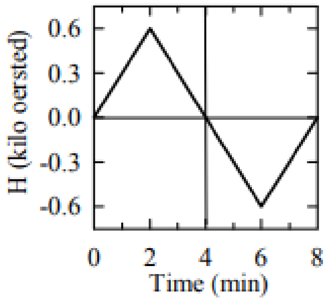
(b) 4 – P, 1 – Q, 2 – R

(c) 4 – Q, 2 – R, 1 – S

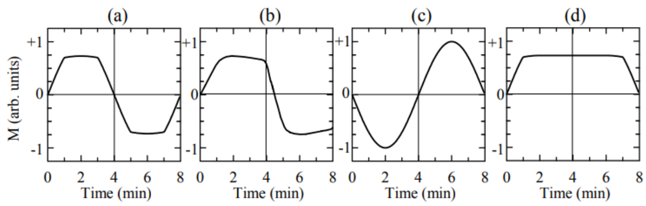
(d) 3 – P, 4 – Q, 2 – R

❖ TFIR PYQ's

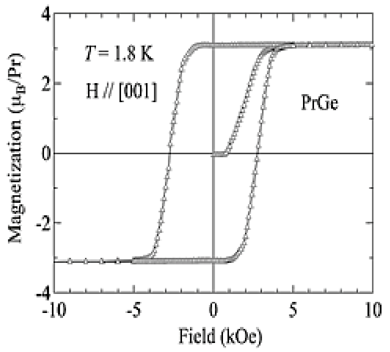
1. An unmagnetized sample of iron is placed in a magnetic field H which varies with time as shown in the plot below. **[TIFR 2011]**



The magnetization M of this iron sample is continuously measured and also plotted as a function of time. The appearance of this plot will be closest to



2.



The Curie temperature of a single crystal of PrGe is known to be 41 K. The magnetization data of this sample is measured at 1.8 K for the magnetic field applied parallel to the [001] direction is shown in the figure on the left. At a temperature of 38 K, the hysteresis loop in the figure will figure will

[TIFR 2013]

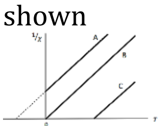
(a) have the same width

(b) increase in width

(c) decrease in width

(d) shrink to a line

3. The magnetic susceptibility χ of three samples A, B and C, is measured as a function of their absolute temperature T, leading to the graphs shown below.



From these graphs, the magnetic nature of the samples can be inferred to be

[TIFR 2013]

(a) A: anti-ferromagnet B: paramagnet C: ferromagnet

(b) A : diamagnet B : paramagnet C : anti-ferromagnet

(c) A : paramagnet B : anti-ferromagnet C: ferromagnet

(d) A : anti-ferromagnet B : diamagnet C: paramagnet

4. The angular position of a star is found to change by an amount of 0.2 arc seconds (relative to the very distant background stars) when measured by a telescope on the Earth on two different nights separated by exactly six months. Note that the distance between the Earth and Sun is known to be approximately 1.5×10^{13} cm.
If the energy flux received from the star is $F = 10^{-7}\text{ergs}^{-1}\ \text{cm}^{-2}$, what is the approximate value of its luminosity? **[TIFR 2023]**

(a) 10^{29}ergs^{-1} (b) 10^{31}ergs^{-1}

(c) 10^{35}ergs^{-1} (d) 10^{33}ergs^{-1}

Answer Key				
CSIR-NET PYQ				
1. b	2. b	3.		
GATE PYQ				
1. a	2. b	3. b	4. b	5. d
6. c	7. c	8. b	9. b	10. b
11.	12. b	13. c, d		
TFIR PYQ				
1.	2. c	3. a	4. d	

❖ **CSIR-NET PYQ's**

1. A flux quantum (fluxoid) is approximately equal to 2×10^{-7} gauss- cm^2. A type II superconductor is placed in a small magnetic field, which is then slowly increased till the field starts penetrating the superconductor. The strength of the field at this point is $\frac{2}{\pi} \times 10^5$ gauss

[CSIR – JUNE 2011]

(A) The penetration depth of this superconductor is

(a) 100Å (b) 10Å

(c) 1000Å (d) 314Å

(B) The applied field is further increased till superconductivity is completely destroyed. The strength of the field is now $\frac{8}{\pi} \times 10^5$ gauss. The coherence length of the superconductor is:

(a) 20Å (b) 200Å

(c) 628 A (d) 2000Å

2. The critical magnetic fields of a super-conductor at temperatures 4 K and 8 K are 11 mA/m and 5.5 mA/m respectively. The transition temperature is approximately

[CSIR – JUNE 2015]

(a) 8.4 K (b) 10.6 K

(c) 12.9 K (d) 15.0 K

3. In the AC Josephson effect, a supercurrent flows across two superconductors separated by a thin insulating layer and kept at an electric potential difference ΔV. The angular frequency of the resultant supercurrent is given by:

[CSIR – DEC 2019]

(a) $\frac{2e\Delta V}{\hbar}$ (b) $\frac{e\Delta V}{\hbar}$

(c) $\frac{e\Delta V}{\pi\hbar}$ (d) $\frac{e\Delta V}{2\pi\hbar}$

4. Lead is superconducting below 7 K and has a critical magnetic field 800×10^{-4} tesla close to $0K$.

At $2K$ the critical current that flows through a long lead wire of radius 5 mm is closest to

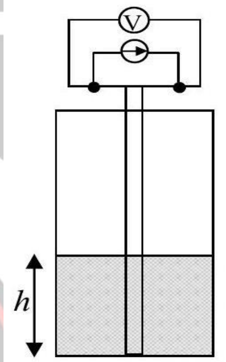
[CSIR – JUNE 2021]

(a) 1760 A (b) 1670 A

(c) 1950 A (d) 1840 A

5. To measure the height h of a column of liquid helium in a container, a constant current I is sent through an $NbTi$ wire of length l, as shown in the figure. The normal state resistance of the $NbTi$ wire is R. If the superconducting transition temperature of $NbTi$ is $\approx 10K$ then the measured voltage $V(h)$ is best described by the expression

[CSIR – JUNE 2021]



(a) $IR\left(\frac{1}{2} - \frac{2h}{l}\right)$ (b) $IR\left(1 - \frac{h}{l}\right)$

(c) $IR\left(\frac{1}{2} - \frac{h}{l}\right)$ (d) $IR\left(1 - \frac{2h}{l}\right)$

❖ **GATE PYQ's**

1. An external magnetic field of magnitude H is applied to a Type-I superconductor at a temperature below the transition point. Then which one of the following statements is NOT true for H less than the critical field H_C ?

[GATE 2003]

(a) the sample is diamagnetic

(b) it magnetization varies linearly with H

(c) the lines of magnetic induction are pushed out from the sample

(d) the sample exhibits mixed states of magnetization near H_C

2. The critical magnetic field for a solid in superconducting state

[GATE 2004]

(a) does not depend upon temperature

(b) increases if the temperature increases

(c) increases if the temperature decreases

(d) does not depend on the transition temperature

3. Which one of the following statements is NOT TRUE?

[GATE 2004]

(a) Entropy decreases markedly on cooling a superconductor below the critical temperature, T_c

(b) The electronic contribution to the heat capacity in the superconducting state has an exponential form with an argument proportional to T^{-1}, suggestive of an energy gap

(c) A type I superconductor is a perfect diamagnet

(d) Critical temperature of superconductors does not vary with the isotopic mass

4. For a conventional superconductor, which of the following statements is NOT true?

[GATE 2005]

(a) Specific heat is discontinuous at transition temperature T_c

(b) The resistivity falls sharply at T_c

(c) It is diamagnetic below T_c

(d) It is paramagnetic below T_c

5. A solid superconductor is placed in an external magnetic field and then cooled below its critical temperature. The superconductor

[GATE 2007]

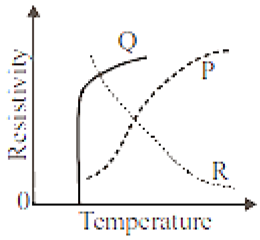
(a) retains its magnetic flux because the surface current supports it

(b) expels out its magnetic flux because it behaves like a paramagnetic material

(c) expels out its magnetic flux because it behaves like an anti-ferromagnetic material

(d) expels out its magnetic flux because the surface current induces a field in the direction opposite to the applied magnetic field

6. Variation of electrical resistivity ρ with temperature T of three solids is sketched (on different scales) in the figure, as curves P, Q and



Which one of the following statements describes the variations most appropriately? **[GATE 2007]**

(a) P is for a superconductor, and R for a semiconductor

(b) Q is for a superconductor, and P for a conductor

(c) Q is for a superconductor, and R for a conductor

(d) R is for a superconductor, and P for a conductor

7. A superconducting ring is cooled in the presence of a magnetic field below its critical temperature (T_c). The total magnetic flux that passes through the ring is

[GATE 2009]

(a) 0 (b) $n\frac{h}{2e}$

(c) $\frac{nh}{4\pi e}$ (d) $\frac{ne^2}{hc}$

8. The thermal conductivity of a given material reduces when it undergoes a transition from its normal state to the superconducting state. The reason is **[GATE 2010]**

(a) the cooper pairs cannot transfer energy to the lattice.

(b) upon the formation of cooper pairs, the lattice becomes less efficient in heat transfer.

(c) the electrons in the normal state lose their ability to transfer heat because of their coupling to the cooper pairs.

(d) the heat capacity increases on transition to the superconducting state leading to a reduction in thermal conductivity.

9. Considering the BCS theory of superconductors, which one of the following statements is not correct? (h is the Planck's constant and e is the electronic charge)

[GATE 2013]

(a) presence of energy gap at temperatures below the critical temperature

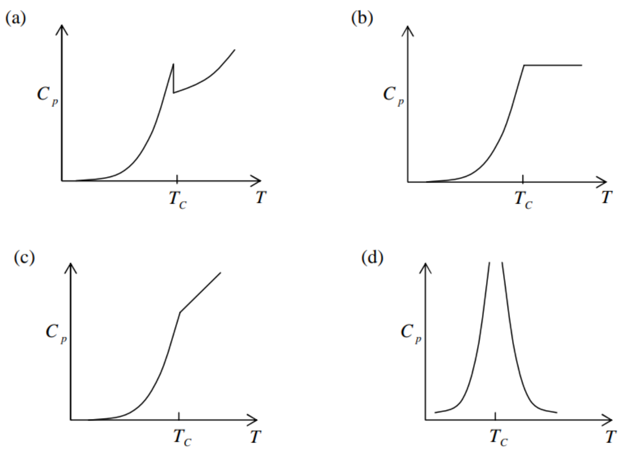
(b) different critical temperatures for isotopes

(c) quantization of magnetic flux in superconducting ring in the unit of $\left(\frac{h}{e}\right)$

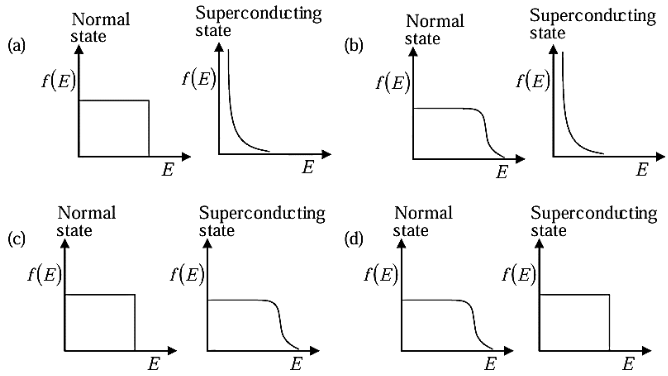
(d) presence of Meissner effect

10. The plot of specific heat versus temperature across the superconducting transition temperature (T_C) is most appropriately represented by

[GATE 2014]



11. Which one of the following represents the electron occupancy for a superconductor in its normal and superconducting states?



12. Amongst electrical resistivity (ρ), thermal conductivity (κ), specific heat (C), Young's modulus (Y) and magnetic susceptibility (χ), which quantities show a sharp change at the superconducting transition temperature?

[GATE 2018]

(a) ρ, κ, C, Y (b) ρ, C, χ

(c) ρ, κ, C, χ (d) κ, Y, χ

13. The relative magnetic permeability of a type-I superconductor is **[GATE 2019]**

(a) 0 (b) -1

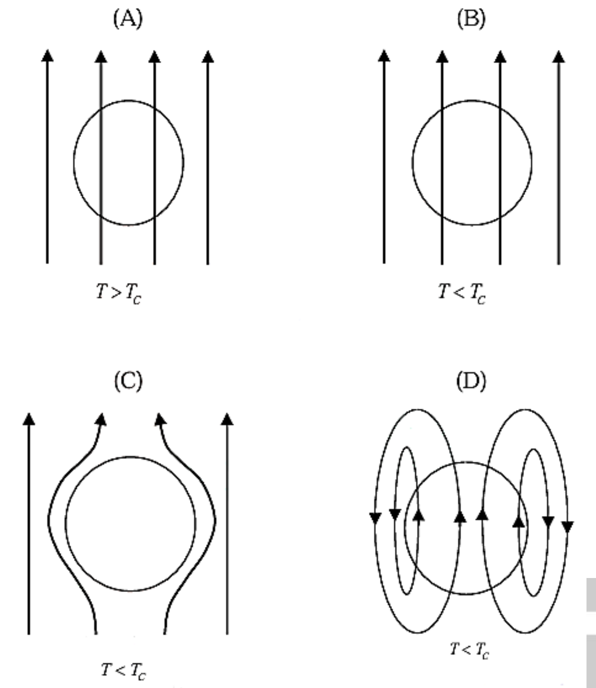
(c) 2π (d) $\frac{1}{4\pi}$

14. A conventional type-I superconductor has a critical temperature of 4.7 K at zero magnetic field and a critical magnetic field of 0.3 Tesla at 0 K. The critical field in Tesla at 2 K (rounded off to three decimal places) is

[GATE 2019]

15. A material behaves as a superconductor below a critical temperature T_c and as a normal conductor above T_c. A magnetic field $\vec{B} = B\hat{z}$ is applied when $T > T_c$. The material is then cooled below T_c in the presence of $\vec{B}$. Which of the following figure represent the correct configuration of magnetic field lines?

[GATE 2024]



❖ **TIFR PYQ's**

1. A solid sample has the property that, when cooled below a certain temperature, it expels any small applied magnetic field from within the material. Which of the following best describes this sample in the cooled state?

[TIFR 2014]

(a) Paramagnet (b) Diamagnet

(c) Ferromagnet (d) Anti-ferromagnet

Answer Key			
CSIR-NE			
1. a, a	2. b	3. a	4. d
5. d			
GATE			
1. d	2. c	3. d	4. d
5. d	6. b	7. b	8. a
9. c	10. a	11. a	12. b
13. a	14. 0.246	15. b,c	
TIFR			
1. b			

❖ **CSIR-NET PYQ's**

1. The energy required to create a lattice vacancy in a crystal is equal to 1eV. The ratio of the number densities of vacancies $n(1200\ \mathrm{K})/n(300\ \mathrm{K})$, when the crystal is at equilibrium at 1200 K and 300 K, respectively is approximately

[CSIR JUNE 2012]

(a) $\exp(-30)$ (b) $\exp(-15)$

(c) $\exp(15)$ (d) $\exp(30)$

2. For a crystal, let ϕ denote the energy required to create a pair of vacancy and interstitial defects. If n pairs of such defects are formed, and $n \ll N, N'$, where N and N' are, respectively, the total number of lattice and interstitial sites, then n is approximately

[CSIR DEC 2019]

(a) $\sqrt{NN'}e^{-\phi/(2k_BT)}$

(b) $\sqrt{NN'}e^{-\phi/(k_BT)}$

(c) $\frac{1}{2}(N+N')e^{-\phi/(2k_gT)}$

(d) $\frac{1}{2}(N+N')e^{-\phi/(k_sT)}$

Answer Key				
CSIR-NET				
1. d	2. a			

❖ **GATE PYQ's**

1. X-rays were produced using Cobalt (Z = 27) as target. It was observed that the X-ray spectrum contained a strong K_α line of wavelength 0.1785 nm and a weak K_α line of wavelength 0.1930 nm. Then, the weak K_α line is due to an impurity whose atomic number is

[GATE 2001]

(a) 25 (b) 26

(c) 28 (d) 30

2. The curves P and Q schematically show the variation of X -ray intensity with wavelength at two different accelerating voltages for a given target material. In the figure $\lambda_1 = 0.25\text{Å}, \lambda_2 = 0.5\text{Å}, \lambda_3 = 1.0\text{Å}$ and $\lambda_4 = 2.25\text{Å}$. Take Planck's constant as 6.6×10^{-34}Js, speed of light as $3 \times 10^8\ \text{ms}^{-1}$ and elementary charge as 1.6×10^{-19}C.

Which of the following statement is/are true?

[GATE 2024]

(a) The accelerating potential corresponding to curve P is greater than that of curve Q

(b) The accelerating potential applied to obtain curve Q is 24750 V

(c) Peaks (II) and (IV) correspond to radiative transitions from L to K shells

(d) Peaks (I) and (III) correspond to radiative transitions from N to K shells

Answers key	
1 – b	2 – a, b, c

❖ **CSIR-NET PYQ's**

1. The power density of sunlight incident on a solar cell is $100\ \mathrm{mW/cm^2}$. Its short circuit current density is $30\ \mathrm{mA/cm^2}$ and the open circuit voltage is 0.7 V. If the fill factor of the solar cell decreases from 0.8 to 0.5 then the percentage efficiency will decrease from

[CSIR – DEC 2014]

(a) 42.0 to 26.2 (b) 24.0 to 16.8

(c) 21.0 to 10.5 (d) 16.8 to 10.5

2. A silica particle of radius 0.1μm is put in a container of water at $T = 300$ K. The densities of silica and water are $2000\ \mathrm{kg/m^3}$ and $1000\ \mathrm{kg/m^3}$, respectively. Due to thermal fluctuations, the particle is not always at the bottom of the container. The average height of the particle above the base of the container is approximately

[CSIR – DEC 2016]

(a) 10^{-3} m (b) 3×10^{-4} m

(c) 10^{-4} m (d) 5×10^{-5} m

3. The active medium in a blue LED (Light Emitting Diode) is a $\mathrm{Ga}_x\mathrm{In}_{1-x}$ N alloy. The band gaps of GaN and InN are 3.5eV and 1.5eV respectively. If the band gap of $\mathrm{Ga}_x\mathrm{In}_{1-x}$ N varies approximately linearly with x, the value of x required for the emission of blue light of wavelength 400 nm is (take $hc \approx 1200$eV-nm)

[CSIR – DEC 2016]

(a) 0.95 (b) 0.75

(c) 0.50 (d) 0.33

4. In an experiment to measure the charge to mass ratio $\frac{e}{m}$ of the electron by Thomson's method, the values of the deflecting electric field and the accelerating potential are 6×10^6 N/C (newton per coulomb) and 150 V, respectively. The magnitude of the magnetic field that leads to zero deflection of the electron beam is closest to

[CSIR – JUNE 2021]

(a) $0.6T$ (b) $1.2T$

(c) $0.4T$ (d) $0.8T$

5. The Hall coefficient R_H of a sample can be determined from the measured Hall voltage $V_H = \frac{1}{d}R_H BI + RI$ where d is the thickness of the sample, B is the applied magnetic field, I is the current passing through the sample and R is an unwanted offset resistance. A lock-in detection technique is used by keeping I constant with the applied magnetic field being modulated as $B = B_0 \sin \Omega t$, where B_0 is the amplitude of the magnetic field and Ω is
frequency of the reference signal. The measured V_H is

[CSIR – JUNE 2023]

(a) $B_0 \frac{R_H I}{d}$ (b) $\frac{B_0}{\sqrt{2}} \frac{R_H I}{d}$

(c) $\frac{I}{\sqrt{2}}\left(\frac{B_0 R_H I}{d} + R\right)$ (d) $I\left(\frac{B_0 R_H}{d} + R\right)$

6. The light incident on a solar cell has a uniform photon flux in the energy range of 1eV to 2eV and is zero elsewhere. The active layer of the cell has a bandgap of 1.5eV and absorbs 80% of the photons with energies above the bandgap. Ignoring non-radiative losses, the power conversion efficiency (ratio of the output power to the input power) is closest to

(a)47% (b)70%

(c)23% (d)35%

7. A solar probe mission detects a fractional wavelength shift $(\Delta\lambda/\lambda)$ of the spectral line $\lambda = 630$ nm within a sunspot to be of the order of 10^{-5}. Assuming this shift is caused by the normal Zeeman effect (i.e., neglecting other physical effects), the estimated magnetic field (in tesla) within the observed sunspot is closest to

[CSIR – DEC 2023]

(a)3×10^{-5} (b)300

(c)0.3 (d)3×10^{5}

❖ **GATE PYQ's**

1. Which one of the following statements is TRUE?

[GATE 2004]

(a) Magnetic tapes are made of Iron

(b) Permanent magnets are made from ferrites

(c) Ultrasonic transducers are made from quartz crystals

(d) Optoelectronic devices are made from soft ferrites

❖ TFIR PYQ's

1. If we model the electron as a uniform sphere of radius r_e, spinning uniformly about an axis passing through its centre with angular momentum $L_e = \hbar/2$, and demand that the velocity of rotation at the equator cannot exceed the velocity c of light in vacuum, then the minimum value of r_e is

[TIFR 2012]

(a) 19.2fm (b) 0.192fm

(c) 4.8fm (d) 1960fm

(e) 480fm

2. In an experiment, a counting device is used to record the number of charged particles passing through it. Once this counter records a charged particle, it does not respond for a short interval of time, called the 'dead time' of that counter.

This device is used to count the charged particles emitted by a particular radioactive source. It is found that if the source emits 20,000 counts/second at random intervals, the counter records 19,000 particles per second on an average. It follows that the counter dead time must be **[TIFR 2021]**

(a) 2.63 microseconds

(b) 2.63 nanoseconds

(c) 50.0 milliseconds

(d) 2.63 seconds

3. A commercial advertisement for a solar power converter claims that when the temperature of the plate (area 1.6 m^2) absorbing 20% of the solar energy (solar constant is about 1.36 $kW\ m^{-2}\ s^{-1}$) reaches 127°C and the rest of the device is at room temperature (27°C), the system will deliver a power of 100 W.

If a prospective customer comes to you for advice about buying this device, your advice should be that **[TIFR 2022]**

(a) it is an efficient device for the given specifications.

(b) the power delivered is very small for the given specifications.

(c) the advertisement is false and the device cannot deliver so much power.

(d) other similar devices are available which can deliver 1.5 - 2.0 times the power with the same specifications.

4. A particular counting system has an average background rate of 50 counts/min. A decaying radioisotope source was introduced and the total 168 counts were measured in one minute. After a delay of 24 hrs, the system measured total 91 counts in one minute. If these measurements were used for determining the half-life (τ) of the source and if the average background rate, and the time have no errors, the % error ($100 \times \sigma_\tau/\tau$) in the calculated half-life value due to counting statistics would be:

[TIFR 2024]

(a) 18.2% (b) 21.2%

(c) 25.7% (d) 24.3%

❖ Answers key			
CSIR-NET			
1. d	2. c	3. b	4. d
5. b	6. a	7. c	
GATE			
1. b			
TIFR			
1. e	2. a	3. a	4. d