UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Basics for Sustainable Valorisation of Materials

2627-2-E3304M014

Aims

General aims

The course's objective is to provide students with basic knowledge of the structure of matter, chemical principles and chemical reactivity, stoichiometric aspects of reactions, equilibrium theory, the theory of acids and bases, and the properties of the most important elements and compounds, including their (anthropo)biogeochemical cycles. While obviously placing particular emphasis on chemical aspects related to the structure and physicochemical characteristics of matter, the course will also discuss, where appropriate, the relevance of the topics covered in terms of environmental sustainability. The latter includes a discussion of organic chemistry, including the physicochemical characteristics of synthetic materials, viewed in part as "novel entities," to better understand discussions on resources and recycling methods.

Knowledge and understanding

At the end of the course the student will have a fundamental understanding of:

- on matter, atomic theory, atomic and molecular mass, the importance of the Avogadro constant, and the use of moles.
- on chemical compounds. Chemical nomenclature, the electronic structure of atoms and molecules, periodic atomic properties, ionic and covalent bonds, bond theories, Lewis formalism, valence bond and molecular orbital theories, intermolecular and intramolecular interactions.
- on the various forms of solid matter, such as crystals and metals, including aspects of crystallography and band theory.
- on the theory of ideal gases and the application of descriptive laws.
- on basic thermochemistry and thermodynamics.
- on stoichiometry.
- on aqueous mixtures and solutions, the solubility of salts and its theoretical description using solubility products, chemical equilibria and their manipulation according to LeChatelier's principle.
- on acids and bases, including conceptual definitions according to Arrhenius, Brønsted-Lowry, and Lewis,

the meaning of pH, and the use of indicators.
- oxidative and reductive processes and their coupling.
- basic notions of electrochemistry
- nuclear chemistry and types of radiation.
- descriptive chemistry of the main elements of the important groups of the periodic table, including (anthropo)biogeochemical cycles.
- principles of organic chemistry, important functional groups and their reactivity, reactions in organic chemistry, selected important biomolecules, and unnatural organic structures representing important classes of organic pollutants.

Applying knowledge and understanding

At the end of the course the student will be able to:

- write correctly a chemical reaction equation.
- perform simple stoichiometric calculations.
- understand the behaviour and classify the substances on the basis of their chemical nature.
- understand the bond types and tridimensional shapes of simple molecules.
- predict the spontaneity of a chemical reaction.
- evaluate the energy transfer related to such chemical transformation.
- describe the condition for the chemical equilibrium.
- evaluate the behaviour of acids, bases and their mixtures in aqueous solutions, as well as the behavior of chemical species that produce insoluble salts.
- understand basic chemistries of organic substances, the importance of functional groups and their interconversion, and the problematic of 'persisting' orgabic structures.

Making judgements

At the end of the course the student will be able to:

- apply the acquired knowledge in various contexts.
- transfer concepts and approaches to new fields.
- elaborate the topics of the course.

Communication skills

At the end of the course the student should be able to:

- analyse a chemistry-related problem in a clear and concise way.
- explain orally with a suitable language the objectives, the procedures and the results of the elaborations carried out.

Learning skills

At the end of the course the student should be able to apply the acquired knowledge to different contexts than those discussed during the course.

Contents

- the fundamental chemical properties such atomic mass and mole
- the electronic structure of atoms and their periodic properties
- bonding theories and the principles that regulate atom binding

- the nature of intermolecular interactions and their relation with the states of matter
- the energy transfer related to physical and chemical transformations, and the criteria to evaluate the spontaneity of a process
- the properties of homogeneous and heterogeneous mixtures
- the basic concepts of chemical reactivity and the main classes of reactions (redox, acid-base, precipitation etc)
- the general principles of chemical equilibria
- the general principles of chemical kinetics
- the general principles of electrochemistry
- the general principles of nuclear chemistry
- the descriptive chemistry of the strategic elements of the periodic table of elements and their (anthropo)biogeochemical cycles
- organic chemistry, comprising basic nomenclature, functional groups and fundamental reaction and mechanisms
- important classes of organic compounds, phenomenon of 'persisting' organic structures
- remediation strategies targeting organic pollutants

Detailed program

- The electronic structure of atoms; modern model of the atom; quantization of energy, electron spin, Schrödinger equation, atomic orbitals, principles of nuclear chemistry.

- The periodic table and periodic properties of the elements; definitions and trends of ionization energies, electron affinity, Pauling electronegativity, polarizability, atomic and ionic radii.

- Chemical bonding: ionic and covalent bonds. The electronic and geometric structure of molecules; the Lewis formalism and the octet rule, resonance and hypervalent compounds, VSEPR theory. VB theory, hybrid orbitals and sigma and pi bonds; foundations of MO theory and its extrapolation to explain metallic bonding.

- Intermolecular interactions; dispersion interactions, dipole-dipole interactions, dipole-ion interactions, hydrogen bonds.

- Macroscopic chemical systems and basic thermochemistry: definition of the thermodynamic state of a system, state functions. Internal energy, work, heat, and the first law of thermodynamics.

- States of matter and transformations between states:
  (i) The gaseous state, ideal gases and gas laws, differences from real gases, gaseous mixtures.
  (ii) The solid state. The crystal lattice and the unit cell of a crystal. Classification of solids based on their structure; ionic solids, metallic solids, and band theory, covalent solids and molecular solids. Conductors and insulators, paramagnetic and diamagnetic substances.
  (iii) The liquid state; properties of liquids; phase diagrams and the phase rule.

- Solutions and colligative properties of solutions; boiling point elevation and freezing point depression, osmotic pressure. Azeotropes and eutectic mixtures.

- Chemical equilibrium. Equilibrium constants as a function of concentrations, partial pressure, and mole fractions. Gas-phase equilibria; methods for determining the quantities of reactants and products at equilibrium conditions. The LeChatelier principle and the effects on equilibrium due to variations in the quantities of reactants and products, temperature, and pressure. Heterogeneous equilibria.

- Theories of acids and bases; definitions according to Arrhenius, Brønsted-Lowry, and Lewis. Autoprotolysis

of water and the ionic product of water. pH and methods for calculating the pH of strong and weak acids and bases. Buffer solutions and their applications. Indicator theory.

- Solubility of salts and solubility product. Methods for calculating the solubility of a salt in aqueous solution. Common ionic effect. Effect of pH on the solubility of a salt.
- Second law of thermodynamics, entropy, and Gibbs free energy. Methods for determining the spontaneous direction of a reaction, statistical definition of entropy, and the Boltzmann equation.
- Electrochemistry; galvanic cells, the SHE electrode, standard reduction potentials, and the Nernst equation.
- Descriptive chemistry of hydrogen, s-block elements, p-block elements, noble gases, and d-block elements, basic coordination chemistry and crystal field theory.
- Fundamentals of transition metal chemistry and coordination compounds.
- Main concepts of organic chemistry, general aspects of nomenclature, recognition and typical chemistries of important functional groups, standard reaction mechanisms including polymerization and condensation reactions, polyaromatic, polycondensate, and perfluorinated compounds.

Prerequisites

- Basic physical concepts (mechanics).
- Basic mathematical concepts (algebra, exponential logarithms, trigonometry).
- Units, conversion factors and dimensional calculations.

Teaching form

- Theoretical lessons in the classroom and numerical exercises on the topics covered in the theoretical lessons:
  -> 20 two-hour lectures, in person, Delivered Didactics
  -> 4 two-hour practical classes with exercises, in person, Interactive Teaching

Textbook and teaching resource

- T. L. Brown, H. E. LeMay Jr., B.E. Bursten, C.J. Murphy, P.M. Woodward, M.W. Stoltzfus
  Fondamenti di Chimica
  EdiSES
- M. S. Silberberg, S. Licoccia
  Chimica. La natura moleculare della materia e delle sue trasformazioni
  McGraw- Hill
- J. C. Kotz, Paul M. Treichel, J. R. Townsend
  Chimica

EdiSES

- C. E. Housecroft, A. G. Sharpe
  Inorganic Chemistry, 4?? edition (solo in lingua Inglese)
  Pearson

- diapositive e appunti mostrati durante le lezioni e materiale aggiuntivo su argomenti selezionati disponibili sul sito elearning della Bicocca.

Semester

I semester (october - january)

Assessment method

The exam consists of a single written test at the end of the course. There will be no mid-course exam.

The written test will consist of a maximum of 12 questions. Three of the questions must be answered in free text format and are intended to assess the student's ability to use specific professional terminology in the given context. Each question is assigned a score between 0 and 5 points; 5 points is the maximum score achievable for a single question.

Students with a score below 50% of the total achievable points have failed the exam.
Students with a score between 50% and 60% of the total achievable points must take a short oral exam, which consists of an in-depth discussion of the topics covered in the written test, to give the student the opportunity to demonstrate sufficient knowledge to pass the exam.
Students with a score higher than 60% of the total achievable points will be assigned final scores between 18 (60% of the total points) and 30/30 with honors (maximum number of points).

The final score will range from 18/30 to 30/30 with honors, based on the overall assessment, taking into account the following criteria:

1. conceptual knowledge and understanding
2. ability to apply knowledge and understanding
3. communication and argumentation skills
4. learning, self-assessment, and self-regulation skills

Grade < 18
Knowledge and Understanding: The student only partially identifies the characteristics of the concepts. The connections between the concepts are fragmented and poorly supported by theoretical knowledge.
Ability to apply knowledge and understanding: The student identifies only a few relevant elements in a phenomenon, unable to integrate them into a coherent analysis.
Communication and Argumentation Skills: In the oral exam, the student develops a basic argument, lacking logical structure and characterized by numerous expository inaccuracies.
Learning, self-assessment, and self-regulation skills: The student is able to reconstruct only some aspects of their learning and professional development journey.

Grade 18-22

Knowledge and Understanding: The student recognizes and explains most of the conceptual features and is able to provide a relatively coherent explanation, albeit with some inaccuracies. Theoretical references are present but not always rigorously.
Ability to apply knowledge and understanding: The student is able to recognize a significant number of elements and provide a partial explanation, while highlighting some gaps in the analysis.
Communication and argumentation skills: In the oral exam, the student constructs a basic argument, with a minimal structure but with some inaccuracies.
Learning, self-assessment, and self-regulation skills: The student demonstrates a basic awareness of their learning path, managing to draw essential connections between learning experiences, albeit with some inaccuracies.

Grade 23-27
Knowledge and Understanding: The student demonstrates a thorough understanding of conceptual characteristics. In the oral exam, explanations are well-articulated and supported by an appropriate use of theoretical references.
Ability to apply knowledge and understanding: The student accurately identifies the essential elements of a phenomenon. The application of knowledge occurs with methodological rigor that is not always solid.
Communication and argumentation skills: In the oral exam, the student develops a coherent and well-organized argument, demonstrating good command of language and a solid logical-argumentative structure. Communication is clear and effective.
Learning, self-assessment, and self-regulation skills: The student analyzes his or her learning journey in a clear and structured manner, highlighting significant relationships between the various developmental stages and demonstrating a good capacity for critical reflection.

Grade 28-30
Knowledge and Understanding: The student demonstrates a thorough mastery of concepts, articulating complex connections and providing comprehensive explanations. Theoretical references are used with relevance and rigor.
Ability to apply knowledge and understanding: The student demonstrates an advanced ability to analyze a phenomenon, comprehensively identifying and interpreting all salient elements. Knowledge is applied with methodological rigor, supported by solid and detailed argumentation.
Communication and argumentation skills: In the oral exam, the student develops a solid and detailed argument, with a rigorous logical structure and a high level of textual coherence. The presentation is fluent and well-structured.
Learning, self-assessment, and self-regulation skills: The student demonstrates an advanced capacity for self-reflection, developing a detailed and in-depth analysis of their learning and professional development journey. The connections between learning experiences and theoretical concepts are clear, coherent, and rigorous.

Office hours

Always, after scheduling an appointment *via* phone or e-mail.

Sustainable Development Goals

QUALITY EDUCATION | SUSTAINABLE CITIES AND COMMUNITIES | RESPONSIBLE CONSUMPTION AND PRODUCTION