

Structural and electronic properties of solids

Teachers :

Lecture :

Marino Marsi, Laboratoire de Physique des Solides (Université Paris Sud 11, Orsay)

Fabrice Bert, Laboratoire de Physique des Solides (Université Paris Sud 11, Orsay)

Tutorials : Victor Balédent, Vincent Jacques

Practicals organisation : Claire Laulhe Synchrotron SOLEIL (and Université Paris Sud 11)

Website : www.equipes.lps.u-psud.fr/m2structure/

Lectures and tutorials : 46h (28h lectures, 18h tutorials)

Practicals : 14h (= 2 days per student)

In this lecture, we aim at providing a conceptual basis to understand modern experimental techniques used to investigate the structural, electronic and magnetic properties of condensed matter: scattering experiments (X-rays, neutrons, electrons), spectroscopic techniques (XAFS, ARPES, NMR), magnetometries, measurements of dynamical conductivity. The theoretical framework we address includes the description of symmetries, the interaction of radiation and matter, linear response and related tools – correlations functions, generalized susceptibilities – in close relation to the concepts and formalisms introduced in the “theory of condensed matter” lecture. All along the course, we use the same few representative materials to illustrate the input of each technique in our understanding of topical research subjects: high T_c superconducting cuprates, transition metal oxides, spin chains etc... In addition practicals in the lab and at large scale facilities (SOLEIL, LLB) provide the necessary hands-on experience, complementary to the academic lecture.

1. Order in condensed matter

Order. Correlation functions. Introduction to different kinds of order (short range, long range, intermediate). Bragg peaks.

Symmetry. Point groups.

Periodic crystal order: lattice, space groups, reciprocal lattice

Aperiodic crystal order: quasi-crystals and beyond...

Short range order: Glasses, amorphous materials, fractals...

Intermediate order: soft matter, polymers

Disorder and defects (Phonons, alloys, dislocations, surfaces)

2. Interaction of photons and electrons with matter

Basic interaction processes: Scattering, absorption, sources (synchrotrons, FELs)

Absorption and electron spectroscopies: EXAFS, XANES, fluorescence, XPS

Scattering : kinetic theory $S(q, \omega)$ and $G(r, t)$.

Scattering on quasi-ordered systems: Glasses, liquids, liquid crystals

Diffraction : Laue condition. Structure factor. Diffraction techniques.

Disordered systems: Phonons, alloys

Phase transitions : Applications of fluctuation-dissipation, critical exponents

Small angle scattering: Guinier, Porod, Fractals, polymers

Dynamics : Out of equilibrium and excited states of matter, ultrafast dynamics, relaxation processes

Magnetism : magnetic scattering with neutrons and X-rays

3. Electronic properties of Solids

- **Linear response and generalized susceptibilities:** brief introduction/reminder of the basic concepts and important theorems (Kramers-Kronig, Fluctuation/dissipation)
- **Response to a magnetic field**
Magnetic susceptibilities and spin-spin correlation functions. Different types of magnetic susceptibilities (diamagnetism, localized moments,, metals, nteractions) – Experimental techniques : static susceptibility –macroscopic techniques (SQUID, faraday force, torque) ; local technique (NMR, ESR) – dynamical susceptibilities: NMR, inelastic neutron scattering
- **Response to an electric field**
Optical conductivity : definition, relation to linear response, dielectric susceptibility and optics
Drude model, for metals, interpretation of reflectivity experiments, beyond Drude model
- **Band structure and Fermi surface**
Quantum oscillations : Landau levels, oscillation of the density of states, experiments: in particular. oscillations of the magnetizaton (de Haas-Van Alphen) and magneto-resistance (Shubnikov-de Haas)
Angle resolved Photoemission (ARPES) : Spectral functions, quasiparticle, fermi surface and band structure

Practicals :

Each student performs two days of practical work, one in laboratories and one at a large scale facility of the Saclay plateau. These practicals are based on the use of advanced instrumentation available at the LPS, as well as state-of-the-art neutron and X-ray sources present on the Saclay plateau at LLB and SOLEIL synchrotron. Our goal is to introduce modern experimental techniques that are used to investigate key themes of condensed matter physics: superconductivity, multiferroics, metal-insulator transitions...

Each student performs two practicals among the 6 listed below (indicative list):

- Charge density wave in chromium
- Suspensions of gold nanoparticles
- Mechanical response of a thin film deposited on a flexible substrate
- Quantum oscillations in bismuth
- Electronic structure of graphene
- Spin waves and phonons in a Nickel alloy