Solid State Physics Syllabus / Academic year 2012-2013

Introduction

Crystalline structures: Bravais lattice, primitive vectors and primitive cell; the reciprocal lattice: definition, primitive vectors and construction of the primitive cell. Direct and reciprocal lattice examples for sc, fcc and bcc structures. Miller indices. X-Ray diffraction: the Bragg approach and the Von Laue approach. Ewald sphere. (Chapt. 4, 5, 6 [1])

The free electron model

The Drude Model; conductivity and dielectric constant of a metal in the framework of the free electrons gas. Quantum approach to the free electron model: the Sommerfeld model. Boundary conditions for the free electrons gas, Fermi energy and Fermi level, density of states. Failures of the free electron model. (Chapt. 1, 2 [1])

Electrons in a periodic potential

The ions periodic potential and Von Karman boundary conditions; the Bloch's theorem, Schrodinger equation in momentum space. Fermi energy and Fermi surface. Electrons in a weak periodic potential: gap opening near a Bragg plane, energy bands and their representation (extended, reduced, and repeated zone scheme). The Fermi surface and its deformation close to Bragg planes. (Chapt. 8, 9 [1]). Different methods for the calculation of electron levels in a solid: tight-binding (TB) method (application of the TB method to a band arising from s-levels), (Chapt. 10 [1]); orthogonalized plane wave (OPW) method and pseudopotentials (Chapt. 11 [1]).

The semiclassical model

The main hypotheses of the semiclassical model; interplay between band structure and electronic transport. Electronic motion in presence of a constant electric field, of a constant magnetic field and in presence of both fields. Effective mass, Hall effect and magnetoresistance. (Chapt. 12 [1])

Fermi Surface and band structure

The shape of the Fermi surface: the de Haas – Van Alphen effect (Chapt. 14 [1]). Band structure for alkali and noble metals. Optical properties of metals, direct transitions. (Chapt. 15 [1]; [4])

The contribution of electron-electron interactions

Hartree and Hartree-Fock approximation; Slater determinant as N-electrons wavefunction. Interaction effects on electron levels energy; exchange contribution. (Chapt. 17 [1]). Second quantization approach: costruction and destruction operators, (Chapt. 2 [2]) field operators, single electron energy evaluation, Koopman's theorem (Chapt. 5 [3]). Electron-electron interaction: direct and exchange processes. Electrons gas susceptibility and contribution to the metal dielectric constant (screening) (Chapt. 17 [1]).

The contribution of lattice vibrations

Failure of the static lattice approach; adiabatic and harmonic approximations. Dynamical matrix approach; acoustical and optical branches. Phonons: energy dispersion curve, contribution to specific heat; comparison with the electrons contribution. Probes used to access phonons energy dispersion curves: neutrons, phonons and photons (Chapt. 22 – 24 [1]).

Electron-phonon interaction: temperature dependence of electronic conductivity, umklapp processes and momentum conservation (Chapt. 25 [1]).

Phonons contribution to the dielectric constant of a metal; phonons contribution to electron-electron interaction (Chapt. 26 [1]). Binding energy of a Cooper pair; features that stabilize the Cooper pair: gap opening and Fermi sphere. Properties of superconductors: outline. (Chapt. 3[2])

Dielectric constant of a ionic crystal: atomic and displacement polarizability. Clausius-Mossotti relation; dielectric constant dependence on frequency in the low-frequency approximation. (Chapt. 27 [1], chapt. 3 [3])

Magnetic properties of matter

Spin and Orbital contribution to electron magnetic moment; paramagnetism of isolated magnetic moments, Brillouin function (Chapt. 31, [1]). Weiss molecular field theory (Chapt. 33, [1]). Exchange interaction and Heisemberg Hamiltonian (Chapt. 32, [1]); ferromagnetic solution of the Heisemberg Hamiltonian using mean field theory [5].

[1] Solid State Physics, Neil W. Ashcroft and N. David Mermin

[2] http://campus.unibo.it/69871/1/TQM-2011.pdf Appunti di Meccanica Quantistica, prof. Fabio Ortolani, Università degli Studi di Bologna

[3] Quantum Theory of Solids, C. Kittel

[4] Representations of the shape of the Fermi Surface for different materials may be found here or here.

[5] Many Body Quantum Theory in Condensed Matter Physics, H. Bruus and K. Flensberg.