UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Solid State Physics

2526-1-FSM02Q001

Aims

The Course is aimed to let the students acquire concepts, methods and models of the physics of perfect and infinite crystalline solids. To this purpose, topics are divided into two parts. A first part of the course is devoted to the treatment of simpler phenomena, as described in terms of the crystal periodicity, with no interaction between electrons and ions. Particular attention will be payed to the calculus of macroscopic properties on the basis of microscopic ones. The second part includes the phenomena where the electrons interact with the crystal lattice and the variations in its periodicity, returning the band structure of crystals and the transport properties of solids, respectively. At the end of each macro-subject, an appropriate slot of time will be devoted to review, in order to getting familiar with the concepts and refresh the mathematical derivations, also by a discussion with the students. The complementation of a main Book with the powerpoint presentation of the lessons, as uploaded to the Course webpage, is one important aspect of the teaching method that aims also at making the students acquire a correct technical language.
In summary, the main achievements of the students will be:

1. Knowledge and understanding of concepts related to the periodicity of the lattice and to the reciprocal space.

2. Applying knowledge and understanding of approximations and Taylor expansions in deriving microscopic expression of macroscopic properties.

3. Making judgements about the predictive power of models in relation to the experimental data and decide which theory best fits to them.

4. Communication skills, as based on a correct use of technical terms, addressing them inside a story-telling which presents facts and hypothesis.

5. Learning skills, as incentivated by a rich bibliography and the indications of the scientist mostly responsible for experiments, theories, or models.

Contents

Detailed program

PART 1
I. Crystal structures and diffraction

- Bravais lattices and relevant crystal structures
- Theory of diffraction and experimental techniques
- Construction of the reciprocal lattice and the Brillouin zones, in particular for FCC, BCC and HCP structures
- Calculation of the distances between high-symmetry points in the Brillouine zone of silicon.

II. Lattice dynamics

- Foundations of lattice dynamics: force constant matrix and its symmetries, dynamical matrix and the equations of motion
- Dispersion relations and displacement patterns of the diatomic linear chain
- Elasticity theory and sound waves
- Construction and diagonalization of the dynamic matrix for one fcc monatomic: eigenvalues and displacement patterns
- Normal modes as collective modes
- Phonons and their statistics
- Inelastic scattering and measurement of phonon dispersion by neutron scattering

III. Thermal properties of solids

- Density of vibrational states
- Specific heat in Debye and Einstein models
- Anharmonic potentials and their effects: thermal expansion and the heat capacity of 1-D oscillator
- Thermal expansion and the Gruneisen parameter in 3-D
- Thermal conductivity by lattice vibrations in 3-D

IV. The free-electron gas

- The free-electron gas model
- The Fermi-Dirac statistics of electrons
- Density of states: definition and calculation for 3-D, 2-D and 1-D electron gas.

- Trend of the chemical potential in temperature
- Electronic contribution to the specific heat and heavy fermions
- Thermal emission of electrons: physics and application

PART 2

V. Electronic bands

- Periodic potential, central equation and Bloch states
- Construction of the band diagram for the empty lattice
- Band structure in the nearly-free electron model: opening of the gap at the Brillouin zone borders and its interpretation
- Introduction to the Tight-Binding model (TB)
- Band calculation in the TB model: role of neighbors and atomic basis and hopping integrals
- Construction and diagonalization of the tight binding matrix to first neighbors for silicon
- Interpretation of real bands and their density of states
- Measurement of the dispersion of the bands by angle-resolved electron photoemission

VI. Transport of charge by electrons

- The semiclassical model and motion of electrons in bands due to an electric field
- The effective mass tensor and the concept of positive hole
- Boltzmann equation: balance between the process of drift and the one of scattering
- The relaxation time approximation for scattering processes
- Microscopic mechanisms that rule the scattering of electrons in bands
- The electrical conductivity in metals
- Dependence of electrical conductivity on the temperature

VII. Transport of heat by electrons

- Generalization of the Boltzman equation to thermal gradients
- Heat transport by electrons and the Wiedemann-Franz law
- Thermoelectric effects (Peltier and Seebeck) and applications

VIII. Effects of weak and strong magnetic fields

- Weak magnetic fields
- Strong magnetic fields
- Derivation of Landau energy states
- Magnetic properties of materials
- Free electron magnetism

Prerequisites

Atomic and molecular quantum physics

Elementary introduction to Materials

Elements of calculus for complex variables, special functions, series and Fourier transforms

Teaching form

40 one-hour lessons in delivered modality and 12 one-hour practice lessons in delivered modality. In some cases the lessons could be delivered also in remote synchronous modality (at the same time), if the atheneum would require it for students still not present in Italy.

Textbook and teaching resource

MAIN TEXTBOOK:

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

ADDITIONAL CHAPTERS ARE TAKEN FROM THE FOLLOWING BOOKS, STILL AVAILABLE IN ENGLISH IN THE E-LEARNING PLATFORM OR AVAILABLE FROM THE UNIVERSITY LIBRARY:

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

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

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

Semester

First semester.

Assessment method

The exam consists of a written test with four open questions, including the possible mathematical derivation of some physical results, the plotting of graphs, or the description of experiments. The evaluation of the written test is made, in order of decreasing importance, on the correspondence of the answer to the question, on the accuracy and coherence of the arguments, and on the richness of the appropriate comments. The final grade is also decided on the basis of a discussion of the written test with the student, which follows by a few days the publication of the evaluation of the written test and which mainly insists on requesting completion or correction of what is lacking in the written test. Once the Course is completed, nine annual exam sessions are offered, scheduled during the breaking periods of the lessons.
During the period of the lessons of the Course, however, the students enrolled in that academic year will have the possibility of dividing the exam into two partial tests in progress, one relating to the topics of Part 1 of the Course and the other relating to the topics of Part 2. These partial tests will consist of a written test of 3 open questions, with the same methods of evaluation as the written tests mentioned above, followed by a short oral interview to discuss the written test, in the same ways as above. To facilitate preparation, organize and explain the exam methods and answer any questions on the topics of the lessons, before each partial test a meeting will be organized with the enrolled students, and open to all the others. If a student fails the test on the first part, he/she will have one (only) further opportunity to try it again, before the lessons of the second part of the course are finished; if he/she fails the test on the second part, he/she will have one (only) further opportunity to try it again,

within the starting date of the second semester.

Office hours

By appointment writing one e-mail to leo.miglio@unimib.it, or to roberto.bergamaschini@unimib.it for questions related to the exam session organization,

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE