Advanced Engineering Physics, FY2017

“Introduction to the solid state spectroscopy"

by Professor Vladimir S. Krivobok

1. Periodic structures (~ 1 lecture)

Basics: translational symmetry, general overview of translationally invariant functions, reciprocal lattice and its properties, wave function of the system with a translational invariance, Bloch theorem, Brillouin zone, periodic boundary conditions, selection rules for a transition in the periodic systems. X-ray diffraction in solids.

2. Types of solids (~ 1 lecture)

Basic approximations used to obtain the spectrum of solids. Valent and strongly bound electrons, adiabatic approximation, self-consistent approach (single-electron approximation) for electron spectrum. Band structure of the spectra for electron and phonon subsystems. The role of non-adiabatic term.

Fermi statistics for electrons, types of solids: metals, dielectrics, semiconductors. Types and structure of chemical bonds. Types of Semiconductors (elementary, layered, organic etc.) and semiconductor nanostructures. Electrons and holes. Intrinsic absorption edge. The emission spectrum of a semiconductors near its fundamental absorption edge. Basics of the metal optics.

3. Main approaches applied for calculation of electronic spectrum in solids (~4 lectures)

The band structure of solids in the approximation of weakly bound electrons – 1D and 3D cases.

Close coupling method (linear combination of atomic orbitals). Spectrum of semi-infinite 1D atom chain. “Volume” and “edge” solutions. Tamm levels and related phenomena. Close coupling scheme for a 3D periodic system: eigenfunctions and eigenstates. Example of applications: band structure of graphene and the related physical properties.

Orthoganalized waves. Pseudo-wave equation. Why does the model of weakly bound electrons (qualitatively) works? Empiric and ab-initio pseudopotential method.

Kp -method and effective mass. Wannier functions. The motion of an electron (hole) in a slowly changing potential: equation for the envelope of the wavefunction. Shallow electronic levels related to a charged defect in a semiconductor.

4. Vibrational properties of atoms and electron-phonon interaction (~ 3 lectures)

Hamiltonian describing the motion of ions (adiabatic approximation). Classical treatment of the translationally invariant problem. Normal modes and harmonic approximation. Effects related to the unharmonic contributions. Examples: chain of identical atoms, chain containing two types of atoms. Acoustic and optical branches. Influence of lattice polarization. Dispersion and types of phonons in a real crystal. Quantum treatment of the problem.

Phonons in a perturbed lattice - classical treatment of the problem. Green function. Example: chain of the identical atoms containing an isotope. Phonon scattering by the defects and local phonon modes.

Electron-phonon coupling. Deformation potential, piezoelectric interaction, frohlich interaction. Example: Electron-phonon coupling in a simple cubic lattice treated using close-coupling approximation.

The absorption and reflection of light near the lattice resonances. Phonon polaritons. Multiphonon lattice absorption.

Quantum size effects for electrons and phonons in semiconductor nanostructures. Boundary conditions for electron (holes) localized in quantum well.

5. Basics of the light-matter interaction treated for the single-electron approximation (~ 4 lectures)

Maxwell equations in a medium. Dielectric function. The principle of causality. Kramers-Kronig relations: deduction and some examples. Complex refractive index. Electron-radiative interaction.

Linear response of electrons to a periodic perturbation. Random phase approximation. Dynamical screening of an external perturbation in the electron gas. Screening of the static potential in the case of degenerate and non-degenerate electron gas.

Dielectric function of metals. Plasma frequency. Interaction of electromagnetic radiation with a metal. Plasmon and surface plasmon polariton. Plasmon dispersion curve for 3D and 2D electron gas.

Microscopic description of absorption and reflection of light in a semiconductor (dielectric). Complex dielectric function of semiconductor. High-frequency and low-frequency limits for the dielectric function. The frequency dependence of the dielectric function in the one-electron approximation. Van-Hoff Singularities. Direct and indirect intrinsic absorption edges.

6. Some phenomena beyond the single-electron approximation (~ 3 lectures)

Various quasi-particles in solid state physics, arising due to the separation of the “main” part and “perturbation” part in the sectional hamiltonian of a solid state: Exciton, polaron, polariton, plasmaron, trion, cooper pair, etc.

Correlated state of electron and hole: Wannier and Frenkel excitons. Spectrum and wave function of Wannier excitons. Contribution of excitons to the complex dielectric function. Absorption and emission spectra of excitons. Excitons in low-dimensional systems. Charged excitons (trions). Bound exciton. The “giant” oscillator strength of weakly bound exciton.

Mott transition for a system of excitons. Electron-hole plasma and electron-hole liquid. Electron-hole-plasma and electron-hole liquid in low-dimentional structures.

Strong interaction of excitons with light: exciton polaritons. Polaritons in microcavities. Applicability of polariton basis for the description of inhomogeneous system. “Boson” laser.

Cooper pair. Basics of the classical theory of superconductivity.

7. Some types of optical spectroscopy (~ 1 lectures)

Low-temperature luminescence of bulk semiconductors and semiconductor nanostructures. Raman scattering. Modulation spectroscopy. Franz-Keldysh effect. Resonance Ramman scattering. Some examples.