Topics

Quantum Mechanics Course

Group-A

Vibrating molecules

1. Motivation

(a) The greenhouse effect in the atmosphere.
(b) Absorbtion and emission of radiation from matter and the Green- house gases.

(c) The question:
Why are H2O and CO2 greenhouse gases whereas N2 and O2 are not.

2. Basics of the quantum mechanics

(a) Classical mechanics of a single particle: States, phase space, observables, Newtons Laws, equations of motion. Generalised coordinates.

(b) The uncertainty principle and quantum regime. Examples: Di-atomic molecules, electrons in an atom, electrons in quantum dots, cold atoms.

(c) The wave function and Schroedinger equation. Physical meaning of matter waves: probability density, probability current, continuity equation. Wave packets, Fourier transforms and the mathematical realisation of the uncertainty principle.

3. A quantum harmonic oscillator

(a) Diatomic molecule. Rotational and vibrational motion. Harmonic approximation for vibrations. Hamiltonian and parameters for N_2 and O_2.

(b) Schroedinger equation. Stationary states. Spectrum using creation annihilation operators. Wave functions and their physical interpretation.

(c) Monochromatic radiation, photons, description in terms of a quantum harmonic oscillator. Physical interpretation and classical limit.
(d) Interaction of radiation with matter, allowed transitions.

4. Coupled harmonic oscillators

(a) Triatomic molecules. Many particle wave functions. Bosons and fermions.

(b) Vibrational motion of triatomic molecules. Harmonic approximation and hamiltonian. Parameters for H_2O and CO_2.

(c) Normal modes and interpretation.
(d) The quantum spectrum and allowed transitions.

Group-B

Module 1: Double slit experiment a la Feynman, extending to many slits, Laue spots and crystal structure, electron scattering and electron microscopy

Module 2: \delta-function potentials, two \delta functions, (tunneling, oscillation, beats), \delta functions on a line and bands, band heads etc

Module 3: Two level systems, spin-1/2 system, exact result, perturbation Calculations

Module 4: Scattering I - square well, phase shifts, low energy properties, deuteron etc

Module 5: Scattering II - resonences, resonance structure, relation to excited states

Module 6: Identical particles, Fermions, shell model in atomic, nuclear and nanoparticle physics, degenerate case and white dwarf, neutron star.

Group-C

(A) Motivation from HEP and CMP for relativistic quantum mechanics, Dirac equation in 1+1, 2+1 and 3+1 dimensions, reduction to Majorana, Weyl

(B) Graphene, hexagonal lattice, Klein paradox, extensions to other materials like silicene, etc

(C) Particles in an electromagnetic field, Landau levels in non-relativistic and relativistic cases, basic quantum Hall effect in non-relativistic and graphene systems

(D) Many-body wave-functions, Slater determinants, the Laughlin wave-function, application to fractional quantum hall effect

Quantum Field Theory Course

SM (Topics: 1, 2, 4); **SMB** (Topics: 3, 5, 7 cond mat way); **PP** (Topics: 6, 7, 8, 9)

1. Particles to fields
   Classical harmonic chain, phonons, specific heat at high temperature; Quantization, quasi-particles, specific heat at low temperature.

2. Scalar field theory, Lorentz invariance, symmetry and currents, construction of Lorentz invariant Lagrangian, Greens function, phi^4 interaction, renormalization in quantum mechanics and field theory

3. Ising model, Hubbard-Stratanovich transformation, connection with phi^4 model

4. Fermionic field theory, Weyl, Dirac Lagrangians, Physics of neutrinos as an example.

5. Emergence of Dirac equation in non-relativistic situation (Peierls Instability as an example?)

6. Gauge fields, gauge invariance, construction of free and interaction Lagrangians maintaining gauge invariance.

7. Spontaneous symmetry breaking, Higgs mechanism, Goldstone boson, some examples from high energy and cond-mat systems.

8. Doing a bit of non-perturbative field theory (soliton/instantons, tunneling etc).
9. Special topics like CV violation, Mass Generation Mechanism