International Institute of Information Technology, Hyderabad

(Deemed to be University)

SC1.311: Quantum Materials and Devices (Monsoon 2025)

Mid Semester Examination

Date: 25/09/2025 **Duration: 1.5 hour**

Section A: Multiple Choice (1 mark x 10 = 10 marks)

1. **In a semiconductor, increasing temperature generally:**
   A) Decreases the number of carriers
   B) Increases the number of carriers
   C) Does not change carrier concentration
   D) Makes it metallic

2. **Which lattice structure has the highest packing efficiency?**
   A) Simple cubic (SC)
   B) Body-centered cubic (BCC)
   C) Face-centered cubic (FCC)
   D) Hexagonal close-packed (HCP)

3. **The bandgap of a direct bandgap semiconductor occurs when:**
   A) The conduction band minimum and valence band maximum occur at different k-values
   B) The conduction band minimum and valence band maximum occur at the same k-value
   C) The valence band is partially filled
   D) The material is metallic

4. **Which of the following is a characteristic feature of a quantum well?**
   A) Electron motion is confined in all three directions
   B) Electron motion is confined in two directions
   C) Electron motion is confined in one direction
   D) Electron motion is free in all directions

5. **In a quantum wire, the density of states (DOS) varies with energy as:**
   A) $E^{1/2}$
   B) E_0 (constant)
   C) $E^{-1/2}$
   D) E^2

6. **Which material is a well-known 3D topological insulator?**
   a) Graphene
   b) Bi_2Se_3
   c) YBCO
   d) FeSe

7. **Spin–momentum locking in 3D TIs means:**
   a) Electron spin direction is random.
   b) Electron spin is always perpendicular to momentum
   c) Spin is independent of momentum.
   d) Spin aligns with external magnetic field.

8. **What is the nature of the surface state dispersion in 3D TIs?**
   a) Quadratic
   b) Linear (Dirac cone)
   c) Flat bands
   d) Parabolic

9. **Which of the following 2D materials has a zero bandgap with linear energy dispersion near the Dirac points?**
   A) MoS_2
   B) WS_2
   C) Graphene
   D) Black phosphorus

10. **Which property makes transition metal dichalcogenides (TMDs) like MoS_2 attractive for optoelectronics?**
    A) High thermal conductivity
    B) Direct bandgap in monolayer form
    C) Zero effective mass
    D) Metallic behavior in all thicknesses

Section B: Fill in the blanks (1 mark x 10 = 10 marks)

11. Bloch's theorem states that the wavefunction in a periodic potential can be expressed as ____________.

12. A material with completely filled valence band and large bandgap is classified as a ____________.

13. Berry phase is a geometric phase acquired over a closed ____________ in momentum space.

14. Superconductivity was first discovered in ______________ (material) in 1911 by Heike Kamerlingh Onnes.

15. The temperature below which a material becomes superconducting is called the ______________.

16. Superconductors exhibit ______________ effect, which is the complete expulsion of magnetic fields.

17. Superconductors have ______________ electrical resistance at temperatures below T_c

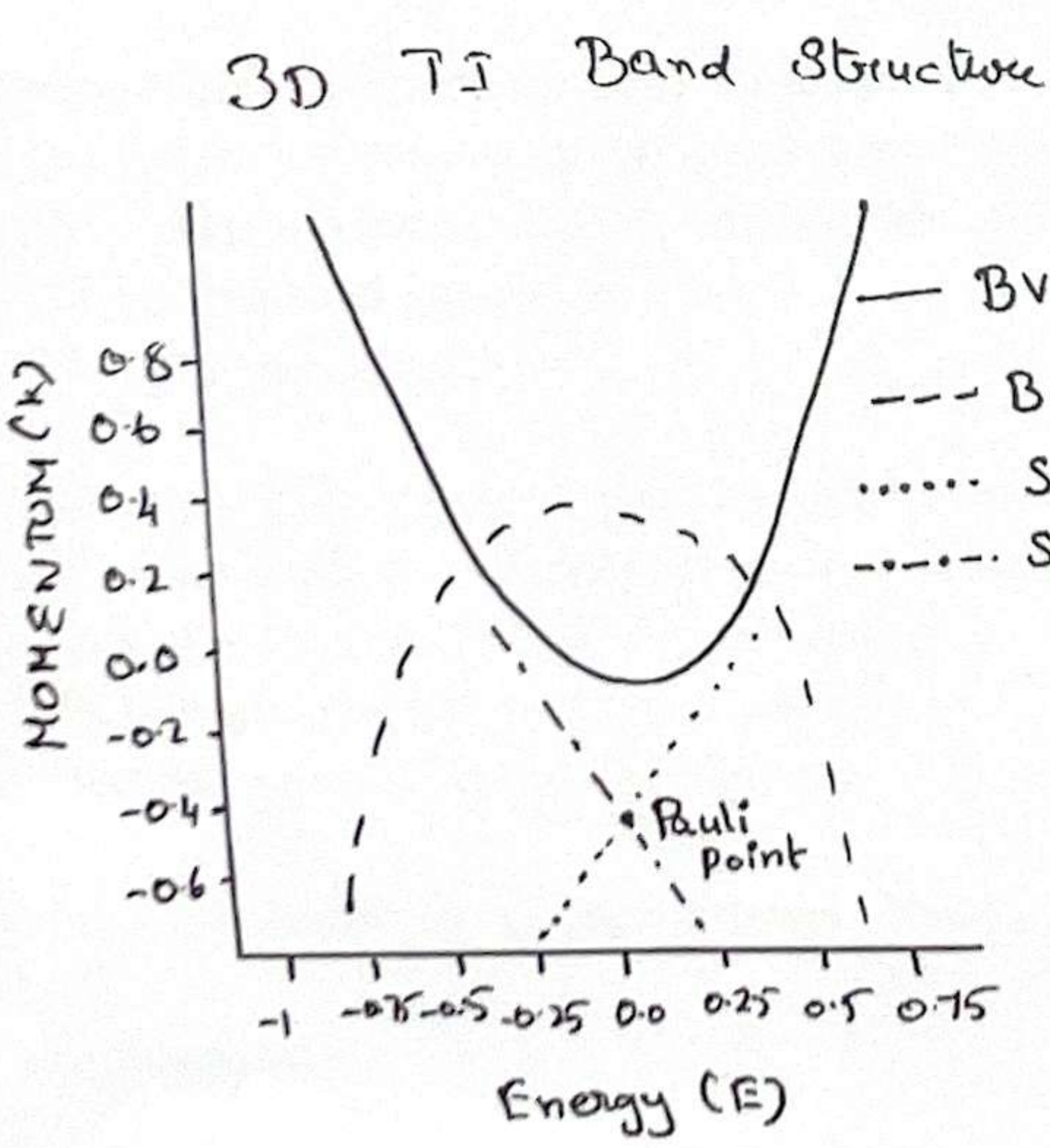
18. In conventional superconductors, the electron pairing is mediated by ______________.

19. A Josephson junction consists of two superconductors separated by a thin ______________

20. High-temperature superconductors typically have a ______________ critical temperature compared to conventional superconductors.

Section C: Short Answers (5 marks x 2 = 10 marks)

21. The graph below shows the band structure of a 3D topological insulator and contains five intentional errors. Identify all five errors



22. Write a short note on Higher-Order Topological Insulators (HOTI)

Section D: Long Answers (10 marks x 2 = 20 marks)

23. A particle of mass m is confined to a one-dimensional box of length L (from $x=0$ to $x=L$) with infinitely high walls.
    a. Derive the time-independent Schrödinger equation for the particle inside the box. (3 marks)
    b. Using the appropriate boundary conditions, solve the equation to show that the energy eigenvalues are quantized. Express the energy levels, E, n, in terms of $n, \hbar, m$, and L. (5 marks)
    c. For the ground state ($n=1$), find the probability of finding the particle in the region $0 < x < L/2$. (2 marks)

24. Describe the various Hall effects. Explain their unique physical origins, key features, and practical applications. Provide a labeled diagram for each of these effects.