WEST BENGAL STATE UNIVERSITY

B.Sc. Honours 5th Semester Examination, 2020, held in 2021

PHSACOR12T-PHYSICS (CC12)

SOLID STATE PHYSICS

Time Allotted: 2 Hours Full Marks: 40

The figures in the margin indicate full marks.
Candidates should answer in their own words and adhere to the word limit as practicable.
All symbols are of usual significance.

Question No. 1 is compulsory and answer any *two* from the rest

1. Answer any ***ten*** questions from the following: 2×10 = 20

(a) Show that the lattice constant for a cubic crystal with n number of molecules per unit cell, molar mass M and density ρ is given by $\left(\frac{nM}{\rho N_A}\right)^{1/3}$, where N_A is the Avogadro number.

(b) The radius of an argon atom is 10^{-10}m. Calculate the electronic polarizability of an argon atom. Given that $\varepsilon_0 = 8.854\times10^{-12}\ \text{Fm}^{-1}$.

(c) Calculate the wavelength of the X-ray if the glancing angle for the 1^{st} order is 30º for a crystal with $2.8\times10^{-10}\text{m}$ separation between the atomic planes.

(d) The Hall voltage for the metal sodium is found to be 0.001 mV, for a current (through the sample) I = 100 mA and a magnetic field B = 2.0 Wb m^{-2}. The width of the specimen is 0.05 mm. Calculate the number of carriers per cubic meter in sodium.

(e) All primitive cells are unit cells but the reverse is not true. Illustrate with an example.

(f) Estimate the specific heat C_V for a material at $30\,\text{K}$ where the Einstein temperature for it is 157 K. Find your answer in terms of the universal gas constant R.

(g) Could you explain the existence of band gap in solids using the Drude model? Explain.

(h) Show on the same graph the schematic variations of frequency ω as a function of the wave number q (considering a one-dimensional solid) for (i) optical phonons and (ii) acoustic phonons near the point $q \to 0$.

(i) How does the magnetic susceptibility, according to Weiss' theory, depend on absolute temperature T for a ferromagnetic material above its Curie temperature? Plot the susceptibility as a function of T.

(j) Band gaps between the highest occupied band and the lowest empty band for five materials, *A*, *B*, *C*, *D* and *E*, are given below

$$A \to 0.8\text{ eV};\ B \to 0.69\text{ eV};\ C \to 5.3\text{ eV};\ D \to 10\text{ eV};\ E \to 1.09\text{ eV}.$$

Identify with justification the prospective semiconductors among these.

(k) For a metal kept in a magnetic field $\vec{H}$ at a very low temperature, it is found that the sample develops a magnetic induction $\vec{B} = 0$ inside it. Calculate its magnetic susceptibility. How do you classify the material in terms of its magnetic property?

(l) What is a Wigner-Seitz cell? Show with a diagram how it is constructed for a two dimensional square lattice.

(m) The two plates of a parallel plate capacitor are identical and carry equal amount of opposite charges. The separation between the plates is 5 mm and the space between the plates is filled with a solid slab of dielectric constant 3. The electric field within the dielectric is 10^6 V/m. Calculate the magnitude of the polarization vector $(\varepsilon_0 = 8.854 \times 10^{-12}\text{ F/m})$.

(n) Why is the Dulong-Petit law not useful for calculation of specific heat of a solid at low temperatures?

2. (a) Show that the reciprocal lattice to a bcc lattice is an fcc lattice. 3

(b) A copper wire has length 0.5 m, diameter 0.3 mm and its resistance at 20°C is 0.12 Ω. The thermal conductivity of copper at 20°C is 390 $\text{Wm}^{-1}\text{K}^{-1}$. Estimate the Lorentz number. 2

(c) The frequency of an elastic wave passing through a one dimensional monatomic lattice is given by $\omega(q) = \omega_0 \sin\left(\frac{qa}{2}\right)$, where a is the lattice spacing and q is the wave number and ω_0 is a material-specific constant. How does ω_0 depend on atomic mass? Calculate the velocity of the wave when the wavelength becomes much greater than the lattice spacing. Explain how a lattice could be used as a mechanical frequency filter. 1+2+2

3. (a) Starting from Laue's equations of X-ray diffraction, arrive at the condition for Bragg reflection. 3

(b) Show that the dc electrical conductivity of a metal is given by $\sigma = \frac{ne^2\tau}{m}$, where the symbols carry their usual meanings. State clearly the assumptions, if any, involved in the derivation. 2+2

(c) Using the Clausius-Mossotti relation, make an estimate of the Avogadro number from the data set given below. 3

Dielectric constant of Ne gas at normal pressure and temperature: $\varepsilon = 1.000148$.

Electronic polarizability of Ne: $\alpha = 0.4 \times 10^{-24}\text{cm}^3$.

Assume an ideal gas behaviour for Ne.

4. (a) Consider the following one dimensional periodic potential $V(x)$ in which an electron is constrained to move. 1+3

$$V(x) = 0 \text{ for } 0 < x < a$$
$$= V_0 \text{ for } a < x < a + b$$

Suggest a form of the wave function that is expected to satisfy the corresponding Schrödinger equation. In the limit $b \to 0$ and $V_0 \to \infty$, the quantization condition of the wave-vector k in the above problem (subject to suitable boundary conditions) turns out to be $\frac{P}{Qa}\sin Qa + \cos Qa = \cos ka$, where $P \propto ba$ is a finite quantity, and $Q \propto \sqrt{E}$ (E is the energy eigenvalue). Hence show that this model explains formation of band gaps of disallowed energy values.

(b) Using Langevin's theory, obtain the temperature dependence of magnetic susceptibility of a paramagnetic gas (mention the inherent assumption in the derivation). 5

(c) Mention an application of Hall effect. 1

5. (a) Consider a lattice with lattice constants $\vec{a}$, $\vec{b}$ and $\vec{c}$. Define the reciprocal lattice vectors and find a relation between the volumes of primitive cells in the direct and the reciprocal lattices. 2+2

(b) Iron is a ferromagnetic material. However, an iron nail usually does not show ferromagnetic properties even below the Curie temperature. Why? What happens to its microscopic structure above the Curie temperature? 2+1

(c) "The dispersion (frequency ω vs. wave-vector k) relation of an elastic wave in a fluid is linear in k. But it is not so in a solid in general" – why? Why does the group velocity of an elastic wave propagating in a solid vanish at the Brillouin zone boundaries? 1+2

N.B. : *Students have to complete submission of their Answer Scripts through E-mail / Whatsapp to their own respective colleges on the same day / date of examination within 1 hour after end of exam. University / College authorities will not be held responsible for wrong submission (at in proper address). Students are strongly advised not to submit multiple copies of the same answer script.*

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