

scuolagalileiana
di studi superiori



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

GALILEAN SCHOOL COURSE CATALOG

CLASSE OF NATURAL SCIENCES

ACADEMIC YEAR 2015-2016

Calculus



Teacher: Paolo Guiotto - UniPd - paolo.guiotto@unipd.it

Motivations.

The aim of the course is to introduce to mathematical modelling of biological systems through differential equations with particular emphasis both on modelling as well as on mathematical tools to discuss the qualitative behaviour of systems described in this way.

Targeted audience.

First year students.

Prerequisites.

No particular knowledge is required, the course is self-contained.

Syllabus.

1. Mathematical models – Malthus and logistic demographic models; multiple species models (prey-predator model and competition models); epidemic models (flu, smallpox, malaria).
2. Differential Calculus – infinitesimals, notions of derivative and main properties, elementary derivatives, rules of calculus, geometrical properties.
3. Calculus of primitives – notion of indefinite integral, elementary primitives, rules of calculus.
4. Differential equations – solution of the Malthus model, linear first order equations; solution of the logistic equation and discussion of the flu epidemic model; separable variables equations, the Cauchy problem and existence and uniqueness of solutions.
5. Systems of differential equations – existence and uniqueness, concepts of oriented orbit and phase portrait, first integrals, solution of the prey-predator model, equilibriums and their stability, linear systems, linearization theorem and local classification of equilibriums. Applications.

Teacher CV.

I'm researcher of mathematical analysis at University of Padova since 1998. I taught courses of mathematical analysis and probability for degree students of mathematics, physics and engineering and for PhD students in pure and applied math. My collaboration with the Scuola Galileiana goes back to 2005. Along these years I've been tutor and teacher of courses of mathematical analysis and probability. In particular I teach the course of Calculus since 2012.

My scientific interests are in the field of analysis on infinite dimensional spaces with particular attention to measures on infinite dimensional space and stochastic partial differential equations.

Textbooks/bibliography

Lecture notes.

Complements of analysis



Teacher: Carlo Mariconda - UniPD - carlo.mariconda@unipd.it

Motivations.

This course takes place in the first trimester of the first year, so it requires no specific mathematical backgrounds. One of the aims of the course is to give insights in some of interesting fields of mathematical analysis (still with plenty of open problems) by means of elementary tools. The topics of the course will be suited in real time depending on what the students are studying in their lessons at the university.

Targeted audience. First year students in Sciences or Engineering.

Syllabus.

Part I. Finite sums: precise and approximate calculus.

Discrete calculus: how to compute finite sums. The fundamental theorem of discrete calculus, the discrete Taylor expansion. Combinatorics revisited: the inclusion/exclusion principle; Stirling numbers of II type; an application to the calculus of finite sums of the powers of integers.

The Euler-Maclaurin formula. Applications to sums of powers of integers (Bernoulli numbers), the approximation of the integral of a positive function (trapezoid rule), Stirling formula for the factorial.

Part II. Discrete dynamical systems. Fixed points of a continuous map, attractive/repulsive points. Limits of orbits of systems induced by monotonic functions. Periodic points. Sarkovskii's theorem. Cantor sets. Chaotic dynamical systems. Topological conjugacy.

Teacher CV. Born in Reggio Emilia on October 8, 1964.

1976/82: French schools in Paris, Copenhagen, Milan. French Baccalauréat C.

1982/1987: University Studies at Padova, degree in Mathematics. Thesis with Prof. Arrigo Cellina "The Kuratowski index of a decomposable set".

1987/1991: Ph.D. student at SISSA/ISAS of Trieste. Ph.D. thesis with Prof. Cellina on the calculus of variations

1992 and 1995: research activity in Paris with Raphael Cerf at the Ecole Normale Supérieure and Paris VI

1992: Ricercatore at the University of Padova, Faculty of Sciences

1998: Associate Professor at the University of Padova, Faculty of Engineering

1998-2014: participation and leader of various research groups.

Courses in Calculus, Mathematical methods for engineers, Discrete Mathematics and probability. Ph. D. courses in Padova and Evora (Portugal).

Research interests:

Functional Analysis, Calculus of variations.

Collaborations: A. Cellina, M. Amar, R. Cerf, G. Treu, S. Solimini, G. De Marco, P. Bousquet.

Textbooks/bibliography

C. Mariconda & A. Tonolo, *Calcolo Discreto: metodi per contare*, Apogeo

R. Devaney, *An introduction to chaotic dynamical systems*, Addison-Wesley.19

Introduction to Thermodynamics

Teachers: Fulvio Baldovin, Enzo Orlandini – UniPd –
fulvio.baldovin@unipd.it, enzo.orlandini@unipd.it



Motivations.

Thermodynamics is a basic interdisciplinary subject which bridges over different areas of Science, including Physics, Mathematics, Chemistry, Engineering, Biology, and Medicine. Although common to many Bachelor curricula, time constraints and needs of focusing on practical application in the specific field tend to hinder the presentation of the simple, symmetric structure which underlies Thermodynamics. As a consequence, Students may be confused about the meaning and use of different thermodynamic potentials and response functions.

Goal of the present course is to introduce the thermodynamics of simple systems. While keeping mathematical aspects at a level suitable for first-year undergraduate students, emphasis will be given to the equivalence of the Entropy and Energy representations, which through Legendre transformations generate all other potentials. Exemplifications and case of study from different fields will help the application and the comprehension of the formal structure.

Targeted audience.

The course targets the Natural Science Class of the Galileian School of the University of Padova, including students in Physics, Mathematics, Chemistry, Engineering, Biology, and Medicine. The ideal audience is supposed having been exposed to an introductory course of Mathematical Analysis in one variable, while a practical knowledge of partial derivatives and Legendre transformations will be offered within the course's lectures.

Syllabus.

Macroscopic measurements, Composition of thermodynamic systems, Measurability of energy and heat, Thermodynamic walls and constraints, Thermodynamic equilibrium, The fundamental problem of Thermodynamics, Entropy and Energy representations, The postulates of Thermodynamics, Intensive parameters and equations of state, Thermal, mechanical and chemical equilibrium, The Euler equation, The Gibbs-Duhem relation, The simple ideal gas, The ideal van der Waals fluid, Electromagnetic radiation, Possible, impossible, quasi-static, and reversible processes, The maximum work theorem, Engine, refrigerator, and heat pump performance, The Carnot cycle, Power output and endoreversible engines, Legendre transformations, Thermodynamic potentials, The Gibbs potential and chemical reactions, Response functions and Maxwell relations, Stability of thermodynamic systems, Le Chatelier's principle and Le Chatelier-Braun principle, Role of symmetries in Thermodynamics

Teacher CV.

Fulvio Baldovin is Assistant Professor in Physics at the Physics and Astronomy Department of the University of Padova. He is author of about 40 original research articles in international journals. He teaches Statistical Mechanics for the Ph.D. degree in Physics, and Biological Physics for the Bachelor degree in Molecular Biology. He is tutor in Theoretical Physics for the Galileian School of the University of Padova. He actively collaborates with Complex Systems groups at the Weizmann Institute in Israel, and Ecole Central Paris.

Enzo Orlandini is Associate Professor in Physics at the Physics and Astronomy Department of the University of Padova. He is author of about 150 original research articles in international journals. He teaches Statistical Mechanics for the Master and Ph.D. degrees in Physics, and General Physics for the Bachelor degree in Molecular Biology. He actively collaborates with Soft Matter groups at the Edinburgh University, Oxford University, and SISSA in Trieste.

Textbooks/bibliography

H.B. Callen, *Thermodynamics and an introduction to Thermostatistics – Second Edition*, Wiley.
A number of problems and examples will be explicitly solved at the blackboard.

Introduction to probability models



Teacher: Alessandra Bianchi, UniPD - alessandra.bianchi@unipd.it

Motivations.

The aim of the course is to provide an introduction to elementary probability theory and its application to sciences. The typical environment will be that of discrete probability spaces that will be introduced in the first lectures together with some basic probability tools. By the construction and the analysis of suitable models, it will be then shown how probability can be applied to the study of phenomena in physics, computer science, engineering and social sciences. In turns, this will led to the discussion of some open problems of the field.

Targeted audience.

The course will be self-consistent and no specific mathematical knowledge is required. Logic and a scientific attitude are always helpful.

Syllabus.

First elements of probability theory: Discrete probability spaces; Combinatorics; Conditional probability; The Ising model in statistical mechanics: Definition and properties; Analysis of phase transitions in dimension 1 and 2; Discrete random variables: Discrete distributions, mean value, independence; Binomial and geometric distribution; Moments generating function; Applications to two common problems: The coupon collector problem; Shuffling a deck of cards; The symmetric random walk in one and higher dimensions: Definition and properties; Reflection principle and return probability at 0; Analysis of transience and recurrence; Electrical networks and random walk on graph: Elements of discrete potential theory; Harmonic functions and their probabilistic interpretation; Random walk on general graphs; Application to the gambler's ruin problem: probability of loss and win in a gambling game; Markov chains (theory): Definition and classification of Markov chains in finite space; Stationary distribution and ergodic theorem; Markov chains (examples and applications): Ehrenfest model; Bernoulli- Laplace model; Galton-Watson branching process; Elements of Monte Carlo method: Definition of Monte Carlo Markov Chain (MCMC); examples and application to optimization problems.

Teacher CV.

Born on 31/12/1977

Education and positions

- July 2003 degree in Mathematics - University of Bologna
- April 2007 PhD degree in Mathematics - University of Roma Tre
- 2007-2009 postdoc fellow at the WIAS of Berlin (Germany)
- 2010- 2012 postdoc fellow at the Mathematics Dep. of Bologna
- Since May 2012 Assistant Professor ("Ricercatore") of Probability and Statistics at the Mathematics Dep. of Padova.

Research interests: probability and Statistical Mechanics, Metastability in Markovian processes, Stochastic dynamics and relaxation time, Interacting particle systems on random structures

She published 8 articles on international journals and gave around 30 talks to students and experts of the field. Teaching: 2010&2011&2012: Probability and statistics – University of Bologna; 2012&2013&2014: Statistics – University of Padova; 2014: Introduction to Probability models- Galilean School of Padova. Since 2012, responsible of the FIRB project "Stochastic Processes and Interacting Particle Systems".

Textbooks/bibliography

1. F. Caravenna, P. Dai Pra. *Probabilità. Un primo corso attraverso modelli e applicazioni*, Springer (2013).
2. W. Feller. *An Introduction to Probability Theory and its Applications. I Volume*, Third edition, Wiley (1968).

For consultation:

3. P. G. Doyle, J.L. Snell. *Random walks and electric networks. Carus Mathematical Monographs, 22, Mathematical Association of America (1984). Available online.*

4. D. A. Levin, Y. Peres, E. L. Wilmer, *Markov Chains and Mixing Times*, American Mathematical Society, Providence, RI (2009). Available online. 5. O. Haggstrom. *Finite Markov Chains and Algorithmic Applications*. Cambridge University Press (2002). Available online.

Measure theory

Teacher: Paolo Ciatti – UniPd - paolo.ciatti@unipd.it



Motivations.

The course is an introduction to the Lebesgue theory of integration in Euclidean spaces. The Lebesgue integral is nowadays a standard tool in the scientific literature. It is a flexible instrument allowing the proof of powerful theorems such as the celebrated Lebesgue dominated convergence theorem. Its wide diffusion is related to the completeness of the Lebesgue spaces of functions, a result of fundamental importance not only in mathematics, but also in quantum physics.

Targeted audience.

This lecture course is particularly directed to students in Mathematics, Physics and Engineering. However, students from other scientific disciplines may take advantage of a rigorous presentation of fundamental notions from measure theory which are often assumed to be known without providing a proof. A basic course in calculus would cover all necessary prerequisites.

Syllabus.

The exterior measure and the notion of measurable sets in Euclidean spaces. Measurable functions and definition of integrals for real or complex-valued functions. The monotone convergence theorem and the dominated convergence theorem. The space of integrable functions and the Riesz-Fischer theorem. The Fubini-Tonelli theorem. A Fourier inversion formula. The space of square integrable functions. An introduction to Hilbert spaces. Applications to Fourier series. The Fourier-Plancherel transform. Differentiation of the Lebesgue integral and the Hardy-Littlewood maximal function. Approximations to the identity and more general maximal functions.

Teacher CV.

Paolo Ciatti. Undergraduate Education: Laurea in Fisica, Università di Torino, 1990. Thesis directed by Prof. Tullio Regge. Graduate Education: PhD in Mathematics, Politecnico di Torino, 1995. Thesis directed by Prof. Fulvio Ricci. Academic Positions: Junior Researcher, University of New South Wales (Sydney), 1996-1997. Ricercatore, Università di Padova, 1998-2008. Professore Associato, Università di Padova, 2008-present. Adjoint Professor, Dalhousie University (Halifax, Nova Scotia), 2013-present.

Textbooks/bibliography.

- Folland, Gerald B. *Real analysis. Modern techniques and their applications*. Second edition. John Wiley & Sons, Inc., New York, 1999.
- Royden, H. L. *Real analysis*. Third edition. Macmillan Publishing Company, New York, 1988.

Algebraic structures

Teacher: Matteo Longo – UniPd - matteo.longo@unipd.it



Motivation.

The course offers an introduction to basic algebraic tools and notions. The idea is to give an overview of basic constructions and results. We will focus on proofs only in the first part of the course, and then we will only sketch the main results.

Targeted audience:

Third year class for non mathematicians.

Syllabus:

Group theory: definitions, examples, main results. Representations of finite groups: main results. Rings modules and basic commutative algebra. Field theory and some basic notions of Galois Theory. Overview of Lie groups and Lie algebras.

Teacher CV.

I am associate professor at the Dep. Math. of the University of Padova. My previous positions were Ricercatore Universitario at the Dep. Math. of Università Statale di Milano (2006-2010) and at the University of Padova (2010-2015).

My collaboration with the Scuola Galileiana starts in 2014, as Tutor for the class of science.

My research area is Number Theory (algebraic number theory, elliptic curves, modular forms, L-functions).

Textbooks.

Note by J. Milne, available on line here: <http://www.jmilne.org/math/>

Interaction Networks in Living Systems

Teacher: Amos Maritan - UniPD - amos.maritan@unipd.it



Motivations

The understanding of living systems, which span 21 orders of magnitude in mass, needs more than a mere generalization of our knowledge of inanimate matter. However the use of the paradigm of interaction networks has allowed to tackle, in a unified framework, complex interdisciplinary problems in biology, ecology and social systems. Such problems exhibit recurrent and universal patterns reminiscent of certain thermodynamic systems poised near a critical point. The three main aims of the course are: 1) to stimulate a scientific attitude when facing a wide variety of natural phenomena without prejudice; 2) to be able to identify some of the key characteristics responsible for the emergence of a phenomenon; 3) to provide general tools, both analytical and numerical which are fundamental for the development of appropriate models for the phenomenon to be understood.

Targeted audience

The program of the course has some flexibility and may depend, to some extent, on the preparation/interests of students. This course can be held in the second or later year. It will be of interest for all students of the Galilean School. In the case all students attending the course are from natural science and engineering some sophisticated math will be utilized, otherwise the two courses of "Calculus" and "Probability" in the first year of the GS will be sufficient.

Syllabus

Introduction: aims of the course; overview of various examples.

Network theory: deterministic and random networks; random walk on networks; electrical networks; Erdos-Renyi networks; degree distribution; Barabasi Albert model; Small Worlds. Scaling theory: Probability distribution function with and without a characteristic scale; playing with power laws; fat tailed distributions. Examples of power law distributions: body mass – metabolism scaling; power laws in cities; power laws in written human communication; spontaneous brain activity etc. Species interaction networks: Dynamical stability of large and complex interacting systems (with a brief introduction to the random matrix theory); complexity-stability paradox; mutualistic and antagonistic networks; emergence of nested interaction networks in mutualistic systems. Food trade networks: analysis of existing data and emerging patterns; dynamics of the food trade and its stability; Optimization principles in Nature: Examples of variational principles in physics; Natural selection and optimization; examples of optimization in interaction and transportation networks. Each "chapter" will have homework where each student is encouraged to find him/her-self examples and data where to apply the theory and the data analysis he/she has learnt.

Teacher CV

Professional experience:

Prof. of Physics, Padova (2003 -)

Prof. of Physics, SISSA Trieste – Italy (1994 -2003), Associate Prof. of Physics, Padova (1991 - 1994), Associate Prof. of Physics , Bari (1987 - 2001), Associate Prof. of Physics, Padova (1983 - 1987)

Education and training: Physics degree at Padova (1979); Ph.D. in Physics at SISSA, Trieste (1983).

Accademic appointments: Dean of the School of Excellence "Scuola Galileiana di Studi Superiori", (2004 - 2010), Scientific consultant, ICTP Trieste – Italy (1997-2003), Correspondent resident member of "Istituto Veneto di Lettere Scienze ed Arti (2006-).

Thesis: About 30 PhD students, 40 undergraduate students.

Summary: The main field of interest is the equilibrium and non-equilibrium statistical mechanics. The main focus is on problems at the interface between physics and biology. > 300 publications in refereed journals including 4 in Science, 12 in Nature, 21 in Proc. Nat. Acad. (USA), and 64 in Phys. Rev. Lett.; 1 book co-edited; 1 patent. More at <http://www.pd.infn.it/~maritan/index.html>

Textbooks/bibliography

M.E.J. Newman, *Network: an introduction*, Oxford University press (2010). Only few chapters.

M.E.J. Newman, *Power laws, Pareto distributions and Zipf's law*, Contemporary Physics, Vol. 46, No. 5, September–October 2005, 323 – 351.

R. M. May, *Stability and complexity in model ecosystems*, Princeton University press (2001).

Chapters 1-3 and 7 and some parts of the remaining chapters.

Various articles will be proposed for each "chapter" of the course. The suggested articles will be chosen depending on the student interest and preparation.

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SPECTRAL THEORY

Teacher: Pier Domenico Lamberti – UniPd - pierdomenico.lamberti@unipd.it



Motivations.

This lecture course is an introduction to the spectral theory for differential operators, a well-established topic which is of actual interest not only in Mathematics but also in Physics, Engineering and other applied sciences. The focus is on partial differential operators defined on open subsets of the n -dimensional Euclidean space, possibly subject to boundary conditions. We shall develop the basic tools of spectral theory for bounded and unbounded self-adjoint operators in Hilbert space and we shall apply them to a number of classical spectral problems arising in Mathematical Physics, in particular Elasticity Theory and Quantum Mechanics. For example, we shall discuss the eigenvalue problems for the Laplace operator subject to homogeneous Dirichlet or Neumann boundary conditions, and the Schrödinger operator. The material will be presented following the modern approach based on representation theorems for quadratic forms in Hilbert spaces and the corresponding realizations of the partial differential operators in Sobolev spaces. Such spaces of distributions have their own interest and will be briefly discussed during the first lectures.

Targeted audience.

This lecture course is particularly directed to students in Mathematics, Physics and Engineering. Students are expected to have some elementary knowledge of Hilbertian and functional analysis.

Syllabus.

Weak derivatives and basic facts from the theory of Sobolev spaces. Unbounded operators, adjoints and self-adjoint operators. Quadratic forms, representation theorems, semi-bounded operators and Friedrichs extensions. Spectral theory for bounded and compact operators. Spectral theory for unbounded self-adjoint operators. Discrete and essential spectra. Courant Min-max Principle. Applications to partial differential operators of elliptic type.

Teacher CV.

Pier Domenico Lamberti is Associate Professor in Mathematical Analysis at the Department of Mathematics of the University of Padova. He got his PhD in Mathematics from the University of Padova in 2003. His scientific interests are mainly in spectral perturbation problems for partial differential operators of elliptic type and include real and functional analysis, theory of function spaces, linear and non-linear spectral theory, calculus of variations and homogenization theory. He has also been interested in didactics of mathematical analysis. He is the author of more than thirty publications in international journals, some of which have been jointly written with his students. He has been visiting a number of mathematical institutions in several countries and he has participated into many international conferences. He has been supervising several undergraduate students, one postgraduate student, and he is currently supervising two postgraduate students.

Textbook

Bernard Helffer, Spectral Theory and its applications. Cambridge studies in advanced mathematics. Cambridge University Press, New York, 2013.

Chemical kinetics

Teacher: Mauro Sambi - UniPD – mauro.sambi@unipd.it



Motivations

The course is aimed at providing students an overview of the conceptual and practical tools for the description of the time evolution of macroscopic reacting chemical systems, with a particular emphasis on the structural analysis of detailed kinetic mechanisms, including the discussion of possible approximations and of their range of validity, in such diverse fields such as the chemistry of combustion, atmosphere chemistry, polymer chemistry, homogeneous and heterogeneous catalysis etc. The relationships between kinetic laws and the main typologies of ideal chemical reactors will be investigated and the main experimental techniques for the determination of reaction rates will be reviewed. Theoretical aspects related to molecular reaction dynamics will *not* be dealt with in this course.

Targeted audience

Third year students of science, engineering (with the exception of chemical engineering) and medical curricula, with a basic knowledge of chemical thermodynamics, kinetics and calculus.

Syllabus

Rates of consumption and production vs reaction rates. Simple kinetic laws: first, second and third order reactions. Consecutive reactions. The rate-determining step. The concept of partial equilibrium. Gas phase reactions and reactions in solution.

Material balances in ideal reactors: Batch Reactor (BR), Continuously Stirred Tank Reactor (CSTR) and Plug Flow Reactor (PFR).

Complex homogeneous phase reaction kinetics: multiple reactions, production and reaction rate vectors, the stoichiometric matrix. Selectivity and yield. Open and closed sequences. Chain reactions.

Examples of complex homogeneous reactions: thermal and photochemical HBr synthesis, ozone dynamics in the atmosphere, thermal and chain-branching explosions, polymerizations, enzymatic catalysis, kinetics of biological systems in a CSTR.

Heterogeneous catalysis: isotherms and reaction mechanisms.

Experimental analytical techniques and methods for the determination of reaction rates. Derivation of the kinetic law from the experimental data in different reactors.

Teacher CV

Mauro Sambi graduated in Chemistry at the University of Padua in 1993 and was awarded a PhD in Chemical Sciences in 1997. He is full professor of General, Inorganic and Surface Chemistry at the Department of Chemical Sciences at the University of Padua.

His present research interests concern molecular self-assembly and reactivity on inorganic surfaces of systems relevant for artificial photosynthesis, organic photovoltaics, molecular electronics and oxygen reduction catalysis.

Textbooks/bibliography

- (1) P. W. Atkins, J. De Paula, *Atkins' Physical Chemistry*, Oxford University Press;
- (2) P. Canu, *Cinetica Chimica per l'Ingegneria*, Padova, CLEUP, 2003.

Fluidynamics



Teacher: Roberto Turolla – UniPD - turolla@pd.infn.it

Motivations

Fluids and their motions play a central role in many areas of physics, engineering, biology and physiology, from the scale of living cells to astronomical ones. Fluids are complex systems, the dynamics of which was (partly) understood only during the last century. The course aims at providing the basics of fluid mechanics, i.e. the dynamics of liquids, presenting at the same time a number of examples and applications.

Targeted audience

Second year students in physics, mathematics, chemistry and engineering. The course is suited also for students in biology and medicine with a sufficient mathematical background (only elementary notions of calculus and vector analysis are required).

Syllabus

Basic properties of fluids: pressure, density, viscosity. Newtonian and non-Newtonian fluids (interlude: how it is possible to walk on a liquid).

Conservation laws and equations of motion. The control volume and the Reynolds transport equation. The conservation of mass, the equations of momentum and energy. The Euler and Bernoulli equations.

Dimensional analysis and the similarity principle. The basic adimensional groups in fluidynamics: force and pressure coefficients, the Reynolds, Froude, Rossby and Mach numbers. Adimensional form of the equations of motion and the role of “numbers” in their analysis. Geometrical and dynamical similarity.

Ideal flows. Two-dimensional flow of an inviscid fluid. Stream function and streamlines. The velocity potential and Laplace equation. Superposition principle. Circulation. Ideal flow past a cylinder. Magnus effect. Lift: why do planes fly ?

The stress tensor. Stresses in an incompressible fluid. The Navier-Stokes equations. Applications to one-dimensional flows: Poiseuille flow, fluid sheet on an inclined plane. Internal laminar flows. Flow in a conduit: critical Reynolds number and the entrance length, Poiseuille law. Flow between two plane-parallel plates: the Couette flow. Lubrication. The boundary layer for a plane surface, Blasius solution. The boundary layer for a curved surface. Viscous flow past a sphere (Stokes flow) and a cylinder. Geostrophic flows and the Ekman boundary layer.

Teacher CV

Roberto Turolla got his Master degree in Physics at the University of Padova, attended a PhD programme at the International School for Advanced Studies in Trieste and is presently a senior associate professor at the Department of Physics and Astronomy, University of Padova. Since 2007 he holds a Honorary Professorship at Mullard Space Science Laboratory, University College London (UK).

Research interests: astrophysics of compact objects (black holes and neutron stars). In particular, his expertise is in astrophysical radiative transfer under strong field (gravitational and magnetic) conditions and in the interpretation of X-ray/optical/radio data from collapsed stars in terms of physical models. Such an activity is sustained by several international collaborations with different institutions, both in Europe and the US. He published more than 170 papers on international refereed journals. He teaches General Physics for the bachelor degree in Astronomy and Relativistic Astrophysics for the master degree in Physics.

Textbooks/bibliography

J.F. Kreider *Principles of Fluid Mechanics*, Allyn & Bacon

Notes of the lectures (in pdf format)

Chemical equilibrium and irreversible processes

Teacher: Giorgio Moro - UniPD - giorgio.moro@unipd.it



Motivations.

In many fields of science, engineering and medicine, the study of complex material systems and their time evolution is required on the basis of macroscopically measurable properties. The classical thermodynamics and its extension to irreversible phenomena provide the essential tools for treating these kind of problems within a unified framework. The main topics of the course, i) the equilibrium in complex chemical systems and ii) the basic description of irreversible processes starting from chemical kinetics, allow a focus on issues of general interest in several branches of science and technology, which are shared by different educational curricula at the University.

Targeted audience.

Second year students of science, engineering and medical curricula, that have already acquired the basic knowledge on the principles of thermodynamics and their applications to simple material systems

Syllabus.

Résumé of Thermodynamics principles and use of thermodynamic state functions.

Thermodynamic equilibrium in the presence of chemical reactions.

Macroscopic description of chemical kinetics.

Fluxes and Entropy production in the Thermodynamics of irreversible processes.

Thermal diffusion, viscous flow and mass transport by diffusion.

Teacher CV.

Giorgio Moro has got the University degree in Chemistry in 1975 and, after two years of post-doc at Cornell University (Ithaca, N.Y., USA), has been research assistant and associate professor at Padua University and Parma University. Presently he is Professor of Physical Chemistry at the Department of Chemical Sciences of Padua University.

His main research interests concern Theoretical Chemistry with applications to the study of molecular dynamics in condensed phases, like: molecular dynamics in Magnetic Resonance, conformational dynamics, molecular models of activated processes, structural and transport properties of liquid crystals, statistical properties of quantum pure states.

Textbooks/bibliography

P. Atkins, J. de Paula, "Chimica Fisica" (4^a Ed., Zanichelli, Bologna, 2010)

H.B. Callen, "Thermodynamics and an Introduction to Thermostatistics" (2nd Ed., Wiley, New York, 1985)

I. Prigogine, "Introduzione alla Termodinamica dei Processi Irreversibili" (Leonardo, 1971, Roma)

Comparative physiology of organisms adaptation to environment



Teacher: Mariano Beltramini, UniPD, mariano.beltramini@unipd.it

Motivations.

The course will address, through the discussion of case studies, the problem of adaptation of organisms to the environment showing how the combination of different elementary processes leads to the evolution of alternative adaptive strategies that allow the homeostatic control of the operating parameters of the organism. Basic knowledge on transport mechanisms of electrolytes/anaelectrolytes across biological barriers and compartments; basic knowledge on bioelectric phenomena such as resting membrane potential, action potential and ion channels functions; basic knowledge on chemical signaling and signal transduction in cells and tissues are preferred. The exact target will be tuned after a preliminary colloquium with the participants.

Target Audience.

Students in biological/biotechnological courses at master level, or equivalent. Students in Medicine.

Syllabus

- Introduction: The concept of homeostasis and internal environment, regulativity and compliance;
- Functions based on diffusional processes: gas homeostasis, breathing in the air and in the water, relationship between respiratory and circulatory systems; the oxygen-carrying proteins: "single versus multiple binding sites", allostery and functional plasticity in the transport of oxygen, intersection of transport of oxygen and of hydrogen ions: respiratory and proton homeostasis; non-respiratory functions of oxygen: the bladder swim; adaptation to hypoxia, apnea, nervous control of respiration;
- Functions based on transport processes of electrolytes, osmotic homeostasis: organisms hyper- and hypo-osmoregulators, comparative physiology of the different systems responsible for osmoregulation in vertebrates, endocrine and nervous control in osmotic homeostasis;
- Functions based on electrical processes: olfactory sensory perception, sensory perception of light: monochromatic or polychromatic vision; vision in water and in the air; simple and composed eyes, mechanical sensory perception, the plaque potential from skeletal muscle to the electric organ and electroreception.

Teacher CV

PhD in Biochemistry at the University of Zurich (1984). 1984-1987: Research assistant at University of Padova; 1987-1990: Associate Professor at University of Calabria; 2002-today: Full Professor of General Physiology;

Scientific and/or organizing committees of Congresses and Post-graduate Schools: 1996, 2000, 2002, 2003, 2010. Research visitor: CFKR, University of Texas; Yeshiva University, New York; University of Mainz; Bulgarian Academy of Sciences, University of Zurich. Member of the university staff and Scientific Committee of CNR Centre for the Study of Physiology and Biochemistry of Metalloproteins: 1992-2001; Secretary of Italian Biophysical Society (SIBPA): 1998-2002. Experimental sessions at the Synchrotron Radiation or Neutron facilities: ILL (Grenoble), ELETTRA (Trieste), ESRF (Grenoble), LBB (Paris), SOLEIL (Paris). Referee of international Journals quoted in JCR. Founding: MIUR (40% and COFIN, 1987-1996; 1989-1990, 1997-1999); CRUI (Project Vigoni 1996-1998; 2000-2002); CORILA (2004-2006, 2006-2008); CNR Strategical Project (1986-1988); CNR Bilateral Projects (1986-1991; 1987-1990; 1990-1992); Joint Scientific Actions CNR- Foreigner Academies (Bulgarian Academy of Sciences 1988-1990, 1991-1993; 1998-2000; Russian Academy of Medicine 1992-1993, 1994-1996, 1997-1999); ENEA (1992-1996, 1997-1999, 1999-2001); Zambon Pharmaceuticals: Pilot Ex-Vivo Study: NAC-V-01-03; PRAT (University of Padova 2005-2007; 2012-2014); EC founding BAG Biostruct-X (2013). The research activity concerns aspects of bioinorganic chemistry of metal active site in metalloproteins, sovramolecular organization and conformational properties of oligomeric proteins, functional regulation and allosteric properties of oxygen binding proteins, proteins involved in metal metabolism and stress response. The scientific activity is documented by 115 full papers in journals quoted by ISI.

Textbooks/bibliography

Eckert et al. *Animal Physiology: mechanisms and adaptations*, Freeman 2002
Lecture notes and literature from scientific journals will be available.

QUANTUM MECHANICS

Axiomatic, Interpretative and Informational Structure



Teacher: Pieralberto Marchetti – UniPd - pieralberto.marchetti@unipd.it

Motivations

The aim of the course is to introduce some topics in the theory of Quantum Mechanics not covered by the standard courses in Physics at the University of Padova. The course is structured in terms of thematic units, with a possible coherent choice between some of the topics proposed depending on the main interests of the students. The proposed themes refer to the axiomatization, also in modern mathematical terms, to the interpretations of problematic features in a physically motivated framework of philosophy and to some aspects of quantum information theory.

Targeted audience

The course is targeted for students possessing a basic knowledge of Quantum Mechanics

Syllabus

Axiomatics

Mathematical structures arising in the description of a physical system: states, observables, probabilities, time evolution- Brief recap of axioms of QM in the Hilbertian formalism: pure states as ray vectors, observables as self-adjoint operators and spectral theory, compatible observables and representations- Mathematical interpretation of Dirac formalism: Gelfand rigged Hilbert spaces- Axioms of QM in the C^* algebraic formalism: observables as self-adjoint elements of the algebra, states as linear functionals, GNS representation theorem, von Neumann uniqueness theorem, classical versus quantum.

Interpretations

Entanglement- EPR “paradox” - Bell inequalities and dilemma non-locality/ non realism-No cloning theorem- Quantum teleportation- The problem of quantum measurement.

Information theory

Open systems as subsystems: mixed states as restriction of pure states, Gleason theorem, POVM as restriction of projective measures, Kraus operators for restriction of projected states- Purification theorems: for states (GHJW) and for measures (Neumark)- Quantum information: Shannon entropy and classical data compression, q.bits, von Neumann entropy and quantum data compression.

Teacher CV

Academic Titles

-Laurea in Physics (110/110 cum laude)-University of Padua-July 1980
-Ph.D.in Theoretical Physics- International School for Advanced Studies of Trieste- 1986

Academic Positions

-Researcher in Theoretical Physics, 1983-1993, University of Padua
-Associate Professor of Theoretical Physics, 1993-present, University of Padua
-Member of the teaching activity Committee of the Council of Study in Physics, 2000-present
-Member of the Scientific Council of CIRSIS/CISFIS (Interdepartmental Center for History and Philosophy of Sciences of the University of Padua), 2004-present

Research Activity

My research activity mainly developed within the framework of Quantum Field Theory, in particular: quantum field theory of solitons with the functional integral, often in mathematical-physics style, with application also to monopoles, dyons and anyons; applications of gauge theory and quantum solitons to condensed matter systems: bosonization in planar systems and Chern-Simons spin-charge gauge theory for high T_c superconductors; anomaly cancellations in p-brane theories.

Textbooks/bibliography

F. Strocchi: “An introduction to the Mathematical Structure of Quantum Mechanics, World Scientific 2005
J. Preskill: Lecture notes for Physics “Quantum Information and Computation

GEOMETRIC METHODS IN THEORETICAL PHYSICS



Teacher: Gianguido Dall'Agata – UniPd - gianguido.dallagata@unipd.it

Motivation

This course will review some mathematical concepts that have interesting non-trivial applications in modern physics. The main objective is to show when and how mathematical rigour becomes effective in giving a better description of physical phenomena.

Targeted audience

Master students in Physics or Mathematics. Familiarity with classical physics and basic special relativity will be assumed.

Syllabus

1. Classical field theory in a nutshell. 2. Physics in terms of differential forms (Differentiable manifolds, differential forms, electrodynamics in the language of differential forms, homology and de Rham cohomology, Fibre bundles, non-abelian gauge theories). 3. Homotopy and physics (homotopy, monopoles, instantons). 4. Coset manifolds (coset manifolds, sigma models, pion physics).

Teacher CV

Gianguido Dall'Agata is an Associate Professor at the Padova University since 2011. He worked as a post-doctoral fellow at the Humboldt University of Berlin, Germany, and at CERN. He has been CNRS Associated Researcher at the École Normale Supérieure and at the École Polytechnique in Paris, France. In 2008 he was awarded the Sigrav Prize for his studies on Classical and Quantum Gravity.

Short course in Robotics & Learning

(Teachers: Jochen Steil and Livia Conti)



Teacher: Jochen Steil – University of Bielefeld, DE - jsteil@techfak.uni-bielefeld.de

Motivations

Robotics is an increasingly important and exciting research field that is cutting across many topics in computer science, engineering, and even the humanities. Robotics applications have matured and now reach beyond classical automation far into our daily life. They cover as diverse fields as industrial robotics, agricultural robotics, humanoid robotics, medical robotics, autonomous cars, mobile service devices, surveillance robots, assistive production systems, or human-robot interaction. Complex movements enabled by many degrees of freedom (DOF), integration of perception and action, increasing autonomy, and cognitive control make contemporary robotic systems interactive and demand sophisticated learning and control architectures, which are often motivated by the human example. The course will introduce fundamental concepts in robotics with some emphasis on cognitive capabilities. It aims to provide an introduction to the field in form of overview lectures that cover some of the most important basic topics. These are accompanied with some practical sessions. Student presentations on contemporary application fields will introduce the richness of actual robot use. The course thereby provides an opportunity to get in touch with robotics and presents it as an interdisciplinary field that draws on many specializations reaching from the basic science through computer science and engineering to the humanities.

Targeted audience

The course will be of interest for all students of the Galilean School.

Syllabus

The course runs from Feb. 15. to Feb 19.

What is a robot ? Taxonomy, Platforms, Humanoids, Cognitive Robotics; Coordinate Systems, Geometry, DH-Parameters, Forward Kinematics, Inverse Kinematics, Redundancy; Task vs. Joint space, Interpolation through via-points, Potential Fields, Landmarks, SLAM; Teach-In, Kinesthetic Teaching, Goal directed movement through Dynamical Systems, Oscillators, Redundancy; Proprioception, Forces, Skin, Vision, Camera Coordinates, Detection vs. Recognition, Blob-Tracking; Inductive Learning, Function approximation, parameter optimization through regression, a unified model, examples from robotics; Motion generation by DMP, Motor Babbling, “Roll-outs”, Weighted Averaging, Task-Space-Exploration; Subsumption, Behavior-Based & Cognitive Architecture, Middleware, Software Engineering.

Students presentations: a short, rather informal and somewhat entertaining presentation about a selected robotics application field. A template is available. Presentations could/should be prepared before start of the course and are part of the examination.

Nao practical: 2-3 students have the opportunity to play around with the Nao robot.

Fields for student presentation (no particular order): large humanoid robots (\geq kid size), small humanoid robots (< 50 cm), industrial manipulators, personal robots, companions, medical robots, space robots, underwater robots, agricultural robots, toy robots, military robots, quadrupeds, nano robotics, snakes, worms, octopus, elephant trunk and other continuum robots, welding and other highly redundant robots, prosthetics, flying robots and quadcopters, autonomous cars, parallel robots and stewart platforms, robotic fish, exoskeletons, robot hands, robot heads, mining robots, entertainment robots, mini robot swarms, robots in science fiction, sumobots.

Teacher CV

The module is given by Prof. Jochen Steil, managing director of the Institute for Cognition and Robotics (CoR-Lab) at Bielefeld University, Germany. CoR-Lab's premises include a robot lab with motion tracking and it has at its disposal two iCub robots, a COmpliant huMANoid (COMAN), a 7-DOF compliant Kuka-LWR4, several humanoid Nao, a biomorphic elephant trunk robot (BHA), a compliant cat-size quadruped Oncilla, and a Kuka mobile omniwheel platform Omnirob. Jochen Steil's research interests are learning in humanoid robotics, artificial cognitive systems, learning and stability in neural networks, robot learning and system architectures. Since 2010, he has served as coordinator of the FP7-EU project AMARSi - Adaptive Modular Architectures for Rich Motor Skills, currently he coordinates H2020 CogIMon - Cognitive Interaction in Motion. He is professor at Bielefeld University and visiting professor at Oxford Brookes University, UK. He has published more than 150 papers in cognitive robotics and learning. See www.cor-lab.de/jsteil

Teacher: Livia Conti - INFN Padova – livia.conti@pd.infn.it



Syllabus

The goal is to develop a two-wheeled, self-balancing robot. In a first phase we will start by solving the system's dynamics; then we will consider all aspects of the robot, including operating conditions, materials, hardware, sensors and software. Hence a design project will be defined. In a second phase of the course, the designed robot will be constructed: manufacturing and assembling of the robot circuits, hardware and chassis and software programming. Whenever possible, mechanical parts will be manufactured with the aid of the school's 3d printer.

Teacher CV

She is researcher at the Padova section of the Istituto Nazionale di Fisica Nucleare. Graduated in Physics at Univ. Padova (1996); PhD at Univ Trento (2000). She was awarded the SIGRAV prize in 2002, and an ERC starting grant in 2008. Her main scientific interests concern the development of ground based gravitational-wave detectors. Since 2014 she is member of the Virgo collaboration responsible for the Advanced Virgo gw detector, near Pisa: she is involved in the development of a squeezed light source for improving the detector's performance. She is an expert of noise sources of thermal origin and investigates the effects of nonequilibrium thermodynamic states on the noise properties of solids. She is also interested into activities that improve the attitude towards science in young people.

Textbooks/bibliography

No specific textbooks are suggested. Application notes and data sheets will be distributed during the course.

Bio-optogenetics. A visual voyage into the brain: advanced imaging technologies lead to new concept of brain functions.



Teachers: Giorgio Carmignoto, Neuroscience Institute CNR, giorgio.carmignoto@bio.unipd.it
Tommaso Fellin, Neuroscience and Brain Technologies, IIT Genova, tommaso.fellin@iit.it
Gian Michele Ratto - Istituto di Neuroscienze CNR NEST, Scuola Normale Superiore - gianmichele.ratto@sns.it

Motivation. The most recent advances in optical technologies have given rise to a new era for biological research. It is now possible to combine different tools, including genetically encoded calcium, chloride and glutamate sensitive dyes, optogenetics, patch-clamp recordings and different transgenic mice in *in vitro* and *in vivo* models with single and two-photon laser-scanning microscopes to see the brain in action. This approach has led to the emerging view of the brain as a circuit of interactive neuron and glial cell networks in which the glia cell astrocyte is actively involved in fundamental phenomena in brain function, including the neurovascular coupling and the plasticity of synaptic neuronal transmission.

Targeted audience. The course is targeted to students in Biology, Biotechnology, Physics and Medicine. Students of different backgrounds with basic knowledge of cellular signaling and brain physiology are also welcome.

Syllabus. The course will start presenting pioneering findings on the physiology of neurons and how our view of brain function and of the cellular mechanisms at the basis of information processing in the brain has changed in the history of neuroscience. The contributions of Ramon Y Cajal and Camillo Golgi to the foundation of neuroscience will be recognized. The course will then focus on advanced optical methodologies, such as single/two-photon laser microscopy and optogenetics coupled with electrophysiological recordings of neuronal activity, and discuss how this new approach has provided fundamental insights into the specialized role in brain function of distinct subpopulations of neurons and interneurons. This topic will be also addressed by specific lectures by Tommaso Fellin and Gian Michele Ratto. Finally, extensively discussed will be the most recent findings that by revealing how astrocytes can weaken or strengthen neuron-to-neuron communication herald a shifting paradigm in neuroscience.

Titles of the seminars given by T. Fellin and G. M. Ratto, following and completing the course by Giorgio Carmignoto:

- Gian Michele Ratto: *Imaging beyond calcium: in vivo quantitative measure of pH and chloride*
- Tommaso Fellin: *Structured light illumination of brain function*

Teacher CV

Giorgio Carmignoto is postdoctoral fellow in the Biophysical laboratory at the Rockefeller University, New York in 1979 and from 1980 to 1990 researcher at the Fidia Research Laboratories of the pharmaceutical company Fidia (Abano, Padova). From 1990 to 1993 he is Research Associate at the Dept of Biophysics of the Georgetown University, Washington. In 1994 is at the Dept of Biomedical Sciences of the University of Padova where he started to study Ca^{2+} signalling in astrocytes. Since 1994, the central theme of his research is to understanding the specific roles of neuron-astrocyte interactions in brain functions and dysfunctions. At present, he is Director of Research at the Neuroscience Institute of the National Research Council (CNR) of Italy.

Tommaso Fellin is postdoctoral fellow at the Institute of Neurophysiology INSERM in Paris in 2003 and at the Dept of Biomedical Sciences of the University of Padova in 2003-2004. From 2005 to 2008 is postdoctoral fellow at the Department of Neuroscience, University of Pennsylvania School of Medicine, Philadelphia. His research focuses on the study of cortical microcircuits and on the development of innovative methods, including spatial light modulators and digital micromirror technology and optogenetics, that allow to illuminate cellular networks with high spatial and temporal resolution to probe their function. Using mainly the neocortex as a model system, he is interested in understanding the mechanisms through which information is processed at the level of the individual elements of brain circuits including principal neurons, interneurons and glial cells. Since 2008 is team leader at the Department of Neuroscience and Brain Technology of the Italian Institute of Technology (IIT, Genova).

Gian Michele Ratto is postdoctoral fellow at the Department of Physiology and Biophysics of the University of California, Berkeley from 1984 to 1988 and researcher at the Institute of Neurophysiology CNR (Pisa) from 1988 to 1990, with a Fellowship of the National Academy of Lincei. From 1990 to 1991 is Research

Associate at the Physiological Laboratory, Cambridge (UK). He has been developing a two-photon laser scanning microscope and the associate technology to study the role of Extracellular signal-Regulated Kinase (ERK) 1/2 in the mechanisms of synaptic plasticity in the visual cortex and to explore the relationship between neuronal and glial activity in the brain in physiological and pathological conditions. Since 2007 is Senior scientist at the NEST center of the Scuola Normale Superiore (Pisa).

Textbooks/bibliography

Araque, A, Carmignoto G., Haydon P.G., Oliet S.H.R., Robitaille R., Volterra A. (2014) Gliotransmitters Travel in Time and Space. *Neuron* 81, 728-239.

Haydon P.G. and Carmignoto G. (2006) Astrocyte control of synaptic transmission and neurovascular coupling. *Physiol. Rev.* 86, 1009-1031

Bovetti S. Fellin T. Optical dissection of brain circuits with patterned illumination through the phase modulation of light" *Journal of Neurosci. Methods* (2015) 241: 66-77.

GM Ratto, D. Arosio (2014) Twenty years of fluorescence imaging of intracellular chloride. *Frontiers in Neurosci.* DOI:10.3389/fncel.2014.00258