

Master in Chemical Engineering

Curriculum “Chemical engineering for innovative processes and products”

Syllabus 2026-27

Classes for the first year of the Master will be given in two Semesters:

Semester 1: September 22 – December 19, 2026

Semester 2: February 23 – May 29, 2027

All classes will be given in the headquarters of the Faculty of Civil & Industrial Engineering, in [Via Eudossiana 18 – 00184 Rome, RM](#)

Common courses, required

Course	ECTS	Year	Semester
Mathematical methods for chemical engineering	9	1	1
Non equilibrium thermodynamics with an application to the microscale	9	1	1
Chemical reactors	9	1	2
Economics of technology and management	9	1	2
Theory and development of process design	9	2	2
Computer aided process control	9	2	1
Chemical & Biochemical Plants	9	2	1

Elective courses (4 courses to be selected)

Course	ECTS	Year	Semester
Advanced metallic materials	6	1	1
Green and Sustainable Hydrogen Production	6	1	1
Process and product safety in the chemical industry	6	1	1
Transport phenomena in multiphase systems	6	1	1
Corrosion engineering	6	1	2
Principles of biochemical engineering	6	1	2
Environmental Chemical Engineering	6	2	1
Green chemistry and process engineering	6	2	1
Sustainable design of materials	6	2	1
Nanobiotechnology	6	2	1
Transport phenomena in microsystems and micro/nano reactive devices	6	2	2
Computational methods for chemical and biochemical reactor dynamics	6	2	2

To complete their Master curriculum, students must get a total of 120 ECTS, distributed as follows:

Course	ECTS
Common courses, required	63
Elective courses	24
Additional elective courses (may be chosen among Elective courses indicated above or among all the courses given in English by Sapienza University, provided their contents are compatible with a Chemical Engineering Master)	12
Seminars	1
Final thesis work	20

First year - first semester

Green & sustainable hydrogen production (6 CFU)

Modulo I - Processes (3 CFU):

Prof.ssa Maria Anna Murmura (mariaanna.murmura@uniroma1.it)

Modulo II – Fundamentals (3 CFU):

Prof.ssa Benedetta De Caprariis (benedetta.decaprariis@uniroma1.it)

Objectives

The course aims to introduce the main processes for the production of green and sustainable hydrogen. The course is dedicated to students who want to deepen their knowledge on renewable energy production, which in this historical period is becoming a fundamental aspect of chemical engineering. The course will be focused both on processes that are already developed at industrial scale and on those which are now under study and have a high industrial interest. The course will also take into consideration the critical aspects of hydrogen storage and transportation.

Program

Fundamentals

- Hydrogen properties
- Traditional processes overview: possible feed fossil and renewable (Steam reforming, partial oxidation, autothermal reforming)
- Carbon capture and Storage in hydrogen production (Steam reforming with CCS, sorption enhanced reforming, methane cracking)
- Biomass gasification
- Chemical looping hydrogen processes and thermochemical cycles
- Electrolysis coupled with solar energy sources
- Transportation and storage

Processes

The course will cover the following areas

- Hydrogen properties
- Overview of traditional H₂ production processes using either fossil or renewable feeds (steam reforming, partial oxidation, autothermal reforming)
- Carbon capture and storage in hydrogen production processes (steam reforming with CCS, sorption-enhanced reforming, methane cracking)
- Biomass gasification
- Chemical looping hydrogen processes and thermochemical cycles
- Electrolysis coupled with concentrating solar energy systems
- Hydrogen transportation and storage

Textbooks

Scientific articles and material supplied by the professor

Type of lectures

The lesson will be held in classroom

Final evaluation

Oral exam

Mathematical methods for chemical engineering (9 CFU)

(6 CFU) Roberto Conti (roberto.conti@uniroma1.it)

(3 CFU) Prof. Anna Vidotto (anna.vidotto@uniroma1.it)

MAT/05

Objectives

Provide an elementary treatment of the theory of partial differential equations (PDE), including important examples from mathematical physics. Some first-level mathematical analysis tools indispensable for the understanding of the program will be recalled, many examples will be presented and various exercises will be solved with the use of classical techniques such as the method of separation of variables, Fourier series, the heat kernel, the Green's function

Program

Chapter 1 Review and basic tools.

Review of basic concepts in vector-space algebra: Algebra of vectors and its representation, scalar product, vector product, projections, exponential of a matrix.

Review of Vector Calculus: functions of several variables, integral theorems on curves, integral on surfaces, Gauss-Green Formula, Divergence and Stokes Theorems, Helmholtz decomposition.

Review of Ordinary differential equations (ODE): Existence and uniqueness of solutions for general ODE's of first and second order, phase space and qualitative behavior of solutions, explicit solutions of first ODE's and of second order ODE's with constant coefficients.

Banach and Hilbert Spaces: Dual Space, Lebesgue measure and Lebesgue spaces, weak derivatives and Sobolev spaces (H^1), Motivation: Dirichlet Principle (Sketch).

Review of Fourier Transform: Plancherel Theorem, Inverse Fourier Transform and applications to ODE's (Sketch).

Review of Fourier series: Parseval Identity and convergence theorems.

Chapter 2: Partial Differential Equations.

First order PDE's: method of characteristics, shocks, entropy solutions.

Second order PDE's: Hyperbolic Equations: wave equations in dimension 1 and $N \geq 2$;

Parabolic Equations: Fundamental solution, Maximum principle, Cauchy problem in dimension 1;

Elliptic Equations: Harmonic functions, Green functions (space, disk, semispace...), minimization and weak formulation of elliptic problems, Lax--Milgram Theorem.

Chapter 3: Probability.

Introduction to the elements of theory of probability: events, random variables, probability densities and distributions, joint densities and covariance matrices, correlation, conditional probabilities and Bayes Theorem, functions of random variables (one-to-one).

Limit theorems and applications: convergence in law, convergence in probability, weak law of large numbers, Monte Carlo methods, central limit theorem, random walks (Gaussian).

Markov processes: semigroups and generators (Brownian motion).

Time-changed processes: Phillips' formula and subordinate semigroups (Stable processes).

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Textbooks

Salsa, Sandro: Partial differential equations in action. From modelling to theory.

Prerequisites

Contenuto dei corsi di Analisi Matematica I e Analisi Matematica II

Type of lectures

Chalk and talk

Attendance

Attendance is not mandatory

Final evaluation

Written examination consisting of exercises, and oral examination including a discussion of the written exam

MAT/06

Objectives

Provide an elementary treatment of the theory of probability and the PDEs connection with stochastic processes.

Program

Events. Operations on events. Probability of events. Random variables. Probability distributions. Expected value and moments. Stochastic independence. Cumulative distribution function and density function. Random vectors and marginal distributions. Transformations of random variables. Sum of random variables. Introduction to convergences and limit theorems. Introduction to stochastic processes (Brownian motion and boundary value problems).

Textbooks

Lecture notes + Probability Essentials, Jean Jacod, Philip Protter, Springer-Verlag, 2004

Prerequisites

Analysis, Geometry

Type of lectures

Chalk and talk

Attendance

Attendance is not mandatory

Final evaluation

Oral and written exams aimed at verifying the achievement of the course objectives. In particular, the evaluation takes into account acquired skills (written exam, 50%) the acquired theoretical knowledge and the ability to process and communicate (oral exam, 50%). Please, consult the web page

<https://www.sbai.uniroma1.it/~mirko.dovidio/PGS/lectures>

Examples:

Evaluate the probability of some events (example: number of success in n independent trials).
Evaluate the density of a given transformation.

Non equilibrium thermodynamics with an application to the microscale (9 CFU) – SSD ING-IND/24

Prof. Massimiliano Giona (massimiliano.giona@uniroma1.it)

Objectives

To provide the students with the basic physical (thermodynamical, statistical mechanical) tools and kinetic approaches for tackling the analysis of out-of-equilibrium and irreversible processes, and for expressing macroscopically the dynamics of thermodynamic variables in terms of transport equations. The goal of the course is also to foster the physical sensitivity for setting up the analysis and the design of processes at micro/mesoscale, which is the prerequisite for the subsequent more applied classes.

Program

1) Introduction to the theory of transport phenomena: kinetic theory (Boltzmann equation, continuous approaches, stochastic methods). Theory of transport phenomena as the thermodynamics of out-of-equilibrium (irreversible) processes.

2) Structure of balance equations: concentration/fluxes formulation and constitutive equations. Continuous formulation of balance equations for mass, momentum and energy transport. Thermal balance equation. Lagrangian and Eulerian approaches to the analysis of transport phenomena. Entropy balance and its application in the assessment of the thermodynamic consistency of the constitutive equations. Classical constitutive equations: Fick, Newton and Fourier laws. Boundary conditions for the mass, momentum and thermal balance equations.

3) Mass transport. Diffusion in bounded and unbounded domains. Spectral properties of the Laplacian operator. Classical case studies of mass transport of chemical engineering interest. Chromatographic processes and moment analysis.

4) Momentum transport. Navier-Stokes equations. Hydrodynamic regimes: Stokes and Moffat regime and transition to turbulence. Inviscid flows and their properties. Incompressible flows: stream function (in two-dimensional problems) and its properties. Representation of incompressible flows in three dimensions. Stream function/vorticity formulation of two-dimensional flow problems. Elementary flow problems: Poiseuille, Couette flow and other simple examples. Axial symmetric flows and solution of the Stokes problems for the motion around a solid sphere. Stokes law, friction factor and particle motion in a fluid phase. General solution of the Stokes problem: Oseen tensor and introduction to computational methods for Stokes flows.

5) Thermal transport: natural and forced convection. Examples. Blackbody radiation and radiative transfer.

6) Interaction between convection and diffusion: Taylor-Aris dispersion in straight tubes. Survey of boundary layer theory.

7) Introduction to the stochastic theory of transport phenomena: random walk on a lattice, Langevin equation and connection with the Fickian nature of the constitutive equations.

8) Transport phenomena at microscales: examples and case studies.

Mathematical background: Review of vector analysis. Representation of differential operators in orthogonal curvilinear systems. Helmholtz decomposition.

Textbooks

- 1) De Groot, Sybren Ruurds and Mazur, Peter, Non-equilibrium thermodynamics, Dover Publ., 2013.
- 2) Balescu Radu, Statistical Dynamics: Matter Out of Equilibrium, Imperial College Press. 1997.
- 3) Bird, R Byron, Stewart, Warren E and Lightfoot, Edwin N, Transport Phenomena, John Wiley & Sons, New York, 2004.
- 4) Lecture notes edited by the instructor.

Final evaluation

Oral exam

Process and product safety in the chemical industry

Prof. Paola Russo (paola.russo@uniroma1.it)

Objectives

Il corso mira a fornire una comprensione più approfondita delle proprietà e della natura pericolosa delle sostanze chimiche, effettuando l'analisi dei processi chimici.

Il corso mira a raggiungere i seguenti tre Objectives:

- fornire agli studenti una panoramica delle statistiche sugli incidenti, gestire un incidente come processo dinamico e introdurre un approccio sistemico nei confronti degli incidenti

- essere in grado di valutare i pericoli che sono proprietà intrinseche dei prodotti e pericoli legati alle condizioni fisiche dei materiali o dei processi, per avere familiarità con la classificazione dei prodotti pericolosi
- essere in grado di valutare una strategia di prevenzione per l'uso di sostanze chimiche pericolose (in ambiente di laboratorio e industriale) e di adottare le misure di protezione adeguate contro gli incidenti

Program

Introduction to Safety in Chemical Industry. Definitions of safety, danger and risk. Accidents and statistical surveys. The types of process accidents. Some significant accidents (Flixborough, Seveso, Bhopal).

Substances that are hazardous to health and the environment

Classification, hazardous characteristics, safety data sheet. Regulation (EC) No 1272/2008 (GHS CLP), REACH; Atex; Seveso Directive.

Toxicity of substances. Effects of toxic substances on biological organisms. Dose-response curves and related models; threshold limits. Industrial Hygiene: identification, assessment and control of exposure to toxic substances. Remediation of contaminated soils.

Reactivity and stability of the substances. Runaway reactions. Identification of unstable structures. Incompatibility. CHETAH Criteria. Examples of exothermic reactions of decomposition, isomerization, polymerization.

Fires and Explosions. Combustion reaction. The fire triangle, flammability limits, limiting oxygen concentration, flammability diagram, ignition sources and energies, auto-ignition temperature. Fire: ignition sources, heat dispersion from the fumes. Types of fire in industrial processes. Effects of fires on structures and people. Detonations and explosions, confined explosions, flammable vapor cloud explosions, physical explosion, airborne dust explosions. Effects of the pressure wave on people and structures. Designs to prevent fire and explosions.

Textbooks

D. A. Crowl e J. F. Louvar, Chemical Process Safety, Fundamentals with Applications, 3rd ed., Prentice Hall, 2011

F. Stoessel, Thermal Safety of Chemical Processes: Risk Assessment and Process Design, Wiley 2008

Prerequisites

Conoscenze di Chimica e Chimica Organica, Termodinamica, Impianti e Processi Chimici

Type of lectures

Il corso prevede lezioni frontali e esercitazioni

Attendance

La frequenza è obbligatoria

Final evaluation

Prova orale

Transport phenomena in multiphase systems (6 CFU)

Prof. Stefano Cerbelli (stefano.cerbelli@uniroma1.it)

Objectives

The course aims at providing the students with the basic theoretical and numerical tools to characterize transport of diluted solutions and solid particle suspensions entrained in laminar flows through confined geometries. These tools are then exploited for the optimal design of selected separation/fractionation operations, ranging from industrial scale adsorption units to lab-scale and

microfluidics-assisted chromatography of biologically and clinically relevant analytical targets. Practical design cases are developed through tailored projects that involve the use of commercial software as well as in-house developed code.

Program

1. Basic fluid dynamics of low Reynolds number flows. Creeping flow. General properties and basic solutions of flows through simple geometries. Numerical approaches to laminar flows.
2. Separation in single-phase flows: Adsorption equilibria. Dispersion in laminar flows through capillaries and through packed columns with simultaneous adsorption. Macrotransport approach. Gas and liquid chromatography. Adsorption columns.
3. Separation of suspended nanoparticles: hydrodynamic chromatography and flow-based separations of suspensions and colloids. Current research trends in nanoparticle analysis and fractionation.

Textbooks

1. Panton, Ronald L. Incompressible flow. John Wiley & Sons, 2006.
2. Brenner, Howard. Macrotransport processes. Elsevier, 2013.
3. Articoli pubblicati su riviste scientifiche di riferimento

Prerequisites: Batchelor-level knowledge of equilibrium thermodynamics and transport phenomena.

Final evaluation

Oral exam. Access to oral examination is granted by the presentation of a computational project assigned by the instructor.

First year – second semester

Chemical Reactors (9 CFU)

Prof. Antonio Brasiello (antonio.brasiello@uniroma1.it)

Objectives

Starting from the basic knowledge, already gained, in chemical thermodynamics, transport phenomena, and chemical plant design, the course seeks to lead the student toward a critical analysis of the phenomena that act in reacting systems. Additionally, students will acquire the skills required for the design and modeling of chemical reactors.

By the completion of the course, the student should be able to:

- Recognize the main variables that affect chemical reactor design and modeling
- Discuss problems related to the thermal effects occurring in chemical reactors and their implications on the design of heat exchange devices and the reactor stability
- Carry out the basic design of homogeneous and heterogeneous reactors (catalytic reactors, fluid-solid reactors, and gas-liquid reactors)
- Develop models for reactor simulations.

Program

Heat and mass balance in reacting systems; chemical equilibria

Kinetics of chemical reactions

Ideal reactors (BSTR, CSTR, PFR)

Heterogeneous reactors: general discussion; diffusion and chemical reaction

Heterogeneous catalysis: reaction mechanisms and kinetic models

Interaction between chemical kinetics and diffusional phenomena. Thermal effects.

Design of fixed bed reactors

Fluid-solid reactions: shrinking core and distributed conversion models
Fluid-solid reactor design
Gas-liquid reactions: slow reactions; fast reactions; instantaneous reactions.
Design of gas-liquid reactors and chemical absorption devices

Textbooks

O. Levenspiel - Chemical Reaction Engineering - J Wiley & Sons, 1999
H. S. Fogler - Elements of Chemical Reaction Engineering - Prentice Hall 2005
G. F. Froment - Chemical Reaction Analysis and design - J. Wiley & Son 1990
M. C. Annellini - Lezioni di Reattori Chimici - Edizioni Efesto 2023

Final evaluation

The students' preparation will be assessed through a written and an oral exam.

The written exam will last 3 hours. The students will be asked to solve problems on the topics discussed throughout the course. In some cases, the numerical solution may also be required. During the written exams, students will be allowed to consult their textbooks and notes. The aim of the exam is to determine the students' ability to independently apply the knowledge gained throughout the course to solve original problems.

Admittance to the oral exam is subjected to the achievement of a threshold result in the written exam, which may also be lower than 18/30.

The written test can be replaced by the presentation of a project assigned by the teacher during the lessons.

The oral exam may include both theoretical questions and the solution of problems regarding the design or simulation of chemical reactors. This examination is intended to verify the full grasp of the theoretical fundamentals introduced in the course, the ability of identifying the correct procedure for the solution of problems, and the capacity of critically analysing the procedures and the results obtained.

Corrosion Engineering (6 CFU)

Prof. Cecilia Bartuli (cecilia.bartuli@uniroma1.it)

Objectives

GENERAL PURPOSE: The course aims to provide the student with the necessary information to recognize the main forms of corrosion of metallic materials in contact with different aggressive environments, to understand the different mechanisms of degradation and to identify correctly the most suitable diagnostic tools and the potential preventative measures and protection systems, with special reference to the field of the chemical industries.

SPECIFIC PURPOSES: With specific reference to Dublin descriptors

Knowledge and understanding of the physico-chemical phenomena at the basis of the corrosion mechanisms of different metallic materials in different environments and in the presence of any additional stresses (either thermal or mechanical) (D.D. A)

Ability to recognize the main forms of corrosion of metallic materials in contact with different aggressive environments and to identify the diagnostic tools suitable for the aforesaid recognition (D.D. B)

Ability to identify and plan the most suitable preventative and protective measures in the most general lines: choice of the most suitable materials and additional protection measures (protective coatings, environmental conditioning, electrical protection systems) (D.D. C)

The exam is sustained entirely in the form of an oral interview, and it is the teacher's special care to motivate students to pay careful attention to the correctness and amplitude of the technical vocabulary and to stimulate a good expressive capacity (D.D. D).

Program

Effects and costs of corrosion. General principles of dry and aqueous corrosion: chemical and electrochemical reactions, definitions and expressions of corrosion rate and corrosion current, Faraday's law.

Thermodynamics of aqueous corrosion processes: electrode potential, electrochemical series, potential-pH Pourbaix diagrams.

Kinetics of aqueous corrosion processes: polarization. Evans diagrams. Concentration and activation polarization. Passivity.

Forms of corrosion: Uniform Corrosion in Acidic and Aerated Solutions; Galvanic corrosion; Differential aeration and Crevice corrosion; Pitting corrosion, Selective corrosion of alloys, Intergranular corrosion and exfoliation; Mechano-chemical corrosion: Erosion, Cavitation, Fretting, Stress corrosion cracking, Fatigue corrosion, Hydrogen -induced corrosion; Stray current corrosion. Corrosion environments: water, soil, atmosphere, concrete. Corrosion in petrochemical plants.

Corrosion Monitoring and Inspections. Non-destructive tests.

Prevention of corrosion by design.

Protection: Coatings, Inhibitors, Electrical protection (Cathodic and Anodic)

High temperature corrosion.

Textbooks

- P. Pedefferri, "Corrosion Science and Engineering", Springer 2018

ISBN 978-3-319-97624-2, ISBN 978-3-319-97625-9 (eBook)

- Teacher's notes from the lectures.

Prerequisites

No specific prerequisites are formally indicated for the course. However, the knowledge of fundamentals of metallic materials science and engineering represents a necessary basis for the acquisition of competences on corrosion and protection of materials: crystalline structure, defects, microstructure and mechanical properties of engineering alloys (steel, copper, titanium, nickel, aluminum-base alloys) and relative working, machining and thermal treatments. Physico-chemical knowledge of thermodynamics and kinetics of chemical and electrochemical reactions is also considered an important precondition. Useful can be the knowledge of extractive metallurgy and metallurgical processes.

Type of lectures

The activities are organized in: - face-to-face lectures (for the acquisition of knowledge) - discussion of case studies (for the acquisition of the capability of applying the knowledge and understanding for recognizing corrosion forms and identifying remedies and proposals for corrosion prevention/protection)

Attendance

The attendance to the lectures, though encouraged, is not mandatory. However, in case of autonomous preparation for the final interview, students are strongly recommended to seek for previous contact with the teacher, in order to be given important directions on the general sense of the course and on specific critical aspects.

Final evaluation

The assessment will be based on the results of an oral interview, aimed at verifying the acquisition of the following knowledge and skills:

- Knowledge of the physico-chemical mechanisms of corrosion.
- Ability of identify the main causes and forms of corrosion of metals in contact with various aggressive environments.
- Correct identification of the most suitable diagnostic tools and of the potential preventative measures and protection systems, with special reference to the field of chemical industry.
- Ability to communicate the acquired knowledge and to illustrate the proposed technical solutions with clear expression and convincing attitude.

During the course students are offered the opportunity to test their preparation by conducting self-assessment written tests (multi-choice questions, solution of numerical problems, essay questions), followed by common correction and, for those who request it, an evaluation of the test.

For the final vote the following aspects will be considered:

- the level of knowledge
- the ability to securely correlate different topics
- the ability of applying knowledge to the solution of problems of limited complexity in the field of materials engineering
- the ability to communicate the acquired knowledge and to illustrate the technical solutions proposed with clarity using a proper technical vocabulary.

To obtain the highest marks (30/30 cum laude), the student must demonstrate that he/she has acquired excellent knowledge of all the topics covered in the course, and that he/she can apply this knowledge to the solution of problems in the field of industrial engineering, proposing original solutions and showing the results of an autonomous extension of knowledge.

Economics of technology & management (9 CFU)

Prof.ssa Katiuscia Lavoratori (katiuscia.lavoratori@uniroma1.it)

Objectives

Knowledge and understanding

The course deals with the decision making processes of firms. In particular, students are expected to learn the basic principles of

- microeconomic analysis of the firm,
- firm technology strategy,
- economic evaluation of investment projects,
- financial accounting

Applying knowledge and understanding

Students will be able to apply basic methods and models of microeconomics, organization theory and corporate finance in order to:

- identify the determinants of firms' strategic choices,
- analyze the relationship between technological change in the industry and firms' strategies
- evaluate the profitability of investment projects
- analyze the financial statement of a company

Making judgements

Lectures, practical exercises and problem-solving sessions will provide students with the ability to assess the main strengths and weaknesses of theoretical models when used to identify firms' strategies.

Communication

By the end of the course, students are able to discuss ideas, problems and solutions provided by the microeconomics of the firm and corporate finance both with a specialized and a non-specialized audience. These capabilities are tested and evaluated in the final written exam and possibly in the oral exam.

Lifelong learning skills

Students are expected to develop those learning skills necessary to undertake additional studies on relevant topics in microeconomics and corporate finance with a high degree of autonomy. During

the course, students are encouraged to investigate further any topics of major interest, by consulting supplementary academic publications, specialized books, and internet sites. These capabilities are tested and evaluated in the final written exam and possibly in the oral exam, where students may have to discuss and solve some new problems based on the topics and material covered in class.

Program

PART I

1. Prerequisites: Analyzing Economic Problems; Demand and Supply Analysis

2. Technology

Technological sets and production function. Total, average and marginal productivity. Isoquants and marginal rate of technical substitution. Elasticity of substitution and types of technology. Long run vs short run. Returns to scale and returns to varying proportions. Elasticity of scale. Technological Progress. High tech labour vs low tech labour.

3. Costs

The cost function and isocosts. Conditional input demands and Shephard's lemma. Price and output elasticity of input demands. Expansion path. Short run vs long run cost functions. Total costs. Variable, fixed and quasi-fixed costs. Sunk costs. Average and marginal costs. Economies of scale and the minimum efficient scale. Economies of scope and learning curves

4. Competitive markets

Economic profits and opportunity costs. Profit maximization in the long run. Duality of production, cost and profit functions. Hotelling's lemma. Short run profit maximization. Profit maximization and return to scales. Supply curves and producer's surplus. Short run vs long run supply curves.

Market demand. Individual supply and market supply. Perfect competition. Short run and long run market equilibrium. Meaning of 0-profits. Pareto efficiency; Applications (taxes, subsidies and quotas)

5. Monopoly

Demand elasticity. Elasticity and revenues. The monopolist maximization problem. Inefficiency of monopoly and deadweight loss. Causes of monopoly. Subadditivity of costs and economies of scale. Natural monopoly. Price discrimination (first degree, second degree, third degree).

6. Innovation

Product innovation vs process innovation. Drastic innovation. Willingness to pay for innovation. Innovation and market structure.

PART II

1. Financial accounting

The Balance Sheet and Account Categories: Assets, Liabilities, Owners' Equity. The Income Statement: Revenues, Cost of Sales, Gross Margin, Expenses, Net Income. Relation between Balance Sheet and Income Statement. The Statement of Cash Flows. Misconceptions about Depreciation. Sources and Uses of Cash. Working capital flows. Analysis of the Cash Flow Statement.

Part III

1. Value

Future Values and Present Values. Net Present Value. Risk and Present Value. Present Values and Rates of Return. Calculating Present Values When There Are Multiple Cash Flows. The Opportunity Cost of Capital. Perpetuities and Annuities. Continuous Compounding. Real and Nominal Rates of Interest. Calculating the Present Value of an Investment.

2. Investment Decisions

Net Present Value and Other Investment Criteria. Discounted Payback. Internal Rate of Return. Pitfalls of IRR. Making Investment Decisions with the Net Present Value. Relevance of Cash Flow. Estimation of Cash Flows on an Incremental Basis. Treating of Inflation. Investment Timing. Equivalent Annual Cash Flows and Inflation. Equivalent Annual Cash Flow and Technological Change

Textbooks

Besanko, D., Dranove, D., Shanley M., and Schaefer, S. (2013). Economics of Strategy. Wiley, 6th Edition. (Selected chapters, see lecture slides).

Puranam, P., & Vanneste, B. (2016). Corporate Strategy: Tools for Analysis and Decision-Making. Cambridge (UK): Cambridge University Press. (Selected chapters, see lecture slides).

Brealey, R. A., Myers, S. C., Allen, F., Principles of corporate finance (12th Edition). Mc Graw Hill. (Selected chapters, see lecture slides).

Prerequisites

Analyzing Economic Problems; Demand and Supply Analysis

Final evaluation

Written exam (exercises and theoretical questions)

Principles of biochemical engineering (6 CFU)

Prof. Massimiliano Giona (massimiliano.giona@uniroma1.it)

Objectives

The course provides the student with the qualitative and quantitative tools for understanding subcellular processes and / or involving microorganisms. It provides the biochemical basis and kinetics necessary for the characterization of enzymatic processes of genetic regulation and growth of microorganisms and cell lines and their quantitative description.

Program

Review of biochemistry of the macromolecules of biological interests (polypeptides and nucleic acids), stoichiometry and kinetics of biochemical reactions.

Enzyme kinetics. Elementary enzyme kinetics (Michaelis-Menten). Quasi-steady state approximation and its dynamic and perturbative interpretation based on the existence of slow-manifolds. Linearized representations. Enzymatic inhibition. Kinetics with multiple substrates. Allosteric enzymes. Sequential and symmetric approach. Reaction rates for homotrope and eterotrope allosteric kinetics from the symmetric model. Examples: glycolytic oscillations. Reaction and regulation networks in the presence of allosteric enzymes.

Kinetics of immobilized enzymes: interaction between reaction kinetics and transport. Transport phenomenology in the presence of porous solid matrices: boundary layers and mass fluxes within a porous medium. mathematical modeling of enzyme kinetics at/in non-porous and porous solid supports. Porous matrices: efficiency factor. Instability effects (multiplicity of steady states) in the presence of substrate-inhibited kinetics. Shooting methods or solving the corresponding boundary-value problems.

Transcriptional regulation in procaryotes: the Monod operon model. Lac and Trp operons. Mathematical modeling of operon regulation.

Growth of procaryote and eucaryote (cell lines) population Structured and unstructured models. Descriptive models and models based on control parameters. Biomass growth in a batch reactor. Influence of substrate concentration: the Monod model (specific growth

rates and yield factors).

Analysis of flow reactor for the growth of microorganisms. Predator-prey systems: the Volterra-Lotka descriptive model and the Monod approach for the interaction between bacteria and protozoa in a flow reactor. Aerobic growth.

Review of some concepts from dynamical system theory. Linear systems. Qualitative characterization of dynamical systems: equilibria, periodic orbits (central orbits, limit cycles) and more complex phenomena. Nonlinear system and linear stability analysis.

Concepts of bifurcation theory. Elementary bifurcations of equilibria: saddle-node, transcritical and pitchfork. Hopf bifurcation and birth of limit cycles.

Textbooks

- 1) J. Bailey e D. F. Ollis, Biochemical engineering fundamentals (McGraw-Hill, New York, 1976).
- 2) Course notes edited by the instructor.
- 3) Mark Ptashne and A. Gann, Genes and signals (Cold Spring Harbor, New York, 2002).

Prerequisites

No prerequisites.

Attendance

Participation to classes is not mandatory

Modalità di valutazione

Oral exam with the possibility of developing a study project to be discussed with the instructor.

Second year - first semester

Computer aided process control (9 CFU)

Prof. Marco Stoller (marco.stoller@uniroma1.it)

Objectives

The course introduces advanced digital control strategies in process industry.

Typical chemical engineering concepts are recalled, such as instrumental technical drawing and details on chemical units. This part of the course includes exercises. In addition, typical elements of controlled systems, such as measuring elements and control valves, will be introduced.

Successively, the controller was introduced, starting from the basic one (feedback controller) up to more advanced ones. At the same time, the concepts of digital control, applied in different operations, will be presented. Finally, the control will be discussed not only with insight to its basic function of monitoring elements of production processes, but as an element capable of achieving technical, technical-economic and safety optimization.

At the end of the course, the student should acquire a basic knowledge of P&I and of typical chemical units characterizing the framework of process engineering; moreover, the ability of a correct application of measuring elements and controls to ensure best operation should result as established.

Program

Introduction to the course, control systems, block schemes and understanding the P&I
Measurement devices and Regulation valves

Introduction to analogue feedback controllers, Laplace transform, open loop and closed loop feedback control schemes
Brief description of process units and their control
Going from analogue to digital controllers: Z-transform and digital feedback controllers
Quality and stability of control loops, coupling and digital decouplers
Digital feedforward controllers and digital feedback-feedforward controllers
Digital inferential, adaptive, predictive and neural controllers
Digital multivariable controllers
Safety devices in controlled processes
Distributed control systems

Textbooks

Process Control, Designing Processes and Control Systems for Dynamic Performance, 2nd Edition
by Thomas Marlin

Final evaluation

The written exam will last 100 minutes and will cover the topics of drawing a P&I and optionally perform some design calculations.

At the same day, after 30 min from the end of the written exam, or in a different day depending on the number of candidates, oral exams will start according to the order of booking of admitted candidates (not by alphabetical order). The test consists of three questions, which focus on knowledge and problem solving.

The students should send by e-mail the solved exercise on controller tuning as reported at the end of the lesson CAPC E04, at least 2 days before sitting the written exam. The exercise can be solved in group with other colleagues (max 3 people) or alone.

Chemical & biochemical plants (9 CFU)

Prof. Marco Bravi (marco.bravi@uniroma1.it)

Objectives

This course equips you with the knowledge and tools to design and operate chemical and biochemical plants, particularly those focused on consolidated bioprocessing and biorefineries.

You'll gain a thorough understanding of:

Momentum, Heat Transfer, and Mass Transfer: Learn how to analyze these fundamental processes critical for efficient plant operation in biorefinery applications.

Distillation Techniques: Master various distillation methods (simple, fractional, steam, vacuum, etc.) for separating components in biorefinery products.

Liquid-Liquid and Solid-Liquid Extraction: Explore these techniques for selectively extracting desired compounds from biomass and other biorefinery feedstocks.

Membrane Separations: Discover how membranes can be used for fractionation, purification, and concentration in biorefinery processes.

Industrial Chromatography: Learn how chromatography can be used for large-scale separation and purification of biorefinery products.

Industrial Bioreactors and Photobioreactors: Gain expertise in the design, operation, and management of bioreactors used for microbial and phototrophic cultivation in biorefineries.

Sterilization Processes: Explore various techniques for sterilizing equipment and products in biorefineries to ensure product safety and quality.

By the end of this course, you'll be able to:

Apply fundamental chemical engineering principles to design and analyze biorefinery processes.

Select appropriate unit operations for separation, purification, and product recovery in biorefineries.

Ensure product safety and quality through proper sterilization techniques.

This course is ideal for students interested in careers in the biorefinery industry, bioprocess engineering, and sustainable chemical production.

Programme

1. Momentum, Heat Transfer, and Mass Transfer: Learn how to analyze these fundamental processes critical for efficient plant operation in biorefinery applications.
2. Distillation Techniques: Master various distillation methods (simple, fractional, steam, vacuum, etc.) for separating components in biorefinery products.
3. Liquid-Liquid and 4. Solid-Liquid Extraction: Explore these techniques for selectively extracting desired compounds from biomass and other biorefinery feedstocks.
5. Membrane Separations: Discover how membranes can be used for fractionation, purification, and concentration in biorefinery processes.
6. Industrial Chromatography: Learn how chromatography can be used for large-scale separation and purification of biorefinery products.
7. Industrial Bioreactors and Photobioreactors: Gain expertise in the design, operation, and management of bioreactors used for microbial and phototrophic cultivation in biorefineries.
8. Sterilization Processes: Explore various techniques for sterilizing equipment and products in biorefineries to ensure product safety and quality.

Textbooks

Study material for individual learning comprises monographs and scientific articles. The lecturer will specify the material and ensure its availability in accordance with copyright legislation.

Source textbooks:

- Singh, R. P., & Heldman, D. R. (2001). Introduction to food engineering. Gulf Professional Publishing. (covering Parts I-II)
- Pauline M. Doran, Bioprocess engineering principles, 2 nd Edition, Academic Press, 2013 (Covering Parts I and III)
- Stanbury, P. F., Whitaker, A. (2005). Principles of fermentation technology. Elsevier. (Covering Parts I and III)
- Review scientific papers or chapters/small parts of monographic books, provided by the teacher (covering some specific topics)

Prerequisites

General physics, General and organic chemistry, Thermodynamics, Computer Science

Evaluation

The written exam consists of ten multiple-choice questions/small problems and one open-ended question/exercise, the answer to which may require calculation, but may also involve the recognition of an image or a process diagram. The time available for completing the exam is two hours.

The exam text is provided in English; the solution must be given exclusively in English.

The oral exam involves a discussion on a specific topic which, at the discretion of the instructor, may extend to a maximum of a second topic, not necessarily closely related. The oral exam may last from 20 to 60 minutes (typically 30 minutes).

The final grade is calculated as the average of the grades obtained in the two exams.

Green chemistry and process engineering

Prof. Marco Scarsella (marco.scarsella@uniroma1.it)

Objectives

Principles of Green Chemistry

Objectives

- To learn the fundamental philosophy and tools of green chemistry
- To develop an awareness of the legislative, financial and social factors connected with reducing environmental impact

- To understand the importance and role of solvents in chemical and related processes
- To understand why solvent replacements are being sought
- To understand the importance of heterogeneous catalysis to green chemistry
- To recognise the key difference between homogeneous and heterogeneous catalysis in chemical processes

Application of Green Chemistry to Process Engineering

Objectives

- To use real examples to illustrate how the principles of green chemistry can be applied to chemical process engineering.
- To study the changing trends in raw material utilisation and to understand the potential of alternative feedstocks.
- To study engineering methods for improving process efficiencies and sustainability.
- To calculate the mass and energy balance in a chemical production process
- To learn about the importance of energy efficiency and the range of energy sources
- To understand the role between energy pollution and climate change
- To understand how biomass can be used as a feedstock for future production industries

Commercialisation of Green Chemistry

Objectives

- To understand the potential for and difficulties in achieving the use of greener chemical products.

Program

Principles of Green Chemistry

- Introduction to Green Chemistry
- Control of Environmental Impact
- Alternative Reaction Media
- Catalysis for Green Chemistry

Application of Green Chemistry to Process Engineering

- Clean Synthesis
- Renewable Resources
- Energy Efficiency & Emerging Technologies
- Chemical Engineering & Clean Technology

Commercialisation of Green Chemistry

- Greener Products

Textbooks

Green Chemistry and Engineering: A Pathway to Sustainability. (2014) John Wiley & Sons, Inc., Hoboken, New Jersey. Online ISBN: 9781118720011; Print ISBN: 9780470413265

Prerequisites

Basic knowledge of physical chemistry and chemical engineering gained during the Bachelor's degree

Final evaluation

oral exam

Nanobiotechnology (6 CFU)

Prof. Marco Bravi (marco.bravi@uniroma1.it)

Objectives

Aim of this course is getting to know the technologies to produce biocompatible nanometric particles by using highly sustainable and maximally green processes which mainly resort to using naturally-sourced biological matrices.

The student will learn: 1. The main classes of biological substances, 2. The methodologies for obtaining these substances from natural biomass, 3. the methodologies for producing functional nanoparticulate from each of these classes of substances, 5. The main processes and equipment that implement these production processes. The student will also learn the main problems of biomedical and cosmetic use of nanotechnologies.

The student who will exhibit a regular attendance of the course will be able to participate in group work intended to develop and strengthen soft skills such as: the ability to work in a group, the ability to dialogue with colleagues from different backgrounds, the ability to write a scientific/technical report and the ability to present one's work.

Program

Biological substances and microorganisms as biocatalysts and raw materials feedstock for the formation of nanoparticles (fundamentals, biological fractions of nanotechnology relevance, production of biological fractions of nanotechnology relevance). Nucleation and crystallisation of proteins (fundamentals, characterisation, process screening and identification, production). Formation and use of nanoparticles by biotechnological techniques (microorganisms, culture media, extracts, switchable solvents). Applications of nanoparticles in the bio-related fields (food, pharma, cosmetic, agriculture).

Textbooks

ALL information relating to the teaching activity of prof. Marco Bravi (lesson times and any exceptions; methods of conducting lessons and tools used; student reception hours; exams; available project works), updated in real time, can be found by consulting the URL:
<https://sites.google.com/site/marcobravi/>

Study materials (generally scientific review articles) will be shared to the attending students during the semester the course is being taught. Students will receive a Google Drive share by being included in the Google Classroom of the course itself.

Attendance

Attendance is facultative. However, only regularly attending students will have their "small groupwork projects" evaluated for the final mark (together with the compulsory written test).

Final evaluation

The written exam includes 10 multiple choice questions, plus an open-ended question (to be provided by the student).

The oral exam is optional. If it is not carried out, it will be counted as passed with the vote of 18/30.

The final mark will be assigned as the average of the marks obtained in the two tests.

Only those admitted to the "evaluated groupwork" can replace the oral test with the presentation of their groupwork.

Environmental chemical engineering (6 CFU)

Prof. Luca Di Palma (luca.dipalma@uniroma1.it)

Objectives

The course aims to provide students with:

- The principles of sustainability and circular economy applied to Environmental Protection
- the theoretical aspects and design criteria of innovative tertiary processes for the treatment of industrial wastewater
- Basic and advanced knowledge on the characterization and treatment of contaminated sites (land reclamation and groundwater treatment)
- The chemical-physical fundamentals of the design of units for the treatment of industrial and hazardous waste, aimed at the recovery of material and energy

Program

1. Sustainability, Circular Economy and Environmental protection. Waste minimization and clean technologies.
 2. Water/Wastewater Advanced Tertiary treatment Processes: Membrane operations and MBR, Constructed wetlands, Wet Air Oxidation, Advanced Oxidation processes, Electrochemical processes, Photocatalysis, Biological electrochemical system and Microbial Fuel Cell.
 3. Effluent disposal: direct and indirect toxicity in natural systems, dispersion models in water
 4. Soil and groundwater characterization.
 5. Principles of groundwater contamination: Causes, Fate, Transport of contaminants in groundwater
 6. Soil and groundwater remediation: Soil Vapour Extraction, Biosparging, Bioventing, Thermal desorbing, Bioremediation, Multi Phase Extraction, Ex situ thermal treatments, Soil washing, Pump&Treat, Air Sparging, In situ chemical oxidation, In situ chemical reduction, Permeable Reactive Barrier, Plume Containment.
 7. Solid and Hazardous waste treatment: Characterization, Landfilling, Composting, Thermal treatment, Stabilization and vetrification
- Nanotechnologies and nanostructured materials for innovative wastewater treatment and soil remediation: application and environmental and toxicological issues.

Textbooks

L. Di Palma - Course materials available on Sapienza e-learning platform

Testi consigliati

M.L. Davies - Water and Wastewater Engineering: Design Principles and practice, 2010,

Prerequisites

Water characterization and chemistry – Wastewater Treatment Processes (Unit design and calculation)

Type of lectures

Front-end lectures and exercises

Attendance

Face to face (unless otherwise specified by Sapienza)

Final evaluation

Written test: two exercises and five theoretical open questions.

Evaluation criteria for the written test: procedure correctness, numerical results accuracy, correct results interpretation.

Oral test: discussion on theoretical aspects of environmental processes and remediation technologies and questionnaires on practical exercises.

Second year – second semester

Computational methods for chemical and biochemical reactor dynamics (6 CFU)

Prof. Antonio Brasiello (antonio.brasiello@uniroma1.it)

Objectives

The course aims to broaden the skills in the theory of complex systems with particular reference to the non-linear dynamics of chemical and biochemical reactors. It also provides a critical approach to

numerical techniques for dynamic analysis leading students to the development of algorithms and their translation into computational codes using high-level programming languages (e. g. Fortran, C ++, etc.).

Programme

Balance and constitutive equations for reacting systems.

Elements of chemical kinetics.

Linear and non-linear dynamical systems theory: elements and complex scenarios.

Chemical and biochemical reactors as dynamic systems: batch, semi-batch, CSTR, PFR, Packed bed reactor, Reverse Flow Reactor.

Introduction to programming using high-level languages (e.g. Fortran, C ++, etc.).

Applications of numerical methods for dynamical systems analysis: equilibrium points calculation, numerical integration of systems of ordinary differential equations, numerical integration of systems of partial differential equations, parametric continuation.

Textbooks

Teacher's lecture notes

Bequette B. W., Process Dynamics Modeling, Analysis, and Simulation, Prentice Hall, 2002

Kuznetsov Y. A., Elements of applied bifurcation theory, Springer, 2004

Quarteroni A., Sacco R. Saleri F., Numerical Mathematics, Springer 2007

Parker T. S., Chua L. O., Practical numerical algorithm for chaotic systems, Springer-Verlag, 1991

Bibliografia

Strogatz S. H., Nonlinear dynamics and chaos: with application to physics, biology, chemistry and engineering, Addison Wesley, 1994 Hale J., Kocak H., Dynamics and Bifurcations, Springer, 1991

Wiggins S., Introduction to applied nonlinear dynamical systems and chaos, Springer, 2003 Nayfeh A.

H., Balachandran B., Applied Nonlinear Dynamics - Analytical, Computational, and Experimental Methods, WILEY-VCH, 2004

Prerequisit

Good knowledge of calculus, linear algebra, and ordinary differential equations is required.

Type of lectures

Lectures and computer exercises

Attendance

not compulsory

Final evaluation

Evaluation of a project and oral exam

Sustainable design of materials (6 CFU) -

Prof. marco Valente (marco.valente@uniroma1.it)

Objectives

What is intended to be transferred as training objectives are the basic knowledge of the principles on which the analysis of the potential environmental impacts related to the production processes of the products and the growing problem of impacts on the environment is based. The above will be analyzed from the point of view of the different types and classes of materials in consideration of the volumes of use and the growing demand for energy involved in their production. A further objective of the course is to transfer to the students the approach of designing production processes and design choices aimed as much as possible at an evaluation of choices that allow a greater "circularity" of the resources used and a lower impact on the environment. . All this through an integrated vision between resource, contained energy and impact of production through the study and knowledge of the LCA philosophy.

Program

Basic analysis of the general characteristics of the various classes of materials: polymers, ceramic metals and composites, highlighting the strengths, criticalities and properties microstructure bonds of the various classes of materials. Subsequently, the production processes and especially the transformation of the different materials will be analyzed, which will be used in the second phase, relating to the LCA assessments.

In a second part we will try to outline methods for the "strategic" design of components and systems considering the materials both from the point of view of the optimization of the functional and mechanical characteristics as well as of the processes and the impacts they have on the global costs of the processes and products; looking in particular at the entire life cycle of the components and the potential economic and industrial repercussions in terms of environmental costs. This last part will be addressed with the approach and philosophy of the Life Cycle Assessment.

Textbooks

Notes and texts by the teacher

Final evaluation

Oral exam

Theory & development of process design (6 CFU)

Prof. Alessandra Adrover (alessandra.adrover@uniroma1.it)

Objectives

- 1) analytical and numerical approaches for the characterization of dynamical behaviour of chemical engineering systems, with and without controls.
 - 2) identification of the possible coexistence of multiple steady states, limit cycles and attractors
 - 3) Identification of model parameters controlling the asymptotic behaviour of chemical engineering systems and construction of bifurcation diagrams
- Students should be able to apply analytical and numerical techniques for characterizing the dynamical behaviour of chemical engineering systems and for constructing bifurcation diagrams for dynamical systems operating with and without automatic controls.

Program

1. CHEMICAL PROCESS MODELING

Characterization and classification of mathematical models for chemical processes.

Process models in the presence of controls. Parameters and uncertainty.

2. NUMERICAL SIMULATION OF CHEMICAL PROCESSES:

Algorithms for integration of concentrated parameter systems.

Algorithms for stiff problems.

Algorithms for distributed parameter systems.

Application to transient analysis of chemical reactor and process units..

3. NONLINEAR DYNAMICAL SYSTEMS

Continuous and discrete systems.

Transient behaviour and asymptotic regimes.

Floquet multipliers and Liapunov exponents.

Numerical methods for identification of limit cycles and attractors.

4. BIFURCATION THEORY

5. APPLICATION TO CHEMICAL PROCESSES

Phase diagrams for chemical reactor operating with and without automatic controls.

Multistability and basin of attraction.

Textbooks

Stephen Wiggins "Introduction to applied nonlinear dynamical systems and Chaos " ,II edition, Springer Verlag 2003

Steven Strogatz : "Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering", Perseus Books Publishing L.L.C 1994
Teacher's handouts

Testi consigliati

Stephen Wiggins : " Introduction to applied nonlinear dynamical systems and Chaos " ,II edition, Springer Verlag 2003
Steven Strogatz : "Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering", Perseus Books Publishing L.L.C 1994
Dispense preparate dal docente

Prerequisites

Calculus

Final evaluation

Written test and evaluation of a project

Transport phenomena in microsystems and micro-nano reactive devices (6 CFU)

Prof. Massimiliano Giona (massimiliano.giona@uniroma1.it)

Objectives

The basic units of a microfluidic circuit are analyzed, namely micromixers, micro heat exchangers, and separation units. Background on the constitutive relationships governing molecular transport of momentum, mass and energy, and their use in local and macroscopic balances constitute the incipit of the course. Emphasis is focused on the interaction between mass and momentum transport and externally imposed electromagnetic fields (electroosmotic and magnetohydrodynamic pumps). Analytical solutions derived for simple geometries are used as a paradigm to orient the design of real world devices, the performance of which is established through commercial software.

Program

Review of transport phenomena fundamentals and of the thermodynamic of irreversible processes: continuum approach, kinetic theory (Boltzmann equation).

Stochastic theory of transport phenomena. Review of probability theory. Stochastic processes: Markovian and non-Markovian.

Chapman-Kolmogorov equation. Wiener processes. Stochastic integrals: Ito and Stratonovich formulation and their properties.

Ornstein-Uhlenbeck processes: fluctuation-dissipation relation (Stokes-Einstein) and thermodynamic analysis.

Fokker-Planck equations and their properties. Stochastic processes possessing finite propagation velocity. Analogy with the Dirac equation.

Fluid mixing in microdevices. Kinematic approach. Chaotic mixing and its characterization. Influence of diffusion. Spectral analysis. Applications and numerical simulation of fluid mixing processes. Physical analogies: interaction between deterministic vector fields and fluctuations. Quantum analogies (with the Schrodinger equation). Reactive flows in microdevices.

Dispersion in microchannels. Taylor-Aris theory: moment analysis and determination of the effective dispersion coefficient.

Numerical simulation of dispersion in microchannel using the stochastic Lagrangian approach.

Microdevices for particle separations based on their sizes. Deterministic lateral displacement devices. Particle transport in periodic arrays of obstacles and potential and determination of their long-term/large-distance properties: effective velocity and effective dispersion tensor. Lumped description using space-time diffusion models with a finite number of states. Relativistic analogies.

Textbooks

- 1) G. Karniadakis, A. Beskok and N. Aluru, Microflows and nanoflows (Springer, New York, 2005).
- 2) H. C. Ottinger, Stochastic processes in polymeric fluids: tools and examples for developing simulation algorithms (Springer, New York, 2012).
- 3) Course notes edited by the instructor.
- 4) B. Gaveau, T. Jacobson, M. Kac and L.S. Schulman, "Relativistic extension of the analogy between quantum mechanics and Brownian motion, Phys. Rev. Lett. 53 (1984) 419-422.

Attendance

Participation to classes is not mandatory

Final evaluation

Oral exam with the possibility of developing a study project to be discussed with the instructor.

Seminars (Activities useful for entering the job market) (1 CFU)

Prof. Cecilia Bartuli (cecilia.bartuli@uniroma1.it)

Program

Students must register to individual seminars in advance, and the attendance of students is recorded and transmitted to the President by the person in charge of the seminar.

The database reporting the attendance of students to the past seminars, updated monthly, is available in the Download Area at this link

Once the student has been certified the attendance of at least 8 seminars, he/she will register for the exam "Altre attività utili all'inserimento nel mondo del lavoro" (1 CFU) on INFOSTUD platform. Exam sessions are opened about 1 month before the deadline for the application for the final thesis discussion. For more information, please contact Prof. Bartuli.

Final evaluation

Attendance and participation will be certified by the organizing commission.

A final evaluation will not be required