COURSES 2017

GENERAL PHISICS AREA

COMPUTATIONAL PHYSICS (6 CFU-30 hours)

D.Galli UNIMI davide.galli@unimi.it

1) Introduction to Probability Theory and pseudo-random number generators;
2) Monte Carlo integration, sampling of random variables;
3) Variance reduction techniques, stochastic processes, Metropolis algorithm;
4) Metropolis algorithm and the Central Limit Theorem: data blocking;
5) Resampling methods, Gibbs sampling, importance sampling and Metropolis algorithm, smart Monte Carlo;
6) Quantum Monte Carlo;
7) Introduction to Simulations in Statistical Physics;
8) Monte Carlo methods in classical Statistical Mechanics, canonical Monte Carlo, Molecular Dynamics;
9) Introduction to Parallel Computing and programming (Message Passing Interface);
10) Stochastic optimization: Simulated Annealing, Genetic Algorithms & Inverse Problems;
11) Introduction to stochastic differential equations;
12) Simulation of stochastic processes, Econophysics.

QUANTUM THEORY OF MATTER (6 CFU-30 hours)

N.Manini UNIMI nicola.manini@unimi.it, G.Onida UNIMI giovanni.onida@unimi.it, A.Parola UNINSUBRIA alberto.parola@uninsubria.it

This course aims at familiarizing the student with the main theoretical concepts and state-of-the-art methods for the calculation of structural and spectroscopic properties of molecules and solids.

Core topics:

- The Born-Oppenheimer separation, adiabatic dynamics and non-adiabatic terms, adiabatic-diabatic transformation;
- Many-body Theory, second quantization, functional analysis, diagrams;
- Density Functional Theory (static);
- Electron dynamics, excited states and time-dependent phenomena;
- Strong electron correlations: Hubbard models and beyond.

Optional further arguments (can be inserted upon request):

- Time-Dependent Density-Functional Theory;
- The Car-Parrinello method;
- Entanglement of vibrational and electronic motion. Geometric phases;
- Anharmonic corrections to the adiabatic harmonic theory of vibrational properties for molecules and solids.

General Methods and concepts.

- Symmetries in physics and group theory. Subgroups. Group representations. Examples. Product groups. Representation reducibility. Fundamental theorems of the group representation theory. Representation characters.
- Examples and applications to problems in condensed matter and solid state physics
- Born Oppenheimer separation. Diabatic-adiabatic transformation. Examples and applications. Ehrenfest dynamics.

The many-electrons problem

- Many-body Hamiltonian for N electrons and M nuclei. Exponential wall. Summary on the variational principle and its application within the Hartree-Fock method. Electron density and density matrix, and their functional derivatives. Matrix elements of 1 body and 2 body operators. Total energy and double counting. Link with Green's functions and Feynman diagrams.
- Hartree-Fock in second quantized theory. Excitation energies and Koopman's theorem.
- Density Functional Theory (static): Hoenberg-Kohn, Thomas-Fermi, Kohn-Sham. Similarities and differences wrt HF. Case of a single electron; case of the homogeneous electron gas. Local Density Approximation. The self-interaction problem.
- Bandstructure: definition, experiments. Theoretical tools. Charged excitations vs neutral excitations. Janak's theorem. Discontinuity of the exchange-correlation potential.
- Spectral functions. Self energy. Equation for the poles of the one-electron Green's function.
- Perturbative schemes. Comparison with experiments.
- Hedin's equations. The GWGamma scheme. The GW approximation. One-shot G0W0.

- Linearization of the energy dependence of Sigma. Examples: bulk copper. Beyond G0W0: self-consistency and vertex corrections.
- GW implementation in open-source codes.
- Hybrid functionals. Examples.
- Excitonic effects in optical absorption spectra. Bethe-Salpeter equation. Local fields. Examples.
- Usage of the "Quantum Espresso" open-source code suite.

Strongly correlated electron systems
- Role of the electron-electron interaction in the electronic structure of solids. Introduction to the second quantization method. Fock space, creation and annihilation operators, second-quantized Hamiltonian for the electron gas.
- Electronic structure of transition metals. Hubbard model. Mott transition. Strong and small coupling limits of the Hubbard model. Origin of antiferromagetism in condensed matter. The Heisenberg model.
- Metal-insulator transition in the Hubbard model: mean field theory. Hubbard model with attractive interactions: superconductivity. Analogies with the BCS theory.

ASTROPHYSICS AREA (BERTIN)

ADVANCED TOPICS IN ASTROPHYSICS AND PLASMA PHYSICS (6 CFU-30 hours)

M.Bersanelli UNIMI marco.bersanelli@unimi.it, C.Grillo UNIMI claudio.grillo@unimi.it, L. Guzzo UNIMI luigi.guzzo@unimi.it, G.Lodato UNIMI giuseppe.lodato@unimi.it, D.Maino UNIMI davide.maino@unimi.it, M.Romé UNIMI massimiliano.rome@unimi.it

The course offers six modules, each covering 10 hours. Students will chose (at least) three modules, to complete (at least) a 30-hour (6 CFU) course.

1) Collective Phenomena in Plasma Physics (Romé)
- Fundamentals of plasma dynamics;
- Waves and instabilities in Magnetohydrodynamics;
- The solar wind.

2) Collective Phenomena in Accretion Disks (Lodato)
- Introduction to accretion disk dynamics;
- Transport processes in accretion disks;
- Gravitational instabilities in accretion disks and their role in:
  a) planet formation;
  b) accretion disks around Super Massive Black Holes.

3) Cosmology (Maino)
- Ganeral relativity and FRW metric;
- Baryogenesis;
- Equation of state;
- Matter-radiation decoupling;
- Spectrum, anisotropy and polarization of the CMB;
- Inflation and alternative.

4) Observations of the CMB (Bersanelli)
- Spectrum, anisotropy and polarization measurements;
- Detector and optics technology;
- Systematic effects;
- Astrophysical foregrounds (galactic, extragalactic);
- State of the art and future perspectives.

5) Dark Matter and large-scale structure (Guzzo)
- The large-scale distribution of galaxies, redshift surveys;
- The density field: statistics of large-scale structure;
- Evolution of density perturbations and the origin of galaxies;
- Baryonic universes: why we need dark matter.

6) Gravitational lensing (Grillo)
- Theory and simple lens models;
- Astrophysical applications:
  a) Dark matter in galaxies and galaxy clusters;
  b) Cosmography;
  c) Lenses as cosmic telescopes.

NUCLEAR AND SUBNUCLEAR AREA (COLO')

ADVANCED TOPICS IN PARTICLE PHYSICS (6 CFU-30 HOURS)

A.Andreazza UNIMI attilio.andreazza@mi.infn.it, L.Carminati UNIMI leonardo.carminati@mi.infn.it, C.Pagani UNIMI carlo.pagani@unimi.it, R.Turra INFN ruggero.turra@mi.infn.it, F.Vissani INFN francesco.vissani@lngs.infn.it

The course covers selected topics in particle physics: introduction to particle accelerators, detector principles and simulation, statistical treatment of data and neutrino physics.

Prerequisitesa are the Dirac equation and had a first acquaintance with Standard Model of elementary particles, basic knowledge of the processes of interaction of radiation with matter and some C++ programming experience.

The exam consists in solving some exercises assigned during the course and a 30' seminar on a topic, chosen by the student.

Introduction to Particle Accelerators: Physics and Technology challenges (5 hours + 2 hours topical seminar)

- History of the evolution of particle accelerators: ideas, technologies and applications;
- Transverse and longitudinal beam dynamics basics and issues;
- Accelerators for physics, human health and industry;
- Colliders for extreme microscopy while pushing the energy frontier

Reconstruction of charged particle trajectories (5 hours)

- Position sensitive silicon and gaseous detectors;
- Track reconstruction and fitting with Geant4 simulation excercises

Calorimetric techniques for energy measurement (5 hours)

- Calibration and performance of calorimetric systems.
- Simulation of a calorimetric system;

Statistical analysis with exercises (5 hours)

- Hypothesis testing, Likelihood method;
- Estimation of confidence levels;

Neutrino Physics (10 hours)

- Topics of neutrino astronomy: sun, supernovae, geoneutrinos, and high energy neutrinos;
- Introduction to neutrino oscillation;
- Neutrino conversion in vacuum and in matter;
- Experimental evidences of neutrino oscillations;
- Dirac and Majorana mass;
- Neutrinoless double beta decay;
- Extensions of the standard model;
  a) Right handed neutrinos, sterile neutrinos, extended matter and extended higgs fields;
  b) Seesaw;
  c) Grand unified groups;
  d) Neutrino masses in supersymmetric theories;
  e) Connections with other phenomena: mu->e gamma, proton decay, baryogenesis;

Bibliography:

Bohm Vogel: Physics of massive neutrinos.
Giunti Kim: Fundamentals of neutrino physics and astrophysics.
Fukugita Yanagida: Physics of neutrinos and applications to astrophysics.
Mohapatra Pal: Massive neutrinos in physics and astrophysics.
Strumia Vissani: Neutrino masses and mixings and ..., hep-ph 0606054.

NUCLEAR STRUCTURE AND NUCLEAR REACTIONS (6 CFU-30 hours)

S.Leoni UNIMI silvia.leoni@unimi.it, G.Colò UNIMI gianluca.colo@unimi.it, F.Scarlassara UNIPD scarlassara@pd.infn.it, A.Vitturi UNIPD vitturi@pd.infn.it

The Course program could be changed agree with the students. Please, contact prof. Leoni about that.

Nuclear structure (Leoni-Colò, Milano)

Lectures will concern the study of modern aspects of the structure of nuclei in the ground state and excited states. The course is divided in two parts, experimental and theoretical (respectively).

Theory (G.Colò, 10 hours): Density functional methods in nuclear physics

Among microscopic methods, those based on Density Functional Theory can be applied to most of nuclei along the periodic table. They are also useful for extrapolations towards uniform matter (for instance, neutron stars).

Tentative program:

- Introduction and formalism, with a review of the Kohn-Sham theory for electronic systems-2 hours;
- Applications to the nuclear ground state (binding energies, radii, superfluidity)-2 hours;
- Theory for excited states: the time-dependent density functional theory with applications-2 hours;
- Covariant (or "relativistic") functionals-2 hours;
- Possibile extensions of the model. The problem of isospin in nuclear physics: conservation, breaking and restoration-2 hours.

Experiment (S.Leoni, 10 hours): Nuclear Structure studied with Stable and radioactive beams
Nuclear Structure properties will be discussed from a phenomenological/experimental point of view, mostly in connection with the present use of accelerated beams of stable and radioactive heavy ions.
Tentative program:
- Production techniques for exotic beams-2 hours;
- High precision Mass measurements with Penning traps-2 hours;
- Collective modes of rotation at finite temperature-2 hours;
- Collective modes of vibration: Giant Resonances-2 hours;
- Lifetime measurements of excited states by gamma spectroscopy-2 hours.

Nuclear Reactions with Heavy Ions (Scarlassera-Vittuiri, Padova)
Lectures will concern the study of nuclear reactions with heavy ions in the energy interval around the Coulomb barrier. At these energies, nuclear reactions are dominated by fusion and transfer processes, and are strongly influenced by the structure of the interacting nuclear systems. The course is divided in two parts, experimental and theoretical (respectively).

Experiment (F.Scarlassara, 10 hours): Experimental study of transfer and fusion reactions
State-of-the art experimental techniques and perspectives with unstable beams will be discussed together with recent, important results obtained at Legnaro National Laboratory. Particular emphasis will be given to experimental problems related to the measurements of observables such as energy, mass, atomic number and cross sections for reactions with heavy ions.
Tentative program:
- Binary reactions: quasi-elastic and transfer
  a) Introduction and experimental aspects-2 hours;
  b) Results on pair transfer-2 hours.
- Fusion reaction, in particular below barrier
  a) "Historical" introduction and experimental aspects-2 hours;
  b) Fusion in "coupled channels"-2 hours;
  c) Deep sub-barrier fusion: the new frontier-2 hours.

Theory (A.Vitturi, 10 hours): Theoretical models for heavy ion reactions around the Coulomb barrier
The theoretical models used to describe the different processes involving heavy ion interactions at energies around the Coulomb barrier will be discussed. In particular, microscopic models will be developed, with the aim of having links between structure aspects and dynamical aspects.
Tentative program:
- The semiclassical description of processes involving heavy ions-2 hours;
- Models for two-body reactions: quasi-elastic and transfer
  a) inelastic Coulomb excitation: microscopic approaches-2 hours;
  b) pairi transfer and pairing interaction-2 hours;
- Fusion reactions (in particolar, below the potential barrier)
  a) coupled channel model-2 hours;
  b) fusion processes involving weakly bound systems-2 hours.

MATTER PHYSICS AREA (CASTELLI)

THEORETICAL PHYSICS AREA (FERRERA)

INTRODUCTION TO CONFORMAL FIELD THEORY AND TOPOLOGICAL QUANTUM FIELD THEORY (6 CFU-30 hours)
S. Caracciolo UNIMI sergio.caracciolo@unimi.it, S. Cacciatori UNINSUBRIA sergio.cacciatori@uninsubria.it

I part (Caracciolo)
This part will focus on the specific properties of conformal invariance in two dimensions where the consequences are so important to allow a classification of the fixed points of the renormalization group at least for rational theories. Topics covered:

- Introduction to the conformal troupe.
- Study of the consequences of conformal invariance in field theory.
- Relevant applications for the study of critical phenomena.

II part (Cacciatori)

- Supersymmetric quantum mechanics: simple models; BRST formulation; symmetry breaking and the Witten index; relations to general index theorems;
- Introduction to topological sigma models: complex manifolds and topological actions; Nicolai map and Bãcklund transformation; observables;
- Topological gauge theories à la Witten: geometry of gauge theories; connections and instantons; Donaldson invariants, Floer homology and Morse theory; on Mathai-Quillen formalism; observables; general constructions.

APPLIED PHYSICS AREA (VAILATI)

EXPERIMENTAL METHODS FOR THE INVESTIGATION OF SYSTEMS AT THE NANOSCALE (6 CFU-30 hours)

The course is focused on the description of experimental methods suitable to manipulate and investigate mesoscopic systems, such as nanostructured materials and interfaces, soft matter, and biological samples. The course is structured as a sequence of self-contained lectures held by specialists in the field. Many of the lectures are accompanied by the experimental demonstration of the method in the research laboratories. Final exam: each student will present a seminar on a topic agreed with one of the lecturers. All the seminars will be grouped within a single session at the end of the course. For general information about the course contact alberto.vailati@unimi.it.

Coherent imaging (M.Potenza UNIMI marco.potenza@unimi.it)

- Radiation emission and propagation;
- Spatial and temporal coherence;
- Illuminating a sample - coherent and incoherent imaging;
- X-ray imaging - phase sensitive imaging methods;
- Tomography;
- Holography.

Molecular Beams (P.Piseri UNIMI paolo.piseri@unimi.it)

- Introduction to molecular beam concepts: effusive sources; free jet sources; seeded expansions;
- Molecular beam techniques and methods: molecular beam apparatus; devices and instruments; selected experiments and applications;
- Synthesis of nanostructured systems by molecular beam deposition.

Laser Sources (S.Cialdi UNIMI simone.cialdi@unimi.it)

- Single mode and multimode lasers;
- Pulsed lasers (Q-switched and mode locked);
- Laboratory activities.

Photoemission Spectroscopy (C.Lenardi UNIMI cristina.lenardi@unimi.it)

Theoretical arguments:

- Surface Physics: motivations to study the electronic properties of surfaces in nanostructured materials;
- Photoemission spectroscopy (XPS, UPS, AES): analysis of the structure of the core levels and the valence band, elemental analysis, chemical shift, spectromicroscopy with synchrotron radiation;
- Instrumentation: experimental apparatus equipped with X-ray and UV sources, electron analyzer, detector.

Laboratory:

- Acquisition of a wide spectrum of a sample in low resolution;
- Acquisitions of core edges in high resolution;
- Data analysis: peak recognition, quantification of elements and chemical bonds.

Nanomagnetism (A.Lascialfari UNIMI alessandro.lascialfari@unimi.it)

Introduction to Nuclear Magnetic Resonance:

- Larmor precession and Bloch equations;
- Longitudinal and transverse nuclear relaxation times;
- NMR spectra.

Few concepts of magnetism:

- Diamagnetism, paramagnetism and ferromagnetism;
- Superparamagnetism.

Laboratory:

- The pulsed NMR apparatus;

- Most typical pulse sequences;
- Measurements of 1H NMR spectra, T1 and T2 on reference oil;
- Fast-field Cycling technique : an example of profiles.

Static light scattering and its applications (M.Carpineti UNIMI marina.carpineti@unimi.it)
- Basic concepts : light scattering, absorption and extinction;
- The scattering problem;
- The case of a single particle and of many independent particles;
- Scattering and index of refraction: the extinction formula;
- Rayleigh and Rayleigh-Gans approximations;
- The scattered intensity and its relation with the sample properties;
- Correlated particles: the pair correlation function, with examples;
- The light scattering instrument;
- Laboratory activities especially related to the last three points.

Intensity Fluctuation Spectroscopy (A.Vailati UNIMI alberto.vailati@unimi.it)
- Brownian motion and fluctuations;
- Homodyne and heterodyne detection;
- Spatial coherence;
- Polarized and depolarized Dynamic Light Scattering;
- Hambury- Brown and Twiss interferometry.

Fluorescence methods in biophysics (M.Buscaglia UNIMI marco.buscaglia@unimi.it)
Introduction:
- spectroscopic properties of fluorophores;
- standard analytical instrumentation.

Advanced methods:
- fluorescence quenching as a probe for inter- and intra- molecular diffusion and conformation;
- fluorescence resonance energy transfer as a nanometer-scale ruler;
- fluorescence correlation spectroscopy and single molecule techniques to directly observe structural and dynamic heterogeneity;
- Laboratory activities

Quantitative Microscopy (R.Cerbino UNIMI roberto.cerbino@unimi.it)
- theory of image formation;
- anatomy of a microscope;
- scattering vs fluorescence based microscopy;
- microscopy vs scattering;
- real vs reciprocal space;
- Laboratory activities.

Rheology and micro-rheology (G.Zanchetta UNIMI giuliano.zanchetta@unimi.it)
- Stress and strain;
- Different types of response to an imposed deformation: elastic solids, viscous fluids,…everything in between!
- Rheological tests;
- Yield stress;
- The importance of micro-structure;
- Micro-rheology: real-space and Fourier-space methods;
- One-point and two-points micro-rheology;
- Passive and active micro-rheology.

Scanning probe microscopies (A.Podestà UNIMI alessandro.podesta@unimi.it)
- Scanning Probe Microscopies e Atomic Force Microscopy. Basic principles;
- Beyond topography. Applying and Measuring forces at the nanoscale;
- Experiments in the lab.

COMPUTING HARDWARE ARCHITECTURES FOR PATTERN RECOGNITION (3 CFU-15 HOURS)
V.Liberali UNIMI valentino.liberali@unimi.it

- Introduction: pattern recognition in High-Energy Physics and the "track trigger";
- Different approaches to the pattern recognition problem: software, firmware and hardware solutions;
- CMOS logic: Fundamentals of MOS transistor operation and CMOS technology; CMOS combinational logic families;
- Technology scaling and Moore's law;

- Dynamic and pre-charge logic families; static and dynamic memories;
- Static and dynamic power, interconnection parasitics and effects of scaling;
- Area/timing/power trade-off in digital designs;
- Content addressable memories (CAM): survey and architectures;
- Associative memories;
- Memories with logic ("intelligent memories");
- Algorithms for associative memories;
- Examples: pattern recognition in high-energy physics, artificial vision, medical applications.

ATMOSPHERIC DYNAMICS: LIGHTING, TORNADOES AND THE WEATHER OF OUR AND OTHER PLANETS (3 CFU-15 hours)

M.Maugeri UNIMI maurizio.maugeri@unimi.it, W.Gallus ISU wgallus@iastate.edu

1) Atmospheric General Circulation, the processes that drive it, and the equations that explain it.
2) Vertical structure of the Atmosphere, lapse rates, and stability.
3) Large-scale circulations, Cyclones and Anticyclones, Quasi-geostrophic dynamics.
4) Air masses, fronts, frontogenesis, and jet streams.
5) Thunderstorms, Thunderstorm morphology, Mesoscale Convective systems, the nocturnal Low-Level Jet, Mesoscale Convective Vortices.
6) Tornadoes and genesis mechanisms.
7) Organized tropical cyclones/Hurricanes.