UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Metodi Strumentali di Indagine Mineralogica

2526-1-F7402Q040

Aims

The aim of the course is to introduce the main instrumental techniques used in mineralogical studies, with the objective of highlighting reactions, phase transitions, and aspects of crystal growth—key elements for understanding major geological processes and for designing solutions to pressing environmental challenges. The topic is of broad interdisciplinary interest and may appeal to mineralogists, petrologists, structural geologists, paleontologists, applied geologists and materials scientists. Case studies will be presented to address both fundamental research questions, such as the deep carbon cycle, and applied research related to environmental issues, through the use of the techniques covered during the course. The training program will conclude with visits to laboratories housing large-scale analytical instruments and a visit to the synchrotron facility in Grenoble.

Knowledge and understanding
By the end of the course, students are expected to understand the theory and functioning of the main analytical techniques used in the study of minerals and materials, with applications in both fundamental and applied research as well as in industry and the workforce.
Applying knowledge and understanding
By the end of the course, students are expected to possess the basic knowledge required to interpret and analyze data generated in laboratory and research contexts.
Making judgements
By the end of the course, students are expected to be able to identify the most appropriate diagnostic techniques to address a simple scientific question.
Communication skills
By the end of the course, students are expected to have acquired an appropriate technical and analytical laboratory vocabulary.
Learning skills
By the end of the course, students will have developed an autonomous learning method, enabling them to deepen their understanding of mineralogy and geology in a critical and informed way. These skills will also be transferable to other scientific fields, such as materials analysis laboratories, environmental investigations, and technological development.

Contents

The course will begin with introductory lectures aimed at providing students with the foundational knowledge needed to understand the topics covered. These include an introduction to radiation–matter interaction, crystallography, and spectroscopic techniques. Subsequent lectures will focus on transmission and scanning probe electron microscopy techniques, diffraction methods, and vibrational spectroscopies, both under ambient and non-ambient conditions. The central part of the course will illustrate the application of these techniques to case studies in both fundamental research and environmental issues. The final part of the course will involve hands-on sessions using scanning and transmission electron microscopy, X-ray diffraction, and Raman spectroscopy. A visit to a major synchrotron light source is also planned.

Detailed program

Lectures (4 ECTS, 28 hours)

1. Introductory concepts (Campione)
   1.1. Crystal structures and reciprocal lattice
   1.2. Radiation–matter interaction
   1.2.1. Elastic and inelastic interactions

2. Introduction to Spectroscopy (Cerantola)
   2.1. Spectrometers from infrared to ultraviolet
   2.2. Principles of quantum mechanics
   2.2.1. Historical background
   2.2.2. The postulates of quantum mechanics
   2.2.3. Heisenberg’s uncertainty principle
   2.2.4. Atomic orbitals
   2.3. Crystal field theory and optical spectroscopy
   2.3.1. Fundamentals of crystal field theory
   2.3.2. Remote sensing of planetary surfaces
   2.3.3. Crystal field spectra of Fe2+ in minerals
   2.3.4. Fluorescence
   2.3.5. Charge-transfer bands
   2.4. Vibrational spectroscopy
   2.4.1. Principles of vibrational spectroscopy
   2.4.2. Vibrations of OH? groups
   2.4.3. Vibrations of small molecules
   2.4.4. Vibrations in crystals
   2.4.5. Thermodynamic properties in vibrational spectroscopy

3. Microscopy Techniques
   3.1. Scanning Electron Microscopy (SEM) (Capitani)
   3.1.1. Secondary electron (SE) and backscattered electron (BSE) imaging
   3.1.2. Electron backscatter diffraction (EBSD)
   3.1.3. Microanalysis with energy-dispersive (EDS) and wavelength-dispersive (WDS) systems
   3.2. Transmission Electron Microscopy (TEM) (Capitani)
   3.2.1. Bright-field (BF) and dark-field (DF) imaging
   3.2.2. High-resolution imaging (HRTEM)
   3.2.3. Selected-area electron diffraction (SAED)
   3.3. Scanning Probe Microscopy (Campione)

3.3.1. Surface topography and surface properties for signal detection
3.3.2. Atomic force microscopy (AFM)
3.3.3. Scanning tunneling microscopy (STM)
3.3.4. Overview of other modalities

4. Introduction to Synchrotron Radiation (Cerantola)
   4.1. Principles of Synchrotron radiation
   4.1.1. History of synchrotrons and large-scale facilities
   4.1.2. Working principles and components
   4.2. X-ray diffraction (XRD)
   4.2.1. Powder diffraction under ambient and non-ambient conditions
   4.2.2. Rietveld refinement
   4.3. Vibrational spectroscopies under ambient and non-ambient conditions
   4.3.1. X-ray absorption spectroscopy (XAS)
   4.3.2. X-ray emission spectroscopy (XES)
   4.3.3. Synchrotron Mössbauer spectroscopy (SMS)

Hands-on Exercises (1 ECTS, 12 hours)

Computer-based sessions using software for data visualization, analysis (including data from crystallographic databases such as ICSD and CSD), and image processing:

1. Esprit, DigitalMicrograph, VisualElectronCrystallography (VEC) (Capitani)
2. General Structure Analysis Software (GSAS II) (Cerantola)
3. WSXM, Gwyddion, Mercury (Campione)
4. SYNCMoss (Cerantola)

Laboratory Sessions (1 ECTS, 12 hours)

1. Practical session on the SEM Zeiss Gemini 500 (Capitani)
2. Practical session on the TEM Jeol 2100P (Capitani)
3. Practical session in the Raman Laboratory (Cerantola)
4. Visit to a large-scale facility (Synchrotron, Grenoble)

Prerequisites

There are no formal prerequisites for this course, although it is recommended to take it in conjunction with other mineralogy and petrology-related courses (e.g., Petrogenesis of Geodynamic Settings, Deformation and Metamorphism of Convergent Margins, Industrial and Environmental Mineralogy, Isotopic Geochemistry, Geochronology and Geochemistry of the Solid Earth).

Teaching form

The course includes in-class lectures (4 ECTS, 28 hours) during which the theoretical aspects will be explained and selected case studies will be presented. It also features hands-on sessions at the computer (1 ECTS, 12 hours), where students will directly use software for data analysis, data visualization, and image handling. Finally, the course includes laboratory sessions (1 ECTS, 12 hours), where students will actively participate in instrumental measurements and analyses.

Textbook and teaching resource

Lectures notes derived from the personal experience of the teacher will be made available. Recommended additional readings:

Andrew Putnis “Introduction to Mineral Sciences”. Cambridge University Press.
Mineral and reactions at the atomic scale: Transmission electron microscopy. Reviews in Mineralogy, 27, Mineralogical Society of America.
Nanoscopic approaches in Earth and Planetary Sciences. EMU Notes in Mineralogy 8. European Mineralogical Union.
Minerals at the nanoscale. EMU notes in Mineralogy 14. European Mineralogical Union.
Victor L. Mironov "Fundamentals of scanning probe microscopy" (http://ipmras.ru/~Mironov/SPM_textbook.html)

Semester

Second semester, first year, usually from the beginning of March to the end of May with a week of break (or more) during Easter holidays.

Assessment method

Assessment and evaluation methods include:

- The development of an original case study (a short written thesis), based on a personal interest (not necessarily related to the student’s Master's thesis), including hypothetical scenarios. The project must incorporate some of the techniques and topics discussed during the course. Topics must be agreed upon with the professors by the end of the lecture period.

- an oral examination focusing on both the project and the topics covered in class.

The written project is worth up to 18 points.
The student’s understanding of the course content will be assessed during the oral exam for a maximum of 12 points.

The overall evaluation will consider clarity of presentation, synthesis skills, scientific accuracy, and the ability to connect theoretical and applied aspects of the studied mineralogical techniques. Originality of approach and the ability to critically frame a research problem, including interdisciplinary perspectives, will also be valued.

To pass the course, students must achieve a final score of at least 18 out of 30.

Office hours

All working days, by appointment, consistently with the off-site teacher's commitments, institutional commitments, and with the exception of summer, Christmas and Easter holidays.

Sustainable Development Goals

QUALITY EDUCATION | AFFORDABLE AND CLEAN ENERGY | INDUSTRY, INNOVATION AND INFRASTRUCTURE | CLIMATE ACTION | LIFE ON LAND