MINERAL SCIENCE I
Raw Materials Exploration and Sustainability

CONTACT INFORMATION

Professor: Giovanni Valdrè
University: University of Bologna, Dept of Biological, Geological and Environmental Sciences
E-mail Address: giovanni.valdre@unibo.it
Webpage: https://www.unibo.it/sitoweb/giovanni.valdre/teachings

COURSE CONTENT AND INTENDED LEARNING OUTCOMES (ILOs)

The objective of the present course is providing the students the necessary tools to understand the mineral sciences related to primary and secondary mineral raw materials, and to characterize them in detail at different scales down to the nanoscale. After an initial part concerning the fundamental aspects of mineral science (crystallography, mineral chemistry, mineral physics and surface properties), the course will deal with the basic physical and instrumental principles behind several techniques (for example, X-ray diffraction, electron microscopy and spectroscopy methods) and their application in deriving properties useful in various and different fields of raw materials exploration and sustainability.
At the end of the course, the students have the ability to:

- explain the mineralogical and crystallographic properties of primary and secondary raw materials, with a focus on minerals;
- explain the physical and chemical properties of primary and secondary raw materials;
- understand the principle behind different qualitative and quantitative techniques, in particular X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), Transmission Electron Microscopy (TEM), Scanning Probe Microscopy (SPM);
- explain how to prepare mineralogical and, generally, material samples for the different kind of analysis;
- select the appropriate experimental method to obtain specific information/properties on primary and secondary mineral raw materials;
- cross-correlate the results from different experimental and theoretical analytical techniques in both mineralogical and material science fields to obtain a clear picture on fundamental and applied properties of primary and secondary mineral raw materials.

Aligning with the EIT OLOs: *please tick ☑ at least two EIT OLOs that your course contributes to reach.*

☑ EIT OLO 1 - Making value judgments and sustainability competencies (2= highly relevant to the course content): the Mineral Science course is intended as the basis upon which the knowledge on primary and secondary mineral (and other) raw materials is constructed in terms of material science. This means that minerals (and materials) properties are discussed from both experimental and theoretical

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points of view, cross-correlating the results at different scales (from macro- to nano-scale) and accuracies that can be obtained by several techniques. This pedagogic approach encourages the students to better acknowledge the various and complex topics of the course, to think beyond boundaries and systematically explore and generate new ideas, aimed at the intrinsic variety and vastness of Raw Materials field.

☐ EIT OLO 2 - Entrepreneurship skills and competencies

☑ EIT OLO 3 - Creativity skills and competencies (1= peripherally relevant to the course content)

☑ EIT OLO 4 - Innovation skills and competencies (1= peripherally relevant to the course content). For both OLOs 3&4, the available experimental and theoretical methods discussed in the course represent a training ground for students who approach material science in general. We try to foster a cross-correlated approach to the study of raw materials by looking at different, and sometimes complementary, properties of minerals and materials in general. Students are stimulated to think creatively towards innovative problem solving. This includes the selection and the flexible combination of different analytical and theoretical methods, the cross-correlation of the results.

☑ EIT OLO 5 - Research skills and competencies (2= highly relevant to the course content): we emphasize the importance of combining cutting-edge research methods and equipment to cross-correlate results and use them in a multi-disciplinary environment. We try to show how the characterization of primary and secondary mineral raw materials from both the mineralogical and material science perspectives is of utmost importance for sustainable exploitation. Several examples along this line are presented and discussed in detail during the course.

☑ EIT OLO 6 - Intellectual transforming skills and competencies (1= peripherally relevant to the course content): the course includes several practicals during which students will prepare samples and will use different laboratory equipment (XRD, SEM, TEM). We believe this good practice will stimulate students to transform practical experiences into research problems.

☐ EIT OLO 7 - Leadership skills and competencies

ASSESSMENT METHODS AND GRADING SYSTEM

Different assessment methods will be used to evaluate the students: content-based, competence-based and impact-based assessments.
Content-based assessment refers to assessment tasks that mainly ask the learner about facts. It deals with answering questions without course material. Traditional essay-type questions, usually 10 questions, every question may give 1 point at max. Comprehensive understanding of main contents in mineral science is expected to be shown. This assessment is functional to evaluate the EIT OLOs 1 and 5 learning outcomes.
Competence-based assessment refers to assessment of intended learning outcomes that ask the learner to show ability to also use these facts, which is related to both EIT OLOs 3 and 4 learning outcomes. This part deals mainly with exercise/problem solving with use of course material, own notes, exercise papers, dictionary and calculator, which may give 10 points max.
Impact-based assessments take the assessment of competencies one step further and ask the learner to use these competencies in a real-life situation to create a change or solve a challenge. This part of the exam, which is instrumental to evaluate EIT OLO 6 learning outcome, aims at simulating real situations, where practical mineral science problems are to be solved, as an example qualitative and quantitative determination of minerals and phases present in a raw material sample through the proper selection and use of the specific instrumentation. This assessment may give 10 points max.

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The grades in the Italian university system are expressed out of thirty. The passing grade is 18/30. In case of full grade (30/30) the Professor(s) may also decide to award honours (lode).
Below there is the breakdown of the final grade:

ASSESSMENT METHOD	POINTS ON FINAL GRADE
Content-based	0-10
Competence-based	0-10
Impact-based	0-10

COURSE SESSIONS

Suggested pre-course reading materials:
Klein C., Hurlbut C.S. Manual of Mineralogy, John Wiley & Sons, Inc.
Hammond, C. Introduction to Crystallography, Oxford Science Publication.
Nesse, W. Optical Mineralogy, Oxford University Press.
Rickerby G.D., Valdrè G., Valdrè U. Eds. Impact of Electron and Scanning Probe Microscopy on Materials Research, Kluwer Academic Publishers.

Session 1	INTRODUCTION TO THE COURSE
Content	• Introduction of the course; • Basic principles in mineral science; • Basic principles in mineral chemistry and mineral physics.
Readings	Klein C., Hurlbut C.S. Manual of Mineralogy, John Wiley & Sons, Inc.

Session 2	NOTES OF CRYSTALLOGRAPHY AND REVIEW OF SYSTEMATIC MINERALOGY
Content	• Crystallography and crystal-chemistry; • Symmetry and operators; • Crystal structures and main mineral structures; • Basics of mineral classification.
Readings	Putnis A.Introduction to Mineral Sciences, Cambridge University Press, pp. 1-18. Klein C., Hurlbut C.S. Manual of Mineralogy, John Wiley & Sons, Inc. Velde B. (1992) Introduction to Clay Minerals, Chapman & Hall.

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Session 3	**ANISOTROPY AND PHYSICAL PROPERTIES OF MINERALS**
Content	• General concepts of anisotropy; • Properties of minerals and control of physical properties; • Basics of structural defects in minerals.
Readings	Putnis A. Introduction to Mineral Sciences, Cambridge University Press.

Session 4	**MINERAL THERMODYNAMICS I**
Content	• Basic concepts and principles of mineral thermodynamics.
Readings	Putnis A. Introduction to Mineral Sciences, Cambridge University Press.

Session 5	**MINERAL CHARACTERIZATION METHODS**
Content	• Optical and confocal mineralogy; • X-ray diffraction (XRD) and X-ray fluorescence (XRF); • Scanning and Transmission Electron Microscopies (SEM, TEM, STEM, ESEM) and microanalysis (EDS-SDD); • Scanning probe microscopy and surface techniques (SPM, AFM, KPFM, ShFM); • Micro and nano-spectroscopic methods (FTIR, Raman)
Readings	Putnis A. Introduction to Mineral Sciences, Cambridge University Press. Nesse, W. Optical Mineralogy, Oxford University Press. Goldstein et al. Scanning Electron Microscopy and X-Ray Microanalysis, Springer. Williams D.B. and Carter C.B. Transmission Electron Microscopy, Springer. Meyer E. et al. Scanning probe microscopy, Springer.

Session 6	**MINERAL SCIENCE CHARACTERIZATION LABORATORY**
Content	• Preparation of different mineral samples; • XRD analysis and interpretation of diffraction patterns; • Mineral chemistry analyses via XRF; • SEM morphological and EDS-SDD chemical analyses; • TEM analyses of mineral samples; • SPM mineral topography and surface physical properties; • Mineral structures and simulations.
Assignment	Laboratory exercise on mineral identification and property analysis through lab methods.

Session 7	**FINAL EXAM**
Date - hours	

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Content	• Written test regarding laboratory topics (four open questions, duration 1 hour); • Oral examination (to integrate competence and impact based assessments, duration 20-30 minutes)

MINERAL SCIENCE II
RAw Materials Exploration and Sustainability

COURSE CONTENT AND INTENDED LEARNING OUTCOMES (ILOs)

This course aims at giving the students solid foundations on the physical and chemical properties governing the behavior of primary and secondary mineral raw materials. The fundamental subjects of the present course will be the theory of thermodynamics related to mineral processes, including phase stability and diagrams, solid solutions and mineral reactivity at different pressure and temperature conditions. Computer-aided methods will be employed in practical laboratory experiences to obtain thermodynamic quantities and calculate phase diagrams (single-component, binary and ternary) of minerals and materials of interest, using specific thermodynamic databases.

At the end of this course, the students will be able to:

- explain the physics and chemistry behind the thermodynamic stability of mineral raw materials;
- explain the stability and meta-stability of primary and secondary mineral raw materials;
- explain the kinetics of mineral processes;
- use thermodynamic databases and procedures to obtain the properties of mineral phases and big data on geomaterials;
- construct single-component, binary and ternary phase diagrams using thermodynamic databases and computer-aided methods (CALculation of PHAse Diagrams, CALPHAD);
- understand and extract the information present in single, binary and ternary phase diagrams.

Aligning with the EIT OLOs:

☑ EIT OLO 1 - Making value judgments and sustainability competencies (2= highly relevant to the course content).
Research and innovations in mineral (and material) thermodynamics are discussed taking into account both theoretical and experimental approaches at different scales (from macro- to nano-scale), encouraging the students to think beyond boundaries and systematically explore and generate new ideas in the context of the challenging and ever-changing Raw Materials field. For example, the acquired skills in thermodynamics and mineral kinetics can help students proposing new, more sustainable routes, or modify the existing ones for a better exploitation of both primary and secondary mineral resources.

☐ EIT OLO 2 - Entrepreneurship skills and competencies

☑ EIT OLO 3 - Creativity skills and competencies (1= peripherally relevant to the course content)

☑ EIT OLO 4 - Innovation skills and competencies (1= peripherally relevant to the course content): regarding OLO 3&4, the course is intended to present and address thermodynamic stability and

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transformation reactions of both primary and secondary mineral raw materials, by employing different approaches, such as experimental methods (*e.g.* differential scanning calorimetry) and *ab initio* simulation methods. This approach supports creative and innovative problem solving, which includes the selection, combination and adaption of different methods in the thermodynamics and transformation kinetics fields.

☑ EIT OLO 5 - Research skills and competencies (2= highly relevant to the course content): the ability to use cutting-edge research methods, software and techniques and to apply these also in cross-disciplinary teams and contexts, is emphasized. For the sake of an example, it is possible to obtain thermodynamic data of minerals, metals, ceramics and, in general, raw materials from different experimental and theoretical approaches. The accuracy of the results, and consequently of the thermodynamic databases built with them, are discusses during the course.

☑ EIT OLO 6 - Intellectual transforming skills and competencies (1= peripherally relevant to the course content): the course includes several practical exercises based on thermodynamic databases and CALPHAD methods, stimulating the students to transform practical, computer-aided experiences into research problems.

☐ EIT OLO 7 - Leadership skills and competencies

ASSESSMENT METHODS AND GRADING SYSTEM

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Competence-based assessment refers to assessment of intended learning outcomes that ask the learner to show ability to also use these facts, which is related to both EIT OLOs 3 and 4 learning outcomes. This part deals mainly with exercise/problem solving with use of course material, own notes, exercise papers, dictionary and calculator, which may give 10 points max.
Impact-based assessments take the assessment of competencies one step further and ask the learner to use these competencies in a real-life situation to create a change or solve a challenge. This part of the exam, which is instrumental to evaluate EIT OLO 6 learning outcome, aims at simulating real situations, where practical mineral science problems are to be solved, as an example qualitative and quantitative determination of minerals and phases present in a raw material sample through the proper selection and use of the specific instrumentation. This assessment may give 10 points max.

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Below there is the breakdown of the final grade:

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Content-based	0-10
Competence-based	0-10
Impact-based	0-10

COURSE SESSIONS

Suggested pre-course reading materials:
Atkins P.W. Physical Chemistry. Oxford University Press, pp. 51-72.
Lukas H.L., Fries S.G., Sundman B. Computational Thermodynamics: The Calphad Method. Cambridge University Press.
Ashcroft N.W., Mermin D. Solid State Physics. Cengage Learning, Inc.
CRYSTAL17 Manual, http://www.crystal.unito.it/Manuals/crystal17.pdf

Session 1	**INTRODUCTION TO THE COURSE**
Content	• Objective of the course; • Mineralogy as the link between geology, physics/chemistry and natural material science; • Basic principles of physics and chemistry in the mineralogy of mineral raw materials.

Session 2	**MINERAL THERMODYNAMICS II**
Content	• Experimental and theoretical determination of thermodynamic quantities. • Theory of mineral phase transitions; • Basic principles of phase diagrams; • Solid solutions, Order-disorder solid solutions. Partial solid solutions; • Enthalpy variations related to different processes (phase transitions, phase formations, reactions between mineral phases); • Thermal and pressure dependency of enthalpy.
Readings	Putnis A. Introduction to Mineral Sciences, Cambridge University Press Atkins P.W. (1994) Physical Chemistry. Oxford University Press. pp. 51-85. Anderson O.L. (1995) Equations of State of Solids for Geophysics and Ceramic Science, Oxford University Press, pp 31-55.

Session 3	**KINETICS OF MINERAL PROCESSES**

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Content	• The kinetic theory and reaction rates; • Heterogeneous reactions; • Mineralogical relevant examples and applications.
Readings	Putnis A. (1992) Introduction to Mineral Sciences, Cambridge University Press, pp. 309-331.

Session 4	**MINERAL RED-OX REACTIONS**
Content	• Notes on mineral red-ox reactions; • Mineralogical relevant examples and applications.
Readings	Redox-reactive minerals: Properties, reactions and applications in natural systems and clean technologies. EMU Notes in Mineralogy 17, Ed. Ahmed I.A.M and Hudson-Edwars K.A. (2017), pp. 55-87, 357.372, 405-433.

Session 5	**MINERAL MECHANICS**
Content	• Basics of mineral deformation; • Mineral equation of state.
Readings	Anderson O.L. (1995) Equations of State of Solids for Geophysics and Ceramic Science, Oxford University Press, pp 159-173.

Session 6	**COMPUTATIONAL MINERALOGY LABORATORY**
Content	• *ab initio* codes for the evaluation of the properties of mineral phases; • Calculation of phase diagrams via CALPHAD method.
Assignment	Laboratory exercise using an *ab initio* software package on a model system.

Session 7	**FINAL EXAM**
Date - hours	
Content	Please provide a clear description of the final exam • Written test (10 open questions and/or exercises regarding all course topics, including laboratory. Duration: 3 hours); • Oral examination (a brief oral examination might integrate the written test in order to improve competence and impact-based assessment. Duration: 10-15 minutes)

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