CONDENSED MATTER PHYSICS

Programme

Crystal structures and Bravais lattice. Reciprocal lattice. Diffraction and solid crystals, structure factor. Born-Oppheneimer approximation. Lattice vibrations, phonons, specific heat (Einstein's and Debye's model, density of states). Electrons in solids, Bloch's theorem,. Band structure. Tightly and weakly bound electrons. Holes and effective mass. Electrons in metals and interaction with an electromagnetic field (dielectric response, metal transport properties): Drude's and Sommerfeld's models. Intrinsic and extrinsic semiconductors. Temperature dependence of charge carrier density. p-n junction.

Adopted texts

N.W. Ashcroft, N.D, Mermin, "Solid State Physics", Holt-Saunders Int. Ed. 1981
C. Kittel, "Introduzione alla Fisica dello Stato Solido", Ed. CEA, 2008
J. M. Ziman-Principles of the Theory of Solids - Cambridge University Press, 1979
M.L. Cohen, S.G. Louie, Condensed Matter Physics - Cambridge University Press, 2016

PHYSICS LABORATORY I (THEORY)

Programme

Syllabus
1. Diffraction from a crystal
Brief introduction to the crystalline systems - Bravais lattices - Symmetries – Diffraction, Thomson scattering, the structure factor; diffraction techniques, reciprocal lattice, X ray, electron, neutron diffraction [for ex. Kittel, chapt. 1,2]
2. Imaging and spectroscopy techniques at the atomic scale
Scanning Tunneling Microscopy (STM) and Spectroscopy (STS) - Atomic Force Microscopy (AFM) [notes on the web site]
3. Anelastic scattering techniques
Anelastic neutron scattering - Rayleigh e Raman light scattering - anelastic X-ray scattering [notes on the web site; Wiesendanger, chapt. 1.1, 1.11, 1.13, 2, 2.1, 2.4, 2.7]
4. General issues on spectroscopy
Physical quantities and measurement units - Brief introduction to the linear response theory - Complex spectroscopy functions - Complex dielectric function - Reflectivity and absorption coefficient [for ex. Wooten, chapt. 2,3; Kittel, chapt. 3,4; notes on the web site]
5. Electronic band structure of exemplary crystalline systems, metals (simple, noble, transition), semiconductors (group IV, III-V), graphene and graphite, boron nitride [es. Bassani, chapt. 4]
6. Optical spectroscopy
Absorption and reflectivity measurements - Sources of electromagnetic radiation – Principles of laser operation - Synchrotron radiation - Analyzers: monochromators - Detectors of e.m. radiation [es. Wooten chapt. 5,9; Bassani, chapt. 5; notes on the web site]
7. Photoelectron spectroscopy and X ray absorption
The photoemission technique - XPS and UPS - ARPES - X ray absorption, XAS (NEFAXS) and EXAFS techniques [notes on the web site; Mariani-Stefani book chapter]
8. Fundamentals of vacuum techniques
Measurement of low pressures - Vacuum pumps, vaccum pipes, vacuum gauges [notes on the web site]

Adopted texts

- F. Bassani, G. Pastori-Parravicini, “Electronic States and Optical Transitions in Solids”; chapters 4, 5.
- C. Kittel, “Introduzione alla Fisica dello Stato Solido”, Ed. CEA, 2008, chapters 1, 2, 3, 4.
- Carlo Mariani and Giovanni Stefani, “Photoemission Spectroscopy: Fundamental Aspects”, Chapter 9, pp. 275-317, in Synchrotron Radiation: Basics, Methods and Applications. Editors: Settimio Mobilio, Federico Boscherini, Carlo Meneghini. Springer, 2015. doi:10.1007/978-3-642-55315-8
- R. Wiesendanger, “Scanning Probe Microscopy and Spectroscopy”, chapters 1.1, 1.11, 1.13, 2, 2.1, 2.4, 2.7
- F. Wooten, "Optical Properties of Solids", Academic Press, 1972; chapters 2, 3, 5, 9
- notes available on the web site: https://elearning2.uniroma1.it/login/index.php

RELATIVISTIC QUANTUM MECHANICS

NEW COURSE NAME (BUT SAME PROGRAM) NEXT YEAR:

INTRODUCTION TO QUANTUM FIELD THEORY

Programme

Recollection of Relativity and Classical Field Theory. Symmetries and Nöther's Theorem. Energy-Momentum Tensor. Angular Momentum Tensor.
Klein-Gordon Equation. Quantization of the Real and Complex Scalar Fields. Creation and Annihilation Operators. Commutation rules. Conserved Charge. Antiparticles.
Covariant Form of Maxwell's Equations. Gauge Invariance. Quantization of the Electromagnetic Field in Vacuum. Energy and Momentum of the Electromagnetic Field. The Spin of the Photon.
Dirac's Equation. Spin. Relativistic Invariance. Properties of gamma matrices. Solution of Dirac's Equation in Free Space. Anomalous Magnetic Moment of the Electron. Quantization of Dirac's Field. Fermi-Dirac Statistics.
Free Field Propagators. Scalar, Dirac and Electromagnetic Fields.
Electromagnetic Interactions. Minimal Subsitution. Gauge Invariance. Quantum Electrodynamics (QED).
Time evolution of Quantum Systems. Interaction Picture. S-Matrix. Dyson's Equation. Scattering Processes. Cross Section.
Wick's Theorem and Feynman rules for QED. Calculation of Electromagnetic Processes: Mott and Rutherford Cross Sections; $e^+e^-\to\mu^+\mu^-$ e^+ e^- \to \mu^+ \mu^-; Compton scattering.

Adopted texts

"Relativistic Quantum Mechanics - An Introduction to Relativistic Quantum Fields", L. Maiani and O. Benhar, CRC Press, Taylor & Francis Inc. (2016).
"A Modern Introduction to Quantum Field Theory", Michele Maggiore, Oxford University Press (2005).
"An Introduction to Quantum Field Theory", M. E. Peskin and D. V. Schroeder, Taylor & Francis Inc. (1995). (first 3 chapters)
"Relativistic Quantum Mechanics", J. D. Bjorken and S. D. Drell, McGraw Hill (1965).
"Relativistic Quantum Fields", J. D. Bjorken and S. D. Drell, McGraw Hill (1965). (first 4 chapters).
"Quantum Field Theory", vol.1, S. Weinberg, Cambridge University Press (1995).

COMPUTING METHODS FOR PHYSICS (OPTION 1)

Programme

Object Oriented Programming
Applications in C++
Introduction to Python
Montecarlo Methods
Scripting languages
Introduction to Machine Learning techniques

Adopted texts

Handouts. During the course teaching material will be provided.
Python for Data Analysis, 2nd Edition, by W. McKinney, O'Reilly Media
Hands-On Machine Learning with Scikit-Learn and TensorFlow, by Aurélien Géron, O'Reilly Media

COMPUTING METHODS FOR PHYSICS (OPTION 2)

Programme

Perturbative expansions
Asymptotic expansions
Asymptotic expansions of integrals
Diagrammatic theory

Adopted texts

Advanced Mathematical Methods For Scientists and Engineers
C. Bender and S.A. Orszag
(Springer, 1999)

Perturbation Methods
Ali. H. Nayfeh
(Wiley, 2000)

Asymptotic Expansions of Integrals
N. Bleistein and R. A. Handelsman
(Dover, 1986)

Des phenomenes critiques aux champs de jauge,
Michel Le Bellac
InterEditions/Editions du CNRS (1988)

Quantum Field Theory and Critical Phenomena,
J. Zinn-Justin
Oxford Science Publications (2002)

Path Integrals in Quantum Mechanics,
J. Zinn-Justin
Oxford University Press (2005)

Quantum Field Theory of Non-equilibrium States,
J. Rammer
Cambridge University Press (2007)

Making sense of the Legendre Transform,
R.K.P. Zia, E.F. Redish and S.R. McKay
Am. J. Phys. 77, 614 (2009);
http://dx.doi.org/10.1119/1.3119512

Functional evaluation of the effective potential,
R. Jackiw
Phys. Rev. D 9, 1686 (1974)

Effective action for composite operators,
J.M. Conrwall, R. Jackiw and E. Tomboulis
Phys. Rev. D 10, 2428 (1974)

COMPUTING METHODS FOR PHYSICS (OPTION 3)

Programme

State-of-the-art numerical methods for the study of quantum many-body systems (density functionals, pseudopotentials, quantum Monte Carlo) and their applications to current problems in soid-state theory and quantum fluids. How to access streaming lectures from home, along with many other details on this course, may be found at http://www.giovannibachelet.it/CMP-20-21/syllabus2021.html .

Adopted texts

1) Iterative minimization techniques for ab initio calculations: molecular dynamics and conjugate gradients,
M.C. Payne et al, Rev.Mod.Phys. 64, 1046-1097 (1992);
3) Quantum Monte Carlo simulations of solids, W.M.C. Foulkes et al, Rev.Mod.Phys. 73, 33-83 (2001);
4) Applications of quantum Monte Carlo methods in condensed systems, Jindrich Kolorenc and Lubos Mitas, Rep.Prog.Phys. 74, 026502 (28pp) (2011).

COMPUTING METHODS FOR PHYSICS (OPTION 4)

Programme

The course is devoted to the study of classical many-body systems through numerical simulation techniques. All the founding methods of Molecular Dynamics (MD) and Monte Carlo (MC) simulations of atomic and molecular systems will be discussed within the framework of a object-oriented programming paradigm focusing on C++. The topics proposed during the course include the following ones:
- object-oriented paradigm: encapsulation, inheritance, overloading and generic programming
- introduction to C++ programming language
- implementation of a simulation in C++
- Python: an effective tool to analyze data from computer simulations
- review of classical statistical mechanics
- interaction potentials
- symplectic algorithms to solve the equations of motion
- multiple time-steps integration
- algorithms for constant temperature and/or pressure
- algorithms for holonomic constraints
- rigid body dynamics
- brownian dynamics

- event-driven dynamics
- Monte Carlo methods
- numerical methods to evaluate the free-energy
- umbrella Sampling and rare events

Adopted texts

Theory

- Understanding Molecular Simulation, D. Frenkel and B. Smit, Academic Press
- Computer Simulation of Liquids, M. P. Allen and D. J. Tildesley, Clarendon Press - Oxford
- The Art of Molecular Dynamics Simulation, D. C. Rapapaport, Cambridge University Press
- Statistical Mechanics: Theory and Molecular Simulation, Mark Tuckerman, Oxford Graduate Press - Oxford
- Theory of Simple Liquids, J.-P. Hansen and I. R. McDonald, Academic Press

C++ books

- C++ How to program (5th edition), H. Deitel and P. Deitel, Prentice Hall
[Introductory book, suitable for C++ beginners]
- The C++ Programming Language (4th edition), Bjarne Stroustrup, Addison-Wesley Professional
[Reference book, it is the equivalent of Kernighan-Ritchie book for the C programming language]
- Effective Modern C++, Scott Meyers, O'Reilly Media
[Aimed at C++ programmers for making the transition from C++03 to modern C++, i.e. to C++11 and C++14 standards]

NON-LINEAR AND QUANTUM OPTICS

Programme

Optical resonators and Gaussian modes. Resonator eigenfunctions. Propagation of Gaussian modes through optical systems. ABCD theory (3 hours)Atom-radiation interaction. Interaction Hamiltonian. 2-level system. Spontaneous emission. Fermi’s golden rule. Perturbation theory for a 2-level system. Line broadening. Homogeneous and inhomogeneous broadening. Collision broadening. Radiative broadening. Doppler broadening. Bloch equations. Einstein coefficients. (7 hours)Semiclassical theory of laser. Laser behaviour in steady-state and transient regime. Mode locking. Ultrashort pulse laser. Propagation of ultrashort light pulses through dispersive media. (5 hours)Nonlinear optics. Pockels effect. Electrooptic amplitude and phse modulators. II order nonlinear optical effects, nonlinear polarization. Semiclassical theory of nonlinear optical susceptibility. Nonlinear wave equation. Sum-frequency generation. Up-conversion. Difference-frequency generation. Parametric amplifier, parametric oscillator. Second harmonic generation. Phase matching in birefringent crystals. Ultrashort light pulse measurement by autocorrelation technique. III order nonlinear optical effects: self focusing, self phase modulation, optical Kerr effect. Stimulated Raman scattering. (15 hours)Classical theory of coherence and statistical properties of radiation. Coherent and chaotic light. Beam Splitter. Mach-Zehnder interferometer. I order coherence. Statistical properties of radiation. Brown-Twiss experiment.II order coherence. (4 hours)Quantization of the electromagnetic field. Quantum theory of the electromagnetic field. Commutation rules. Pure states and statistical mixtures of states. Atom-field interaction. Quantized atomic Hamiltonian. Absorption and emission rates. (7 hours)Non-classical light. Density operator. Single mode field operators. Number states. Coherent states. Cahotic light. Photon bunching and photon antibunching. Squeezed light. Quantum theory of beam splitter. Homodine detection. Single photon interference. 2-photon states. Quantum theory of parametric spontaneous emission. Hong-Ou-Mandel interference. (7 hours)

Adopted texts

1) Saleh, Teich, PHOTONICS, Wiley; 2) Svelto, PRINCI PLES OF LASERS, Plenum; 3) Boyd, NONLINEAR OPTICS, Academic Press; 4) Loudon, THE QUANTUM THEORY OF LIGHT, Oxford University Press ; 5) Rulliere, FEMTOSECOND LASER PULSES