## Tutorial 2:

- Band theory of solids – conductors, insulators and semiconductors;
- Thermal properties of solids, specific heat, Debye theory;
- Magnetism: dia, para and ferromagnetism

Q1:

Starting with the expression for the density of states for electrons in a band, show that the Fermi energy of an intrinsic semiconductor is at the middle of the band gap. Use these results to estimate the electron density at 300 $K$ (Assuming $E_g = 1$ eV and the rest masses of electron and hole as $m_e$ and $m_h$). 20

2013

Q2:

The velocity of sound in f.c.c. gold and f.c.c. copper is 2100 m/s and 3800 m/s respectively. If the Debye temperature of copper is 348 K, then determine the Debye temperature of gold. Take the densities of gold and copper as $1.93 \times 10^4$ kg/m$^3$ and $0.89 \times 10^4$ kg/m$^3$ respectively. 10

2014

Q3:

How does the energy gap in superconductors differ from the energy gap in insulator ? How does it vary with temperature for superconductors ? 10

2014

Q4:

Explain the working of SEM and TEM and highlight the major differences in principles. Draw neat schematic diagrams. 20

2014

Q5:

**Find an expression for lattice specific heat of a solid, and its low and high temperature limits. What is Debye temperature ? 20**

2015

Q6:

Describe the motion of an electron in one dimensional periodic potential and show that it leads to formation of bands of allowed and forbidden states in the electron energy spectrum. How are the conductors, semiconductors and insulators discriminated on the basis of band structure ? 20

2015

Q7:

Write down the salient features of the Einstein's theory of lattice heat capacity. Further write down the expression for specific heat in Einstein's theory and explain its high and low temperature limits. *4+6=10*

2016

Q8:

The energy (E) and wave vector (k) for a conduction band electron in a semiconductor are related as $E = \alpha \frac{\hbar^2 k^2}{m_0}$ where $\alpha$ is a constant and $m_0$ is the free electron mass. Calculate the effective mass of the electron. 10

2017

Q9:

A system of paramagnetic atoms (N per unit volume) which can occupy only two energy levels in a uniform external magnetic field H is at a temperature T. If this system follows Boltzman's distribution, find the magnetisation and susceptibility of the system. 20

2017

Q10:

Derive the expression for the average energy of a quantum oscillation of frequency ν. Assume Fermi-Dirac distribution and $E - E_F > 2$, where $E_F$ is the Fermi level. 15

2019

Q11:

Using the expression for internal energy

$U = 3N\frac{\hbar\omega}{e^{\hbar\omega/k_B T} - 1}$, show that Einstein specific heat capacity is given by;

$$C = 3R\left(\frac{\hbar\omega}{k_B T}\right)^2 \frac{e^{\hbar\omega/k_B T}}{\left(e^{\hbar\omega/k_B T} - 1\right)^2}$$

Also show that Einstein specific heat capacity given above is proportional to $e^{-\hbar\omega/k_B T}$ at very low temperature. 10

2021

Q12:

In the metallic state the transition metal scandium has a single electron in $3d$ subshell. Calculate the values of total angular momentum $J$ and the Lande splitting factor $g$ and use these values to determine the energy of the lowest energy dipole moment in a field of $0{\cdot}5\,T$. 20

2021

Q13:

A solid contains a dilute concentration of $Nd^{3+}$ ions, each of which possess three $4f$ electrons. Assuming that there are $10^{25}\,\mathrm{m}^{-3}$ of these ions, calculate the magnetic susceptibility of the sample at $1\,K$. 20

2021

Q14:

Explain the drawbacks of Einstein's theory of specific heat and how it was overcome by Debye. 20

2022

Q15:

Explain classical theory of diamagnetism. Show that the susceptibility of diamagnetic substances is directly proportional to the atomic number. Why all the electrons in an atom contribute to diamagnetism ? 5+8+2=15

2023

Q16:

Derive an expression for the specific heat of a solid based on the Debye theory and show how it agrees with the experimental values. What is the most important assumption of Debye theory in comparison to Einstein theory? Is there any drawback of Debye theory? 15+3+2=20

2023

Q17:

Show that the Fermi level shifts upward, closer to the conduction band in an $n$-type semiconductor and shifts downward, closer to the valence band in a $p$-type semiconductor. 10

2023

Q18.

(i) What is the origin of paramagnetism? Discuss the temperature dependence of paramagnetic susceptibility.

(ii) Calculate the diamagnetic susceptibility of atomic Hydrogen in the ground state at STP. Assume the mean square distance of electronic charge distribution of atomic Hydrogen from the nucleus $r^2 = 3a_0^2$, $a_0$ being the radius of the first Bohr orbit of Hydrogen. *8+7=15*

2024

Q19.

Explain the cause of hysteresis phenomenon in ferromagnetic materials. What does the area of the hysteresis loop signify? 10+5=15

2025

Q20.

Classify diamagnetic, paramagnetic and ferromagnetic materials in terms of their magnetic susceptibility ($\chi$). Plot and explain the variation of $\frac{1}{\chi}$ with temperature for the three materials. 20

2025