UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Solid State Physics

1920-1-F5302Q001

Aims

A first part of the course is devoted to the treatment of simpler phenomena, as described in terms of non-interacting particles (Electrons or phonons), with particular attention in teaching the skill of developing analytical models , which allow to solve complicated problems by ingenious simplifications. The second part analyzes more complex phenomena, generated by the interaction among particles, which give rise to significant macroscopic properties of the perfect and infinite solid. In this part, the focus is placed on the understanding of non-intuitive concepts and the ideal line of reasoning, preferring - also here - the methodological approach rather than the taxonomic one. The complementation of a main text with several others, depending on the topic, is an important aspect of the teaching method , that is, to acquire the habit of consulting different sources and comparing them critically.

Contents

First Part

BRIEF REVIEW OF CRYSTAL STRUCTURES AND BRAVAIS LATTICES

LATTICE DYNAMICS IN THREE DIMENSIONS

THERMAL PROPERTIES OF SOLIDS IN THE AND HARMONIC AND ANHARMONIC APPROACH

FREE AND INDEPENDENT ELECTRON GAS

FUNDAMENTALS AND CALCULATION OF ELECTRONIC BANDS

CHARGE TRANSPORT IN METALS

PARAMAGNETISM, DIAMAGNETISM AND LANDAU LEVELS

Second Part

CALCULATION OF THE ELECTRONIC BANDS WITH SELFCONSISTENT METHODS

ELECTRON SCREENING AND THE STRUCTURAL ENERGY OF METALS

FERROMAGNETISM FOR ITINERANT AND LOCALIZED SPINS

SUPERCONDUCTIVITY AND THE BCS THEORY

Detailed program

Crystal structures and diffraction

_relevant crystal structures

_construction of the reciprocal lattice and the Brillouin zones for fcc and a bcc lattices

_calculation of the distance in silicon.

Lattice dynamics

_ force constant matrix and its symmetries

_ dynamic matrix and the equations of motion

_construction and diagonalization of the dynamic matrix for one fcc monatomic: eigenvalues and displacement patterns

_ diatomic linear chain

_ dispersion curves of real crystals

_ inelastic scattering and measurement of phonon dispersion by neutron scattering

Thermal properties

_ from normal modes to phonons as quasi-particles

_ density of vibrational states

_ specific heat in Debye and Einstein models

_ anharmonic potentials and the heat capacity in Dulong Petit regime

_ thermal expansion the meaning of the Gruneisen parameter _ thermal conductivity

Free electrons

_ recalls on the electronic gas at T = 0, steric repulsion

_ density of states in 1, 2 and 3 dimensions

_ trend of the chemical potential in T

_ electronic contribution to the specific heat

_ the work function and the thermal emission of electrons

Electronic bands

_ expansion in plane waves and the central equation

_ Bloch waves and new meaning of the moment p

_ Construction of the band diagram for the empty lattice

_ opening of the gaps at the Brillouin zone borders and its interpretation

_ expansion of the Bloch wave in atomic orbital: tight binding (TB)

_ band energy as a function of TB parameters and neighbors. Construction and diagonalization of the tight binding matrix in sp3 basis and first neighbors for silicon

_ interpretation of real bands and their density of states

_ measurement of the dispersion of the bands by electron photoemission resolved in angle

Charge transport

_ The semiclassic model by packages of Bloch waves, equations of motion

_ the effective mass tensor and the concept of positive hole

_ Boltzman equation: balance between the process of drift and those of scattering

_ the relaxation time approximation in the processes of scattering

_ microscopic mechanisms that rule the scattering of charges

_ the classic model of transport by Drude and its limits

_ the electrical conductivity as the integral on the Fermi surface

_ dependence of resistivity from the temperature in a metal

_ heat transport by electrons

_ the Wiedemann-Franz law

_ thermoelectric effects (Peltier and Seebeck)

Magnetic properties

_ diamagnetism and paramagnetism in solids, why negligible values for susceptibility

_ Pauli paramagnetism and Landau diamagnetism for the gas of free electrons

_ electron motion in a magnetic field

_ Landau levels and the de Haas - van Alphen effect

The many electron problem

_ the average field approaches: Hartree and Hartree-Fock equations

_ the interacting gas of free electrons and the density dependent energy

_ the Hohenberg and Kohn theorem and the equation of Kohn-Sham

_ the density functional method in the local approximation DFT-LDA

_ cellular methods, the muffin tin potential, and the augmented plane waves

_ orthogonalized valence plane waves, the pseudopotential method

Screening in the electron gas

_ from Poisson equations to relations between epsilon and susceptibility: classical model

_ the Thomas-Fermi model of the electrostatic shield (constant susceptibility)

_ the Linhard model of the electrostatic shield (susceptibility depends on q)

_ the quantum interpretation of the ineffectiveness of the screen beyond 2kF and the charge density waves

_ from the jellium model to the real metal

_ cohesion energy for different structures in metals simple: the two bodiy potential to effective.

Ferromagnetism

_ Stoner model for itinerant ferromagnetism in metallic solids

_ effect of temperature in the Stoner model, Curie temperature

_ origin of ferromagnetic interactions in insulating solids and the Heisemberg hamiltonian

_ ferromagnetism in insulators, the Curie temperature and the susceptibility vs T

_ excited magnetic states and the spin waves; other collective excitations in solids

Superconductivity

_ introduction to superconductivity

_ Meissner Ochsenfeld effect: expulsion of the magnetic field

_ the thermodynamics of the transition to the superconducting state

_ the London and London equations: penetration of currents and magnetic fields

_ origin of the attraction in the Cooper pair, instability of the ground state

_ derivation of the fundamental BCS state

_ existence of the gap, its nature, and definition of the excited states

_ dependence of gap from T, relationship between Tc and gap at T = 0; isotope effect

_ the supercorrent as steady state and the critical values of current and magnetic field

_ some phenomenology of high-temperature superconductors

The defected solid

_Shallow impurity states in semiconductors by Bloch states

Prerequisites

Atomic and molecular quantum physics

Elementary introduction to Solid State Physics

A short course in advanced calculus

Teaching form

Lessons

Textbook and teaching resource

PRINCIPAL TEXTBOOK:

H. IBACH AND H. LUTH, *Solids State Physics*, Springer Verlag

ADDITIONAL CHAPTERS ARE TAKEN FROM:

N.W ASHCROFT AND N.D. MERMIN, *Solid State Physics*, Saunders College Publishing

F. BASSANI E U. GRASSANO, *Fisica dello Stato Solido*, Casa Editrice Boringhieri

G. GROSSO AND G. PASTORI PARRAVICINI, *Solid state Physics*, Academic Press

A.P. SUTTON, *Electronic Structure of Materials*, Oxford University Press

J.R. HOOK and H.E. Hall, *Solid State Physics*, John Wiley & Sons

S. BLUNDELL, Magnetism in Condensed Matter, Oxford University Press.

Semester

First and second semester at different lesson periodicity

Assessment method

The final examination includes a discussion of written derivations for the first, more simple, part of the course, and a fully oral discussion of the second part, more complex in items. The two steps can be undertaken even in a separate sequence.

Office hours

By appointment writing one e-mail to leo.miglio@unimib.it. Usually on Monday, Wednesday and Friday in the same week.