YEAR 2
COURSE OFFERING
Fall Semester

MATHEMATICS

Euclidean and Hermitian Spaces (MAA 201)

Prerequisite: MAA 104
MAA 201 continues the study of linear maps between vector spaces, started in MAA 101. The goal is to obtain simple and efficient models for these applications up to suitable changes of coordinates. The concept of duality is initially introduced in the general context of mere vector spaces. Then, the focus is put on vector spaces enjoying a richer structure, namely prehilbert spaces, which is available in most applications (e.g. in solid mechanics or in quantum mechanics). The geometry of these spaces, as well as their important transformations (*e.g.* normal or unitary maps) is also discussed.

Professor(s):
E. Balzin
ECTS Credits: 5

MANDATORY

Topology and Multivariable Calculus (MAA 202)

Prerequisite: MAA 105
Topology and multivariable calculus (MAA 202) builds on the concepts and techniques introduced in Analysis 102. In particular, students cover notions in topology. The course's goal is to introduce complex functions that include several real variables, which are a more realistic tool for modeling phenomena in physics. Both differential calculus and integration is also covered.

Professor(s):
Y. Bonthonneau
ECTS Credits: 5

MANDATORY

Introduction to Probability (MAA 203)

Prerequisites: MAA 105
MAA 203 covers a wide-range of important notions in probability theory and focuses in particular on discrete and continuous random variables with examples in modelling. A particular emphasis is put on how to perform and use computer simulations.

Professor(s):
G. Conforti
ECTS Credits: 3

Recommended for all double majors, Mandatory for the double major Math/ Economics

MATHEMATICS

Statistics of Finite Samples (MAA 204)

Professor(s):
E. Vernet
ECTS Credits: 3

Recommended for all double majors, Mandatory for the double major Math/ Economics

Prerequisite: MAA 203
MAA 204 is an introductory course in statistics, with complements in probability. Topics include displaying and describing data, writing a statistical model, introduction to statistical inference, confidence intervals, approximations with the Central Limit Theorem.

Algorithms for Discrete Mathematics (MAA 205)

Professor(s):
L. Gérin
ECTS Credits: 3

Recommended for the double major Math/CS, Mandatory for the minor Computational Mathematics in the double major Math/Economics

Prerequisites: MAA 101, MAA 103
The purpose of MAA 205 is to use computer science and programming to solve problems in discrete mathematics, and vice versa. Topics include: graphs and their matrices, combinatorics and generating functions, elementary probability, sorting algorithms. The course consists of lectures and practical labs in python.

COMPUTER SCIENCE

Object-oriented Programming in C++ (CSE 201)

The goal of CSE 201 is to introduce students to the C++ programming language, and the object-based view of software design. C++ is one of the most widely-used programming languages in the world, especially for system-level programming. Much of its power derives from its use of objects, packets of data and functionality that model things and concepts in the real world.

Professor(s):
S. Mover
S. Redon
ECTS Credits: 5

Mandatory for the double major Math/CS

Design and Analysis of Algorithms (CSE 202)

Prerequisite: CSE 103
Algorithms are at the heart of all computation. Building on the algorithms the introduced in CSE112, this course provides a solid foundation in modern algorithmics. Students develop a deeper knowledge of the fundamental algorithms, an understanding of how they work, and an appreciation of how to implement them efficiently. They also learn how to reduce other problems related to these fundamentals.

Professor(s):
B. Salvy
ECTS Credits: 5

Mandatory for the double major Math/CS

Logic and Proofs (CSE 203)

Prerequisite: CSE 101
Logic and Proofs (CSE 203) is an introduction to logic, a science that deals with the principles of validity of demonstration. Its goal is to familiarize students with formal methods for representing arguments and reasoning about them. This encompasses propositional calculus, first-order logic, and deduction systems, as well as the related technologies (e.g. automated provers, proof assistants) for building mechanized proofs. No prior knowledge in logic is required.

Professor(s):
PY. Strub
ECTS Credits: 3

Recommended for the double major Math/CS

ECONOMICS

Intermediate Microeconomics (ECO 201)

Professor(s):
C. Pawlowitsch
M. Nunez
ECTS Credits: 3

Mandatory for the double major Math/ Economics

Intermediate Microeconomics (ECO 201) focuses on the study of consumer and producer decisions and interactions. It also introduces the students to decision-making under uncertainty and basic portfolio theory, market equilibrium and general equilibrium of the economy, monopolistic and oligopolistic competition among firms and other forms of strategic interaction studied in Game Theory. Additional issues are reviewed, including conditions for market efficiency, public goods, the effect of strategically used private information, market failures and their remedies, etc.

Textbook:
Intermediate Microeconomics: A Modern Approach by Hal R. Varian.

Intermediate Macroeconomics (ECO 202)

Professor(s):
G. Lukyanov
ECTS Credits: 5

Mandatory for the double major Math/ Economics

Intermediate Macroeconomics (ECO 202) focuses on both the business cycle and long-term growth. The goal is to understand the relationship between key macroeconomic variables; namely, consumption, investment, money supply, interest rate, inflation, unemployment, and GDP growth. Students investigate the role of monetary and fiscal policy, while reviewing international issues, such as the behavior of exchange rates and capital flows.

Textbook:
Macroeconomics by Olivier Blanchard
Macroeconomics by N. Gregory Mankiw.

PHYSICS

Classical Mechanics (PHY 201)

This course introduces students to mechanics of complex system. After a reminder of the classical concepts of point mechanics (covered in PHY 101), the course extends these concepts to more general systems. Using energy-based formalisms, it provides a comprehensive approach to the concepts of force balance and moments, leading to the equations of the movement. This permits students to approach the concepts of oscillators, stabilities and behavior law. The energy-based approach that is at the heart of this course is also found in many other fields of physics: relativity, quantum physics, electromagnetism, etc.

Upon completion of this course, students master equations and principles in analytical mechanics. They will be able to discuss the relevance of the chosen model, as well as derive and solve simple models taken from their environment.

Main concepts covered: Rigid solids. External force and moment; center of mass. Equilibria. Fundamental law of dynamics; balance of linear and angular momentum; kinetic and potential energy; constitutive laws for perfect of viscous hinges. Linearized equations of motion, oscillations, stability. Lagrangian and Hamiltonian mechanics.

Professor(s):

ECTS Credits: 5

Mandatory for the double major Math/ Physics

PHYSICS

Wave Optics and Radiation (PHY 202)

Professor(s):
J. Faure
ECTS Credits: 5

Mandatory for the double major Math/ Physics

PHY 202 introduces the students to the basics of wave phenomena and focuses, in particular, on optical waves. The major concepts are first presented by studying oscillations from simple systems before waves in general are introduced. Light waves are then described in detail, with a focus on polarization, reflection and refraction at interfaces and scattering. The concept of coherence is developed along with its spectacular experimental manifestations in interferences and diffraction. The course then focuses on the way light is emitted in various situations and covers black body radiation, as well as emission and absorption of light by atoms. The latter provides an opportunity to discuss the quantum behavior of matter and to introduce the electronic structure of atoms in a phenomenological manner. Concrete examples and illustration of these phenomena, such as the principle of the laser, the temperature of stars, and spectroscopy in astrophysics, are given during the lectures.

Upon course completion, students will acquire a deeper physical understanding of wave phenomena, including the basic concepts of wave optics and light emission. They will also master the analytical skills needed to solve basic problems in physical optics and wave physics more generally.

Advanced Lab I (PHY 203)

Professor(s):

ECTS Credits: 3

Mandatory for the double major Math/ Physics

In Advanced Lab I, students have the opportunity to apply the physics knowledge they acquired in PHY201 and PHY 202. PHY 203 consists of 7 distinct lab sessions of 4 hours each. It provides an in-depth study of a wide range of physical phenomena such as electronics (passive and active electronics, Fourier synthesis, Arduino micro-controller), wave-optics (diffraction, interference and polarization of light), nuclear physics (Rutherford scattering experiment) and the mechanics of solid bodies. Upon course completion, students will have acquired advanced experimental skills allowing them to set up, carry out and analyze critically experiments in physics and mechanics.

BIOLOGY

Cell Biology (BIO 201)

Prerequisite: BIO 101
Cell Biology (BIO 201) introduces students to the mechanisms that cells use to regulate the physical properties of their dynamic architecture, to produce force and move, to compartmentalize and transport proteins, to regulate growth and death, and to communicate with their environment. The course focuses on human cells, and emphasis is placed on human diseases where appropriate. Upon course completion, students have a comprehensive understanding of the function and architecture of cells.

Because experimentation is at the heart of progress in cell biology, 50% of classes contain practical work, completed over the course of the semester. The intention is to allow students to develop their knowledge in the subject area, to acquire sound scientific reasoning, and to become familiar with the main techniques of modern cell biology, like quantitative microscopy imaging and computer-assisted data analysis.

Professor(s):

ECTS Credits: 3

Required for the Biology minor

CHEMISTRY

Introduction to Reactivity (CHE 201)

Prerequisite: CHE 101
CHE 201 is an intermediate-level chemistry course that allows students to develop the tools to analyze a chemical transformation. In particular, students explore why, how and at which rate substances react. This interactive course explores these topics through lectures, tutorials and labs.

Professor(s):
A. Guell
ECTS Credits: 3

Required for the Chemistry minor

HUMANITIES AND SOCIAL SCIENCES

History of Science and Technology (HSS 201)

Professor(s):
M. Lyautey
ECTS Credits: 2

Eligible as a supplementary course

History of Science and Technology (HSS 201) seeks to enhance students' understanding of science and its relationship to social concerns throughout history. The course will offer both thematic and chronological approaches to the evolution of science in various societies from the antiquity to modern times. Historical periods covered include: ancient civilizations (*e.g.* Greece, Egypt, India, Babylon, China, etc.), the Renaissance, 17th century scientific revolution, the Enlightenment, the 19th/20th/21st centuries.

PERSONAL DEVELOPMENT

Hands-on Programs: Health or Volunteering (PDV201)

In this unit, students will choose between two hands-on programs designed by their personal development officers. One focused on health (sports, dietetics, sleep…), the other involving group volunteering in a charity. The aim is to take action collectively and develop one's personal skills, all outside of lecture halls.

Professor(s):
M. Bresson
ECTS Credits: 1

Eligible as a supplementary course

YEAR 2
COURSE OFFERING
Spring Semester

MATHEMATICS

Quadratic Forms and Applications (MAA 206)

Prerequisite: MAA 201

Quadratic forms and applications (MAA 206) is a continuation of Euclidian and Hermitian spaces (MAA 201) and covers objects in bilinear algebra. These objects, mainly quadratic forms, have fundamental applications (*e.g.* in Number Theory and Mechanics), and also lead to the study of algebraic objects; for instance, some special groups of matrices, whose applications in mathematics and physics are fundamental, from Number Theory and geometry to the classification of particles.

Professor(s):
T. Gauthier
ECTS Credits: 5

MANDATORY

Series of Functions, Differential Equations (MAA 207)

Prerequisite: MAA 202

Series of functions, differential equations (MAA 207) builds upon the topology notions studied in Topology and multivariable calculus (MAA 202) to allow for a more profound study of functions. Examining functions as limits of simpler ones (*e.g.* for approximation problems) is made possible in a rigorous manner thanks to topological ideas. This provides the possibility of using crucial tools in many scientific fields; the most striking one being Fourier series (first designed to solve the heat equation and now ubiquitous in science and, in a hidden manner, in daily life). The second part of the course deals with a wide array of differential equations, permitting students to better understand complex physical questions.

Professor(s):
R. Tessera
ECTS Credits: 5

MANDATORY

MATHEMATICS

Numerical Linear Algebra (MAA 208)

Professor(s):
T. Pichard
ECTS Credits: 3

Recommended for all double majors, Mandatory for the double major Math/CS

Prerequisite: MAA 106, MAA 201
MAA 208 covers the very important topic of numerical linear algebra. Starting with recalling linear algebra's basic concepts (*i.e.* vectors, matrices, addition and multiplication), we quickly concentrate on methods for solving linear systems. Students study typical direct and iterative methods together with their practical implementation. This permits them to compare the methods in terms of complexity depending on the size of the problem to solve. The emphasis is put on the practical resolution of the problems and the theory that is required to understand the behavior of the methods considered. Subtle notions such as condition number, order of convergence, etc. are covered and explained. The course finishes with a project which is defended in-class during the last week of the semester. Students are evaluated based on this their project presentation, a report, and coursework.

A First Step in Numerical Optimization (MAA 209)

Professor(s):
B. Bogosel
ECTS Credits: 3

Recommended for the double major Math/CS, Mandatory for the minor Computational Mathematics in the double major Math/Economics

Prerequisites: MAA 202, MAA 208
Numerical optimization concerns the minimization or maximization of an objective function. It often relies on the computation of the gradient of this function. MAA 209 covers several aspects of the classical methods that are used in such problems. For instance, the gradient methods (or steepest descent), the non-linear conjugate gradient methods will be seen. A particularly important topic concerns the Newton-Raphson method, which extends the mono-dimensional Newton method to higher dimension. MAA 209 follows MAA 208, since linear algebra methods are heavily used. Applications to the computation of the Eigen elements of a matrix or to the resolution of non-linear systems of equations are also studied. As before, the course heavily uses practical sessions, which are taken under consideration for the grading.

COMPUTER SCIENCE

3 Mandatory courses among all CS courses available for the double major Math/CS

Machine Learning (CSE 204)

Prerequisites:
CSE 101, CSE 102 and CSE 201
Machine Learning (CSE 204) describes some of the methods and algorithms used in contemporary machine learning, with a variety of scientific applications. When brought up to scale, this becomes an important part of what is now referred to as Big Data.

Professor(s):

ECTS Credits: 5

Computer Architecture (CSE 205)

Prerequisite: CSE 201
This course investigates the design and organization of computers at their lowest level. This encompasses computer hardware, and also the operating systems that provide an interface between most programs we write and use with the underlying machine and its network.

Professor(s):

ECTS Credits: 5

Introduction to Formal Languages (CSE 206)

This course introduces different concepts in automata theory and formal languages, including formal proofs, deterministic and non-deterministic automata, regular expressions, regular languages, context-free grammars and languages, and Turing machines.

Professor(s):

ECTS Credits: 3

Introduction to Networks (CSE 207)

This course will introduce students to the architecture and skeleton required for implementing a protocol - and part of that will include creating multiple threads, and synchronized queues.

Professor(s):
T. Clausen
ECTS Credits: 3

ECONOMICS

Introduction to Econometrics (ECO 203)

Professor(s):
A. Simoni
A. Uhlendorff
ECTS Credits: 5

Mandatory for the double major Math/ Economics

Introduction to Econometrics (ECO203) introduces the most common ways to study and analyze economic data, with a focus on emphasizing data analysis for empirical causal inference. Topics include randomized trials, regression, instrumental variables, differences-in-differences, and regression discontinuity designs. Students also learn how to study datasets through practical examples.

Textbook:
Introductory Econometrics: A Modern Approach by Jeffrey M. Wooldridge
Basic Econometrics by Damodar N. Guarati and Dawn C. Porter

Introduction to Finance (ECO 204)

Professor(s):
L. Schilling
ECTS Credits: 5

Mandatory for the double major Math/ Economics

Introduction to Finance (ECO 204) introduces fundamental ideas of modern portfolio theory and corporate finance. Topics include present value and discounting, interest rates and yield to maturity, various financial instruments including financial futures, mutual funds, the efficient market theory, basic asset pricing theory, the capital asset pricing model, models for pricing options and other contingent claims, and the use of derivatives for hedging.

Topics in History of Economic Thought Since 1945 (ECO 205)

Professor(s):
B. Cherrier
ECTS Credits: 3

Mandatory for the double major Math/ Economics

The Economics Workshop (ECO 205) is based on teamwork in which students work in groups of four or five to further explore economics issues. In particular, students discuss current events, create and test economic models, while developing and analyzing computer simulations.

PHYSICS

Classical Electrodynamics (PHY 204)

Classical electrodynamics is an important pillar of physics given that it led to numerous scientific and technological developments since the 19th century. PHY 204 aims to provide students with an introduction to the principles and behaviors of dynamical electric and magnetic systems, and a theoretical foundation in classical field theory. It builds upon the knowledge acquired in PHY104 and begins with reminders in electrostatics and magnetostatics, before moving on to a more formal presentation of Maxwell's equations in magnetic and dielectric media including local and integral forms, conservation laws, potential formulations and Gauge transformations. Applications of the electromagnetic theory such as free or guided propagation, optical phenomena or the emission of radiation by moving charges are presented as key concepts illustrating the development of modern technology. The course concludes with an introduction to relativistic electrodynamics and its covariant formulation.

Upon completion of this course, students will master the fundamental principles in classical electrodynamics. They will be able to understand the origin of Maxwell's equations in magnetic and dielectric media and their essential consequences. Besides deriving and solving simple models illustrating the main concepts, they will also be able to understand the physical principles governing everyday life and modern technological systems, from wave propagation phenomena to optical fibers, to antennas and electrical engines.

Topics covered in this course include: electrostatics, potential problems in 3D, boundary value problems, Poisson's equation, multipole expansion; conservation laws; dia-para-ferro-magnetism, induction laws; field energy; displacement current; solution to Maxwell's equations in vacuum, superconductivity (London theory); plane electromagnetic waves; waveguides and resonators; radiating systems; special theory of relativity; relativistic kinematics; Lorentz transforms of Fields; 4 vectors, covariant formulation of electromagnetism; radiation by moving charges; synchrotron radiation; Cherenkov radiation.

Professor(s):
A. Couairon
ECTS Credits: 5

Mandatory for the double major Math/Physics

PHYSICS

Introduction to Quantum Physics (PHY 205)

Professor(s):
A. Specka
ECTS Credits: 5

Mandatory for the double major Math/Physics

Quantum physics is the theoretical framework for the description of nature at the atomic length scale and below. According to our present knowledge, it encompasses the most fundamental physical theory, and is the basis for everyday applications like semi-conductor electrons, lasers, medical imaging to name only a few. In PHY 205, students discover quantum physics through the formalism of Schrödinger's wave mechanics, and learn to describe simple, non-relativistic quantum phenomena, mainly in one dimension, by applying mathematics of classical waves to which they have become familiar. Subsequently, they are introduced to the quantum-mechanical formalism of which the central notion is the quantum state. Students also become familiar with the underlying mathematical structures, Hilbert spaces and Hermitian operators, and discover the quantum description of known classical systems and concepts such as free motion, the harmonic oscillator and angular momentum. The course also allows students to explore purely quantum phenomena that have no classical counterpart, such as the electron spin, and a brief overview on quantum communication may be provided. Throughout the course, the abstract theory will be illustrated by historic experimental evidence and modern applications whenever appropriate.

Upon completion of this course, students will be able to explain the conceptual difference between classical and quantum behavior, and solve simple one- or two-dimensional problems of quantum mechanics in the framework of wave mechanics. Furthermore, they will be able to wield the abstract formalism of quantum states in Hilbert spaces, and to apply it on simple quantum systems.

PHYSICS

Waves and Heat Transfer in Geophysics (PHY 206)

The course describes waves and heat transfer in fluids, with a preference for illustrations coming from the Earth system, in particular the atmosphere. Waves or oscillations are one essential type of motion present in many fluids. One goal of the course is to demonstrate how one proceeds to obtain wave solutions starting from a physical description of a system and its equations of motion. Acoustic waves will be considered as a first example, surface water waves at different scales (from ripples in the pond to tsunamis) will be derived as further examples. Basics of fluid mechanics (Euler equations, kinematics) will be introduced in order to make these developments possible. Similarities in the behavior of fluid waves and optical waves seen in PHY 202 will be discussed.

The structure of the atmosphere and how we have progressively come to understand it will be reviewed. To describe this understanding and touch upon the subject of climate change, thermodynamics will be revisited and applied to the atmosphere (thermal structure, radiative balance).

At the end of the course, the students will understand how one characterizes a family of waves (dispersion relation, polarisation relations), and how to proceed to obtain, in a given system, wave solutions if they exist. The students will have reviewed thermodynamics and have seen applications to the atmosphere (thermal structure, atmospheric stability, clouds, radiative balance). Finally, some elements of the study of the Earth, and of the atmosphere in particular, will have been introduced.

Professor(s):
R. Plougonven
ECTS Credits: 3

1 Mandatory course to choose between PHY 206 and PHY 208 for the double major Math/Physics

PHYSICS

Advanced Lab I (PHY 207)

Professor(s):
Y. Laplace
ECTS Credits: 3

Mandatory for the double major Math/ Physics

In Advanced Lab II, students have the opportunity to apply their physics knowledge they have acquired over the course of 7 distinct lab sessions of 4 hours each. PHY 207 provides an in-depth study of a wide range of physical phenomena such as fundamental and applied optics (Fourier optics, optical fiber communication), atomic and nuclear physics (Balmer series, Nuclear magnetic resonance), thermodynamics (low temperature physics, SF6 critical point) and the mechanics of deformable bodies.

Upon completion of this course, students will have acquired advanced experimental skills allowing them to set up, carry out and to critically analyze experiments in physics and mechanics.

PHYSICS

Atoms and Lasers (PHY 208)

Light amplification by stimulated emission of radiation (laser) holds a unique place in the heart of physicists. Lasers are at the same time a spectacular manifestation of a quantum phenomenon, a powerful and versatile tool ranging from industrial applications (laser processing, telemetry…) to fundamental research (spectroscopy, cold atoms…) and a remarkable workbench to acquire a better understanding of key concepts in physics.

PHY 208 is an introduction to light-matter interactions through the intricate relationship between atoms and lasers. Importantly, this course will build on experimental situations, and introduce models with increasing complexity to explain the observed results. As the basic component of a laser is a source of light, the course will start with basic spectroscopy, and several atomic models will be considered (Bohr model, Einstein coefficients, Schrodinger model, etc.). The emission of continuous laser light by such atoms will be described from both a classical (effective medium) and semi-classical (population inversion) perspective. The mirror will then be turned back on the atoms, and several applications of laser light revealing the behavior of atoms will be discussed (Light, Stark and Zeeman shift, Rabi oscillations etc.). Finally, some practical perspectives on advanced laser technologies and applications will be given.

This course will not add many new physical concepts, but rather show how results obtained in previous courses (especially in optics, classical and quantum mechanics) can be used. Upon completion of this course, students will have acquired key understandings concerning the bilateral interactions between laser devices and atoms. They will have understood the circumstances under which the emission of useful coherent light can be produced, and also the information that such light can provide when analyzing atomic systems. They will also be able to identify the relevance, necessity, and limitations that classical and quantum models display when analyzing problems in this field. They will also gain familiarity with some laser device technologies.

Professor(s):
D. Suchet
E. Johnson
ECTS Credits: 3

1 Mandatory course to choose between PHY 206 and PHY 208 for the double major Math/Physics

BIOLOGY

Molecular Genetics (BIO 202)

Professor(s):

ECTS Credits: 3

Required for the Biology minor

Prerequisite: BIO 201
Molecular Genetics (BIO 202) provides an in-depth understanding of the mechanisms by which living organisms store, express and transmit genetic information and the basis of human genetic diseases. Lectures will cover a range of topics, including the molecular aspects of DNA replication and transcription, translation of RNA into protein and gene regulations. This course will also cover the latest methodologies used in genomics analysis, like DNA sequencing.

Because experimentation is at the heart of progress in cell biology, 50% of classes contain practical work, completed over the course of the semester. The intention is to allow students to develop their knowledge in the subject area, to acquire sound scientific reasoning, and to combine the modern techniques in molecular genetics with computer-assisted data analysis.

CHEMISTRY

Environment and Energy (CHE 202)

Professor(s):
A. Auffrant
A. Guell
ECTS Credits: 3

Required for the Chemistry minor

Prerequisite: CHE 201
Environment and Energy is an intermediate-level chemistry course that explores topics such as chemistry in water (*i.e.* acid/base, complexation equilibrium), electrochemistry, and selectivity in chemical transformations. This interactive course explores these topics through lectures, tutorials and labs.

HUMANITIES AND SOCIAL SCIENCES

Philosophy: Science and Technology (HSS 202)

This course introduces students to foundational concepts in the philosophy of science. It asks the question of the relationship of philosophy to science and technology throughout history, examines some examples of encounters between science and philosophy with an emphasis on their social and political context and encourages students to exercise their own judgement on contemporary issues in philosophy of science.

Professor(s):
J. Chalier
ECTS Credits: 2

Eligible as a supplementary course

PERSONAL DEVELOPMENT

Speech Contest (PDV202)

In this unit, the students will be trained for and participate in a speech contest. The aim is to succeed in convincing, moving, persuading, expressing oneself fluently on a specific subject.

Professor(s):
M. Bresson
ECTS Credits: 1

Eligible as a supplementary course