

Topics for QuTI PhD Entrance

with specialization in Physics, Materials Science, Nanotechnology and Electronics & Communications

1. Quantum Mechanics:

- Postulates, wave-particle duality, and wave functions.
- Dirac notation (bra-ket), operators, and matrix mechanics.
- Exact solutions: Particle in a box, harmonic oscillator, and the hydrogen atom.
- Angular momentum, spin-1/2 systems, and Pauli matrices.
- Time-independent and time-dependent perturbation theory.
- Quantum tunneling.

2. Materials Science / Solid State Physics:

- Crystal lattices, reciprocal lattices, and Brillouin zones.
- Band theory of solids, origin of bands, Kronig-Penney model, metals, insulators, and semiconductors and Hall effect.
- Calculation of density of states in low-dimensional systems (Quantum wells, quantum wires, and quantum dots) and the quantum Hall effect.
- Semiconductor Physics: Intrinsic and extrinsic semiconductors, carrier concentration, Fermi energy level, drift-diffusion currents, electron-hole pair generation and carrier-recombination, p-n junction physics, BJT and MOSFET characteristics, Impact Ionization and Avalanche Breakdown, RC Time Constants
- Superconductivity: Basic phenomenology, Meissner effect, and Type-I vs. Type-II superconductors. BCS theory, Josephson effect (AC and DC).

3. Thermal and Statistical Physics:

- Temperature dependent behavior of specific heat and thermal conductivity
- Ensembles (microcanonical, canonical, grand canonical).
- Classical (Maxwell-Boltzmann) vs Quantum statistics (Bose-Einstein and Fermi-Dirac distributions).
- Bose-Einstein Distribution & Blackbody Radiation: Planck's radiation law, photon gas, and energy density
- Density matrix formalism, fluctuations, and thermal noise in quantum devices.

4. Applied Electromagnetism and Photonics:

- Electromagnetic wave propagation in vacuum and dielectric media, boundary conditions at interfaces and phase matching & Transfer matrix formulation and Phase shifts
- Wave Optics: Wave Plates, Polarization, interference, diffraction, and coherence. Dielectric tensor, Birefringence, ordinary and extraordinary refractive indices. Electro-optic effect

- Guided Wave Optics: Optical fibers, step-index/graded-index fibers, Fabry-Perot cavities, Optical resonance.
- Interaction of light and matter (absorption, spontaneous/stimulated emission), Einstein Coefficients, Transition dipole moments, Rabi oscillations, and Lorentz oscillator models for atomic resonance. Doppler and Zeeman tuning.

5. Electronics and Mathematical Aptitude

- Linear Algebra: Vector spaces, matrices, eigenvalues, and eigenvectors (the universal language of quantum states and matrix mechanics).
- Basic Probability & Statistics: Probability distributions, expectation values, and variance (essential for parsing quantum measurement outcomes)
- Complex numbers: Euler's Identity, Complex conjugate, Modulus squared, Unitary condition and De Moivre's Theorem
- First and Second order Ordinary Differential equations and partial differential equations
- Analog Electronics: Op-Amp integrators / Differentiators, Differential Amplifiers, RF Impedance matching, Thermal and Shot Noise calculations
- Digital Electronics: Boolean algebra, logic gates (AND, OR, NOT, XOR), and de Morgan's theorems.