GRADUATE COURSES DESCRIPTION

ELECTROMAGNETIC THEORY

Instructor: Prof. M. Bornatici (DFV)
Graduate Students: Belfiore, Cazzola, Livan, Prando
Course Description:

Advanced electromagnetism: Fourier transform and inhomogeneous wave equation in a dispersive anisotropic medium. The emission of electromagnetic radiation, Poynting theorem, multipoles decomposition. The Vavilov-Cherenkov radiation. Sources of Syncroton radiation: (i) Third generation sources of x rays (ELETTRA, ESFR,…); (ii) Astrophysical sources (Crab nebula, residual radiation from gamma-ray bursts,…); (iii) The free-electron laser.

STATISTICAL MECHANICS: STATISTICAL FIELD THEORY

Instructors: B. Pasquini (DFNT) e Marco Guagnelli (INFN)
Graduate Students: Bignamini, Bisio, Costanza, Facchini, Morini
Course Description:

Equilibrium statistical mechanics (2 hours): Statistical Ensembles, Energy, Entropy, Probability distributions, Magnetic systems. Ising model (4 hours): Mean field approximation, Exact solution in D=2. Other models (4 hours): Gaussian model, Low and high temperature expansions, Exactly solvable models, Landau-Ginsburg model. Perturbative expansion (4 hours): Renormalization group, Perturbative evaluation of critical exponents, Transfer matrix, link with relativistic quantum field theories

Lattice Gauge Theories

Field theories on the lattice (2 hours): Wick rotation, Discretization, Scalar fields, electrodynamics. QCD (2 hours): Confinement, asymptotic freedom, Pure gauge, Potential between static colour sources, Fermions on the lattice. Monte Carlo methods (2 hours): Importance sampling, Heath-bath.

Supersymmetric Methods in Quantum and Statistical Physics

Hamiltonian formulation of supersymmetric quantum mechanics (6 hours): Factorization and Hierarchy of Hamiltonians, Shape invariance, Broken supersymmetry, Solvable potentials. Charged particles in External Fields and Supersymmetry (4 hours): Spinless particles, Non-relativistic electrons and the Pauli equation, Relativistic electrons and the Dirac equation , Dirac Particle in a Coulomb field. Supersymmetry in Classical Stochastic Dynamics (3 hours): Langevin and Fokker-Planck equation, Supersymmetry of the Fokker-Planck equation, Supersymmetry of the Langevin equation.

Bibliography:

G. Parisi, " Statistical Field Theory", Addison Wesley, 1988
I. Montvay, G. Muenster, "Quantum Fields on a Lattice", Cambridge U.Press, 19997
F. Cooper, A. Khare, U. Sukhatme, "Supersymmetry in Quantum Mechanics",World Scientific, 2001
G. Junker, "Supersymmetric Methods in Quantum and Statistical Physics",Springer Verlag, 1996.

QUANTUM INFORMATION SCIENCE

Instructors: M.G. D’Ariano (DFV)

Graduate Students: Caridad Hernandez, Dall’Arno

Course Description:

Strumenti matematico statistici. Teoria dell'Informazione Classica.

Concetti base di compressione di informazione e error correction. Binary symmetric channel. Majority-vote error correction. I due problemi di Shannon e presentazione degli argomenti trattati nel corso. (7,4) Hamming block code. Variabili random. Bounds di Chebyshev, Markov,Chernoff, legge dei grandi numeri debole. Quantificazione del contenuto di informazione:Shannon's information content. Entropia di Shannon, sua convessita', Jensen inequality. Entropia relativa, disuguaglianza di Gibbs. Raw bit content. Lossy and lossless compressor. Smallest delta-sufficient set and essential bit content. Typical sequences and typical set. Equipartition theorem. Shannon's source coding theorem. Symbol codes.Lunghezza aspettata di un codice. Decodificabilita' univoca. Prefix code. Kraft-McMillan inequality. Codice completo. Lower bound per lunghezza aspettata. Lunghezze diu codice ottimnali. Source coding theorem per symbol codes. Huffman's code. Stream codes: compressione come guessing game. Arithmetic code. Luempel Ziv coding. Riassunto sui metodi di compressione. Entropie congiunta, condizionata. Subadditivita', bound entropia condizionata, regole di concatenamento per condizionamento, disuguaglianza di Fano. Mutua informazione e sue proprieta', mutua informazione condizionata, catena di Markov, indipendenza condizionata, subadditivita' forte dell'entropia congiunta, riduzione di entropia da condizionamento, regole di concatenamento. Informazione mutua di un canale: inferenza dell'input dall'output. Teorema del data processing. Canali rumorosi. Capacita' di canale. Calcolo della capacita' del canale binario simmetrico e del noisy typewriter. Canale esteso. Codici di blocco. Canali estesi. Optimal decoder. Random coding e typical decoding. Sequenze congiuntamente tipiche. Il secondo terorema di Shannon: enunciato. Decoder come compressore lossy. Output probability di codice a blocco che raggiunge la capacita' di canale. Il secondo teorema di Shannon: dimostrazione.

Informazione classica su canali quantistici

Introduzione. L'entropia di von Neumann. Entropia quantistica relativa. Ineguaglianza di Klein. Proprieta' matematiche dell'entropia di von Neumann: 1) stati puri; 2) valore massimo; 3) invarianza unitaria; 4) entropie marginali; 5) stati con supporto ortogonale; 6) concavita'. Proprieta' matematiche dell'entropia di von Neumann: 7) Upper bound; 8) state-preparation; 9) sistemi statisticamente indipendenti; 10) Misurazione senza lettura del risultato; 11) Entropia della misurazione; 12) Subadditivita'; 13) Subadditivita' forte;14) disuguaglianza triangolare. Entropia in termodinamica. Proprieta' dell'entropia relativa quantistica: 1) disuguaglianza di Klein (richiamo); 2) invarianza per estensione. Proprieta' dell'entropia relativa quantistica: 3) Teorema di monotonicita' di Uhlmann. Il teorema di Lieb. Ulteriori proprieta' di convessita' delle entropie quantistiche: convessita' congiunta dell'entropia relativa, concavita' dell'enropia quantistica condizionata. Subadditivita' forte dell'entropia di von Neumann. Riduzione da condizionamento. Ulteriori proprieta' di convessita' delle entropie quantistiche: diminuzione della mutua informazione quantistica scartando sistemi, e da operazioni quantistiche. monotonicita' dell'entropia relativa sotto marginalizzazione. Monotonicita' di Uhlmann dell'entropia relativa: dimostrazione alternativa. Il bound di Holevo. Altri bounds di interesse.

Teoria dell'Informazione Quantistica

Compressione quantistica. Affidabilita' della compressione quantistica: entanglement fidelity. Sottospazi di Hilbert tipici. Il teorema di Schumaker del quantum source coding. Entropy exchange. Disuguaglianza di Fano quantistica. Canali reversibili sull'input. Informazione coerente. Il teorema del data processing quantistico. Teoria dell'error correction quantistica: condizioni equivalenti per l'inversione del canale. Error correction esempi: Hamming code quantistico. Informazione accessibile. Aumento della distinguibilita' con il metodo di Wootters e Peres. Cenni al teletrasporto e dense coding.

Teoria avanzata: Quantum Lambda calculus (*Lezioni tenute da Benoit Valiron*)

Higher-order and quantum computation: principle.Higher-order and quantum computation: examples: Deutsch algorithm; teleportation; Bell's experiment. A formal language: the quantum lambda-calculus: Encoding. A formal language: the quantum lambda-calculus: Abstract machine. A formal language: the quantum lambda-calculus: Type system. Semantics: a) Strictly linear fragment. b) Full fragment: categorical analysis.

ADVANCED THEORY OF SOLIDS

Instructors: L.C. Andreani (DFV)

Graduate Students: Caridad Hernandez, Giudicatti, Portalupi, Prando, Morini

Course Description:

The course "Advanced Theory of Solids" consists of three modules, for a total of ~30 lecture hours.

1) Elementary excitations in solids: plasmons and polaritons

(L.C. Andreani, M. Patrini, D. Bajoni: 10 hours)

1.1. Macroscopic electrodynamics: Maxwell equations in matter, Coulomb gauge, longitudinal and transverse field, complex dielectric function. Longitudinal excitations (plasmons), transverse excitations (polaritons). Surface modes. (*Andreani*)

1.2. The electron gas: screening, linear response theory (Random Phase Approximation), Lindhart dielectric function. Excitations: electron-hole pairs and plasmons. Surface plasmons: planar and spherical geometries. Retardation and surface plasmon polaritons. (*Andreani*)

1.3. Polaritons: Excitons-polaritons in bulk semiconductors : basic theory and experiments. Excitons-polaritons in planar microcavities : weak and strong coupling regimes. (*Andreani*)

1.4. Surface plasmon polaritons: structures and experiments, focusing and guiding, metal nanoparticles, surface plasmon-polariton applications (*Patrini*)

1.5. Cavity polaritons & nonlinear effects: structures and experiments, stimulated scattering, four-wave mixing, polaritons lasing, Bose-Einstein condensation of cavity polaritons. (*Bajoni*)

2) Semiconductors nanostructures, 0D and 1D: Quantum dots and quantum wires

(D. Gerace: 10 hours)

2.1. Basic Topics: electronic states in confined potential, effective mass and envelope function methods, density of states for 1D and 0D confined systems, brief review on alternative methods for confined states calculations

2.2. Quantum Wires: fabrication techniques, level structure, transport and optical properties, Landauer formalism and conductance quantization

2.3. Electrostatically defined (parabolic) Quantum Dots: fabrication, level structure, transport properties within Landauer formalism, Coulomb blockade and single-electron tunneling, addition spectrum and Hund's rule, Fock-Darwin levels in magnetic field

2.4. Epitaxially grown (self-assembled) Quantum Dots: fabrication, electron and hole confinement, spin and angular momentum quantum numbers, exciton states, oscillator strength, optical properties, radiative recombination and luminescence spectra, line broadening

2.5. Advanced examples: single QDs spectroscopy, autocorrelation of single QD lines and single photon emission, Coulomb blockade and single electron counting, Kondo effect in QDs.

3) One module chosen from one of the following courses (if not already attended):

- Microscopic and Spectroscopic Characterization of Materials (F. Marabelli)
- Strongly Correlated Systems in Condensed Matter Physics (P. Carretta)
- Another equivalent module, to be agreed upon.

The exam consists in a seminar given by the graduate student, on a subject within either module 1 or 2.

MICROSCOPIC AND SPECTROSCOPIC CHARACTERIZATION OF MATERIALS

Instructors: F. Marabelli (DFV) in collaboration with Physical Chemistry and Earth Sciences;

Graduate Students: Caridad Hern., Giudicatti, Palesi, Portalupi, Dal Conte

Course Description:

1) Spectroscopic characterization by FTIR

(F.Marabelli)

Optical spectroscopy: applications and limits. Dispersion methods and experimental configurations. Basic and working principles of FTIR spectroscopy and its advantages Some properties of FT and FFT. FTIR spectrometer. Working with data, spectral resolution and apodization. Libraries and analytical use of FTIR data. Test exercises with an instrument. Rapid scan and step scan: Chromatography and time resolution. Phase measurement and its meaning.

Surface analysis with ToF-SIMS and XPS

G.Ceccone (JRC-Ispra)

Principle of Secondary Ion Mass Spectroscopy: applications and limits. XPS spectroscopy.

2) Microscopies

(F.Marabelli, F. Maglia, E. Quartarone)

The problem of spatial resolution; principles, diffraction and aberrations. Configurations and contrast in optical microscopes. Electronic microscopy TEM, instrument components, direct imaging and diffraction Scanning Electron Microscopy - SEM: probes and data interpretation Micro-analysis with SEM: possibilities and limits. Scanning point microscopy (SPM) Scanning Tunnel Microscopy - STM: measurement and interpretation of the results STM spectroscopy. Atomic Force Microscopy -AFM: measurement, contact and non contact configuration, intermittent contact , lateral force. SPM probes, fabrication and typologies, resolution and aberration effects. Other scanning probes, electric field-, magnetic- and thermal- effects, chemical potential sensitivity. SNOM, near field effects and overcome of diffraction limits

INFORMATION AND DATA ANALYSIS

Instructors: A. Rotondi, A. Fontana, P. Pedroni (DFNT)

Graduate Students: Belfiore, Cazzola, Livan, Protti, Uslenghi, Bignamini

Course Description:

Richiami di calcolo delle probabilita'. Approccio statistico frequentista e teorema di Neyman. Applicazione alla analisi dei dati in fisica. Nuovi approcci alle misure di frequenza ed efficienza negli esperimenti di conteggio. Approccio Bayesiano e sua applicazione in fisica sperimentale. Metodo della massima verosimiglianza. Teoria degli stimatori. Ottimizzazione delle stime attraverso il rapporto di verosimiglianza. Approccio di Feldman-Cousins. Test delle ipotesi e Teorema di Neyman Person. Metodi approssimati e rigorosi per l'estrazione di un segnale dal fondo. Metodo bootstrap e sue applicazioni in fisica. Metodi di unfolding e loro applicazioni in fisica. Metodi di best fit ed uso di ROOT come software statistico. Mathematica ed il suo uso in fisica e nella analisi dei dati.

STRONGLY CORRELATED SYSTEMS IN CONDENSED MATTER PHYSICS

Instructors: P. Carretta (DFV)

Graduate Students: Prando, Branzoli, Dal Conte

Course Description:

1) Phase transitions in strongly correlated electron systems

Introduction to strongly correlated electron systems. The response functions and the critical phenomena. Statistical description of phase transitions in homogeneous and non-homogeneous systems. Magnetic properties of superconductors. Ginzburg-Landau theory and its application to the description of the superconducting phase transition and critical fluctuations.

2) Magnetic properties of low-dimensional systems

2D insulators. From Hubbard to Heisenberg hamiltonian. Basic properties of the 2D quantum Heisenberg model. Dilution and frustration effects in 2D spin systems. Basic magnetic properties of 2D metals and 2D heavy fermion systems. Molecular nanomagnets. The basic interactions in molecular magnets. Introduction to the techniques used to probe molecular magnetism. Single molecule magnets. Typical phenomena observed in 0D and 1D molecular magnets (quantum tunneling, superparamagnetsm, etc...).