INTER-YEAR COURSE OFFERING
All students must attain at least a CEFR B2 level in French to graduate. French is offered at beginner, intermediate, and advanced levels. Students are placed into the appropriate level based on a French test taken at the beginning of the year. Students who have validated the B2 level will take a different foreign language. The offering changes from one year to the next, but typically includes courses like Spanish, Italian, German, and Chinese.
HUMANITIES AND SOCIAL SCIENCES
FALL OFFERING

Students must take at least one HSS course per year in the first two years. The course offer is shared among students from all years.

Geopolitics of cyberspace HSS102
L. Pétiniaud

The aim of the course is to approach a wide variety of subjects related to geopolitics and cybersecurity, cyber defense and cyberspace. To understand the intricate relationships between these concepts, the course studies their definition and the changing meaning of these words in both space and time. We will first address the question of the evolving nature of geopolitics as a method and as a historically changing field of study, but also a renowned tool of geopolitical studies: maps. We will then apply geopolitics to the complex concept of cyberspace through multiple case studies.

The course also reviews the many aspects of cyberspace and cybersecurity where States are not the central actor. The emergence of numerous private actors also raises questions in the political field (Internet giants and their relationships to governments or the EU) and in the military and defense domains (non-State actors including terrorist groups, and their role in cyber conflicts).

After this overview, the course will cover specific and detailed case studies in order to analyze the interactions between geopolitical conflicts and the specificities of cyberspace: disinformation, “geopolitics of infrastructures”, and the geopolitical dimension of the so-called emerging technologies.

ECTS Credits: 2
Politics of the Ecological Mutation shall be divided into three main “chapters”.

The first chapter will be a synthetic presentation of the ecological mutation and the events that led to it (scientific evidence on climate change, biodiversity extinction and resources; nature of the change we are facing; socioeconomic inequalities; climate as an old question; a long list of warnings from the 19th to the 20th century; the great acceleration of the 1970s; the age of the Anthropocene; critical perspective on collapsologie and survivalism).

Next, we will develop a deeper understanding of this mutation through the study of seven different issues (the search for happiness; facts, beliefs and truth; democratic crisis; wars and conflicts: cities: catastrophes and disasters; science and knowledge).

Finally, we will change to a perspective on the cultural dimension of the ecological mutation, in literature, movies and arts.

Through this course, students will gain a better understanding of the ecological mutation and why it is so specific, acquire knowledge of a few key concepts that they can use as tools to reinforce their “critical mind” and improve their ability to argue and express themselves.
Introduction to Sustainable Architecture and Urbanism HSS212
V. Fraigneau

Understanding the emerging initiatives and theories in architecture and urbanism helps support a sustainable and desirable habitability of territories, by giving attention to their dynamic agencies. We introduce strategies and perspectives in architecture and urban planning to understand their transformation, their modes of installation and aesthetics. We’ll explore urban stratifications, interrelations, infrastructure and mobility networks, urban recycling, the place of nature in the city, local and frugal design thinking. We’ll understand what sustainability really is in architecture and urban practice through critique, theory, and the actions and thoughts of major figures promoting this attitude.

ECTS Credits: 2
Masterpieces of Western Literature: Sea and Sailors HSS301
I. de Vendeuvre

This course proposes a fuller understanding of the role played by the sea and seafarers in literature from Homer and The Odyssey up to the twentieth century.

The sea is not only a backdrop in literature. In many masterpieces of the Western canon, the sea is at the very heart of narrative development. It is a place that puts the human will to the test, thus revealing the true nature of men, for better or for worse. More often than not, the sea features as a living being, a character per se.

Oceans have provided opportunities for adventure, discovery, the pursuit of wealth, and encounters with other civilisations. The sea and seafarers have played a decisive part in cultural exchange, political conquest, and scientific knowledge.

Studying them, we shall be carried into a history of crime, war, and death. We shall also find them functioning as pervasive metaphors in metaphysics and poetry, in music and painting.

The sea is the habitat of fascinating, awe-inspiring creatures that connect the natural with the supernatural. The sea is probably the best example of a threshold (in the twofold sense of limes and limen), of a border that keeps some people out and allows others in. It can also mark the frontline where holidaymakers enjoy – or not – the summer through life on the beach, an invention of the late-nineteenth century. Based on multidisciplinary analyses, this course aims to discuss the multifarious aspects of the sea and of sailors in fiction.
HUMANITIES
AND SOCIAL SCIENCES
SPRING OFFERING

French Identity HSS151
P-M. Renaudeau

For students with little or no previous knowledge of French culture/language.

This course aims to define French identity from a historical, geographical, cultural and political point of view. Political science methods will be used to address three questions:

› The social construction of French Identity as seen through France’s history and geography.

› French identity as a social model and national model claiming a universal dimension.

› French identity facing globalization. The purpose will be to be able to analyze the French context and understand its specificities.

ECTS Credits: 2
HUMANITIES AND SOCIAL SCIENCES
SPRING OFFERING

Introduction to Film Studies HSS251
J. Degenève

This course will provide tools to analyse every genre of movie. More precisely, four aspects will be addressed: story, staging, frame and montage. The purpose will be to be able to find and defend ideas, without forgetting the emotions experienced.

Major Issues in Today’s World and the Place of France HSS101
N. Rousselier

For students holding French Bac or having previously studied French History

HSS101 is designed to give a broad and comprehensive view of the political and social place of France in today’s globalized world. Two themes will be addressed this year in order to understand the originality of French Politics. First, we will study the question of the French democracy and its difficulties. French Politics have gone through many different political regimes (Monarchy under different styles, two Bonapartist Empires, five different forms of Republic, Vichy’s Dictatorship) and recurrent upheavals from the Revolution of 1789 to the “Gilets Jaunes” of 2018. It is this “French instability” which is at the core of the first part of the course. Secondly, the course will address issue of the French Secularism, “laïcité à la française”. It was historically and is still today one of the great challenges of French society and the French democracy.
Philosophy: Science and Technology HSS202
J. Chalier

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.

ECTS Credits: 2
YEAR 1
COURSE OFFERING
Fall Semester
Linear Algebra MAA101
S. Bijakowski

Linear algebra (MAA101) is a fast-paced course which provides students with an overview of the most useful techniques of linear algebra. Upon completion of this course, students will fully understand the fundamental concepts of vector spaces, dimension, linear systems, and determinants, and how they apply to problems in other fields of the Bachelor program.
Introduction to Analysis MAA102

F. Pacard

Introduction to analysis (MAA102) is an introductory-level mathematical analysis course that provides a well-balanced approach between calculus and foundational notions; it is designed to equip students with the fundamental analytical tools required in all scientific fields. In particular, this course covers sequences, series and function study. It also introduces students to important mathematical concepts which will be expanded upon later in the program: namely, limits, continuity and derivative.

ECTS Credits: 5

MANDATORY
Introduction to Economics ECO101
Y. Koriyama, J-B. Michaud

Introduction to Economics (ECO101) provides students with the foundational concepts of economics. The course begins with the investigation of the individual behavior of households and firms. Subsequently, students review and develop a thorough understanding of the concepts of supply and demand, before investigating how markets function. The course also covers imperfect competition and other market failures, as well as macroeconomic aggregates and the role of the central bank.

Required reading: Principle of Economics by N. Gregory Mankiw

ECTS Credits: 5
MANDATORY
Physics I: Mechanics And Heat PHY101
S. Ramananarivo

Physics I (PHY101) introduces students to basic concepts in mechanics and thermodynamics. It first covers point-like and simple solids in various coordinate systems; while providing an overview of the fundamental law of dynamics, kinetic and potential energy, linear and angular momentum; central and conservative forces and mechanical work. Harmonic oscillators, resonance, and one dimensional waves are studied in this context. Kinetic theory of ideal gas introduces the basic thermodynamic concepts: heat, temperature, entropy, efficiency, state variables for closed system. Upon completion of this course, students will master basic equations and principles in classical mechanics and thermodynamics and will be able to derive and solve simple models taken from their environment.

ECTS Credits: 5
MANDATORY
METHODOLOGY

Introduction to Computer Programming CSE101
B. Smith

Computer programming (CSE101) introduces students (with or without previous programming experience) to the fundamentals of computer programming in Python, with applications across the sciences. In this course, students will explore fundamental algorithms and data structures, up to and including binary trees, using a mixture of procedural, recursive, and object-oriented techniques. Upon completion of this course, students will have a solid foundation in the culture and practice of modern programming, and the basic skills to solve real-world problems using efficient, well-written programs and open-source tools. These foundations will be extended and completed in CSE 102 and CSE 103.

Maths in Practice: How to Write Maths LAB102
J. Sabin

How to Write Mathematics introduces the central notions needed to pursue advanced mathematics, such as elementary logic (e.g. quantifiers, different methods of proof), sets, numbers and functions. The goal is to provide the right tools and concepts to properly write and understand a mathematical argument, which will be a key component of the whole three years of the bachelor program.
Maths in Practice : Calculus LAB101  
L. Guin

Math. in Practice I enables students to develop the basic practical mathematical skills that will be largely used in the program. It starts by a refresher training before tackling more advanced concepts, using a hands-on pedagogy.

The concepts to be covered are elementary functions and their derivations and integrations, vector calculus, coordinate systems, integration and simple differential equations.

ECTS Credits: 1  
MANDATORY

Discovery labs LAB103  
C. Baroud, Y. Laplace, A. Guell

In the discovery Lab sessions students will discover basic experimental techniques, data analysis and interpretation, and documentation of experimental work.

Examples will cover harmonic oscillators, forces and equilibrium, kinematics and collisions, waves and chemistry.

ECTS Credits: 2  
MANDATORY
TRANSVERSE COURSES

Overall presentation

Transverse teaching in the bachelor program includes courses in humanities and social sciences, foreign languages, personal development and sports, for a total of 5 ECTS per semester. At each of the four first semesters, a student must follow a foreign language class counting for 2 ECTS, either a course in Humanities and Social Sciences or a seminar on personal development counting for 2 ECTS each, and two hours of monitored sport activities per week counting for 1 ECTS. The courses in humanities and social sciences, were presented above, those in foreign languages are to be chosen within a global catalog of classes provided by the corresponding department. The seminars on personal development for the fall semester of year 1 are described hereafter.
Seizing my New Life at University PDV101
B. Destremau

Transitioning from high school to university is an important step that affects all aspects of one’s life: starting university, the student will discover not only a new approach to academics but life on an international campus, new types of relations with adults and peers, a workload to balance, everyday life to take care of.

This unit is designed to help the student get a good start in university life, and address these exciting challenges. It will take the form of group sessions with members of the academic team, a counselor, coaches and/or the head of personal development. The sessions will focus on the questions the student might be faced with on campus and how to deal with them. A focus is put on choice and decision making, aiming to give tools with a view to questions such as: how to make good choices for his/her life?

Students will share points of view, learn to discover each other and tackle methods to work, think and choose effectively.

A Healthy Mind in a Healthy Body PDV 102
B. Destremau

In this unit, students will focus on health (sports, diet, sleep, mental preparation via the TOP…)

During several sessions, students are given some theoretical and practical tools about the four pillars: physical activity including sports; diet and nutrition; sleep and alertness; mental preparation via the Tactics to Optimize the Potential. These tools will enable them to improve their health, to manage their stress in their current life or before/during an exam.
YEAR 1
COURSE OFFERING
Spring Semester
Discrete Mathematics MAA103
F. Alouges

Discrete mathematics (MAA104) introduces students to combinatorics, arithmetics and probability (on finite sets) with examples and applications such as graphical modeling and generating functions. It also presents some more conceptual algebraic subjects. In particular students explore the notion of group.

This prepares them for later questions related to symmetry (including those arising in physics) and number theory.

Integral and Differential Calculus MAA105
J. Bettinelli

Prerequisite: MAA102

Integral and differential calculus (MAA105) develops students’ skills in two crucial analytical tools: Integration and Differential Equations. The approach to Integration employed in this course is Riemann’s integral, a foundational mathematics theory. The course also introduces students to two important and related topics covered in the Bachelor program: Taylor expansions (a tool for function approximation) and differential equations which is required to understand basic physical problems (trajectories, populations, etc.)
Introduction to Numerical Analysis MAA106

Prerequisites: MAA102, MAA103

The aim of Introduction to Numerical Analysis (MAA106) is to provide students with practical knowledge of basic mathematical algorithms and computer programming. Computational Mathematics covers several notions such as representation of numbers, complexity of algorithms, interpolation of functions, numerical integration, optimization, error analysis, etc. The course’s focus is on implementation using Python.
INTRODUCTION TO MAJORS

Advanced Programming CSE102
P-Y. Strub

Prerequisite: CSE101

Advanced Programming (CSE102) is the continuation of the previous semester’s course (CSE101). We will continue to lay the foundations of modern computer science, while developing more sophisticated programming techniques in Python. At the end of this course, students will have the fundamental analytical and programming skills to solve everyday problems in the sciences more efficiently and effectively. They will also be prepared to continue learning other programming languages and paradigms, and the theoretical foundations of computer science itself.
In this course, we introduce vector and Fourier analysis from a hands-on, application-oriented perspective. Vector analysis spans the differentiation and integration of vectors in two and three-dimensional space, eventually culminating with Green’s theorem in the plane and its higher-dimensional generalization, Stokes’ theorem. Changing gears, we introduce the concept of Fourier series, which give an approximation of periodic functions as an infinite sum of cosines and sines.

We conclude the course with a gentle introduction to Fourier transforms, viewed as a limit of Fourier series in the limit of infinite periodicity. Besides their intrinsic mathematical interest, these tools are widely used in Physics (Electromagnetism, Fluid mechanics, Quantum mechanics...), signal processing and areas of Economics (cycle analysis in financial markets and business models).
Introduction to Algorithms CSE103

I. Mackie

Prerequisite: CSE101

An algorithm is a sequence of instructions that allows us to solve a problem using a finite number of steps; as such, algorithms formalize the notion of what it means to “compute”. We study algorithms to know what can actually be computed, in theory and in practice, and to find out how efficiently it can be done. Introduction to Algorithms (CSE103) is an initiation into the art and science of algorithms. This course will train students in how to think about algorithms, how to rigorously compare different algorithms and predict their performance, and how to apply this knowledge to solve computational problems efficiently.
Topics in Economics ECO102
G. Barrows, A. Pérez-Baranoha, B. Schmutz

Topics in Economics (ECO102) provides an overview of how the concepts in economic analysis are applied through the real-life examples of scientific research in economics. Students will learn how theoretical and empirical methods in economics are employed in the analysis of diverse subjects, such as economic growth, environmental regulation, public policy, networks, firms’ behaviors, etc. Topics are chosen from the themes in the frontier of economic research.
Physics II: Electromagnetism and Light PHY104
S. Corde

Prerequisites: PHY101

Physics II (PHY104) provides an overview of numerous physics concepts related to the description of light and of electromagnetic phenomena.

This course introduces the concept of fields in physics, in particular with the electric and magnetic fields, and develops students’ understanding of electricstatics, magnetostatics, electrical circuits, geometrical and wave description of light. In addition, students explore concepts such as Coulomb’s law, Lorentz force, Gauss’ law, Ohm’s law, Kirchhoff’s circuit laws, Faraday’s law, and others.

Upon completion of the course, the students will understand how the classical field theory of electromagnetism with the set of Maxwell equations can describe in a unified way many physical phenomena, from the propagation of light to electrostatics, magnetostatics and electrical circuits.
In the Beginner’s Physics Lab sessions, students will have the opportunity to apply the physics knowledge they have acquired in PHY104 in five distinct lab sessions of 4-hour duration. Students will learn basic experimental techniques, data analysis and interpretation, and documentation of experimental work.

Students will cover, in-depth, the measurement of the speed of light, the measurement of the specific charge \((e/m)\) of the electron, the photoelectric effect and the measurement of the Planck constant, as well as the Franck-Hertz experiment.

ECTS Credits: 2
Mandatory for the double major Math/Physics
**ELECTIVES**

**Biology BIO101**  
C. Le Clainche

Biology (BIO101) is a molecular and cellular biology course, which provides all the concepts required for a scientific understanding of living systems. This course aims both at preparing students for the biology option, which is available in the Mathematics & Computer Science and Mathematics & Physics majors, and at raising awareness about socio-economic issues related to biology, such as health, ethics or bioengineering.

**General Chemistry CHE101**  
A. Auffrant

General Chemistry (CHE101) covers fundamental concepts of atomic structure, and bonding within molecules. It also describes intermolecular interactions and their consequences regarding macroscopic properties. Students also explore the notion of orbital. CHE101 aims to develop students’ fundamental knowledge in chemistry for their study of reactivity aspects in higher-level courses.

**Mathematical Modeling MAA107**  
V. Bansaye, T. Mastrolia

**Prerequisites:** MAA101, MAA102  

Mathematical Modeling (MAA107) introduces the topic as it applies to physics, biology and economics. The course covers mathematical formalization which can be used to describe some dynamics related to the following topics: mechanical and biological systems, evolution of populations, pricing, contract theory, etc. Students learn to evaluate models and motivating questions, to determine how mathematics can provide quantitative or qualitative answers. To this end, the course introduces students to and develops tools and technics from dynamical systems (e.g. recurrence relation and ordinary differential equations) and random evolution (e.g. Markov chain on a finite state space and discrete martingale).
Web Programming CSE104
D. Rohmer

Prerequisite: CSE101

Web Programming (CSE104) introduces the languages, tools, and techniques specific to developing web-based applications. Students will develop a solid understanding of the intricacies of contemporary, dynamic website development, and an insight into the internal workings of the web itself. This is a hands-on practical course that provides students with valuable practice developing their own web-based applications.

ECTS Credits: 3

Applied Physics PHY107
S. Starikovskaia

Recommended previous course:
PHY101, LAB101

Applied Physics (PHY107) provides a combination of lectures and seminars with a clear aim to show the link between advanced engineering and high-level physical/mathematical education.

The course will cover selected questions based on fluid mechanics, thermodynamics, optics, electricity and magnetism. Background obtained during courses of general physics and mathematics will be used to understand the principles of rocket propulsion, engines for hypersonic flights, peculiarities of mass-spectrometry in physics/chemistry and biology, the link between optical spectroscopy, molecular analysis and quantum mechanics etc. As a result of the course, students should be able to look at applied physics problems combining deep knowledge in mathematics and physics and to be able to formulate to resolve a set of estimates giving the idea about mechanisms involved in the considered phenomena.

ECTS Credits: 3
TRANSVERSE COURSES

Overall presentation

Transverse teaching in the bachelor program includes courses in humanities and social sciences, foreign languages, personal development and sports, for a total of 5 ECTS per semester. In the first four semesters, student must follow a foreign language class counting for 2 ECTS, for 2 ECTS again either a course in Humanities and Social Sciences if the student has followed a seminar on personal development for the previous semester or a seminar on personal development if he had not, and two hours of monitored sport activities per week counting for 1 ECTS.

The courses in humanities and social sciences, were described above, those in foreign languages are to be chosen within a global catalog of classes provided by the corresponding department. The seminars on personal development for the spring semester of year 1 are described hereafter.
Meeting Professionals PDV103
B. Destremau

In this unit, the students will interview a professional of their choice and present what they have learnt to their peers, coaches and the head of personal development or other academic staff who will assess their presentation. Discussion will follow. It will help all students better their communication skills and reflect upon academic and career choices.

The unit will start with tutorials on how to network and getting started with LinkedIn.
YEAR 2
COURSE OFFERING
Fall Semester
Euclidean and Hermitian Spaces MAA201
E. Balzin

Prerequisite: MAA101, MAA105

MAA201 continues the study of linear maps between vector spaces, started in MAA101. 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.

Topology and Multivariable Calculus MAA202
Y. Bonthonneau

Prerequisite: MAA102, MAA105

MAA202 is divided into two parts, the first one more theoretical than and setting the foundations of the second one. The theoretical part covers the fundamentals of topology of normed vector spaces and of topology in finite dimension. The second part, more computational, covers differentiation and integration in several (real) variables.
Introduction to Probability MAA203
G. Conforti

Prerequisites: MAA105

MAA203 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.

Introduction to Statistics MAA204
E. Vernet

Prerequisite: MAA203

MAA204 is an introductory course in statistics, with complements in probability. Topics include displaying and describing data, multivariate distributions, Central Limit Theorem and introduction to statistical inference (estimators, confidence intervals and hypothesis testing).
COMPUTER SCIENCE

Object-oriented Programming in C++ CSE201
S. Mover, S. Redon

The goal of CSE201 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.

Design and Analysis of Algorithms CSE202
B. Salvy

Prerequisite: CSE103

Algorithms are at the heart of all computation. Building on the algorithms introduced in CSE103, 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.
Intermediate Microeconomics ECO201
M. Nunez

Prerequisites: ECO101, ECO102

Intermediate Microeconomics (ECO201) 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 Macroeconomics ECO202
G. Lukyanov

Prerequisites: ECO101, ECO102

Intermediate Macroeconomics (ECO202) 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.

ECTS Credits: 5
Mandatory for the double major Math/Economics
Classical Mechanics PHY201
JM. Allain

Prerequisites: PHY101

This course introduces students to the Lagrangian and Hamiltonian mechanics. Starting from the concepts of Newtonian mechanics, the course extends these concepts to a more systematic description of the mechanics, adapted to complex systems. The course will mostly use examples from the dynamics and vibrations of mechanical systems, with progressively increasing complexity. Examples from other fields of physics will be also proposed (electromagnetism, astrophysics, chaos...)

After a reminder of the classical concepts of point mechanics, the course extends these concepts to the Lagrangian formalism and to the least action principle. The Lagrangian formalism will be used to describe the mechanics of rigid bodies. Lagrangian formalism will then be extended to the Hamiltonian mechanics which is at the core of quantum physics and other modern theories in physics.

We will also present some extensions of Lagrangian and Hamiltonian mechanics to other fields of physics.

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.

Wave Optics and Radiation PHY202
J. Faure

Prerequisites: PHY101, PHY104

This course focuses on the description of light as a wave phenomenon. The course starts by reviewing the concepts of waves and oscillations in simple systems. It then turns to the way light is emitted by matter and covers dipole radiation, black body radiation as well as emission and absorption of light by atoms. The latter will be an opportunity to discuss the quantum behavior of matter and to introduce the electronic structure of atoms in a phenomenological manner. Light waves are then described in detail, with a focus on scattering, reflection and refraction at interfaces and polarization. The concept of coherence is developed along with its spectacular experimental manifestations in interferences and diffraction.

Concrete examples and illustration of these phenomena will be given throughout the lectures, so that students, by the end of the course, should be able to explain why the sky is blue and the sun a bright yellow, how the fingerprint detection system of a smartphone works and more.

With this course, students will acquire a deeper physical understanding of wave phenomena, including the basic concepts of wave optics and light emission. They will master the analytical skills needed to solve basic problems in physical optics and wave physics in general.

ECTS Credits: 5
Mandatory for the double major Math/Physics
Advanced Lab I PHY203
C. Baroud, F. Cadiz, Y. Laplace

**Recommended previous courses:**
LAB101, PHY106

In Advanced Lab I, students have the opportunity to apply the physics knowledge they acquired in PHY201 and PHY202. It 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 wave-optics (diffraction, interference and polarization of light), 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.
ELECTIVES

Cell Biology BIO201
C. Le Clainche

Prerequisite: BIO101

Cell Biology (BIO201) 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.

ECTS Credits: 3
Required for the Biology minor
Introduction to Reactivity CHE201
A. Guell

Prerequisite: CHE101

CHE201 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.

Algorithms for Discrete Mathematics MAA205
L. Gérin

Prerequisites: MAA101, CSE101

The purpose of this course is to use computer science and programming to solve problems in Discrete Mathematics, and vice versa.

The main objectives of the course are:
› Learning to use various tools (recursivity, symbolic computing, graphs, matrices…) to deal with complex problems.
› Using computer programming and experimentation to help prove theorems.
› Improving intuition in pure and applied Mathematics.

Discrete Mathematics happen to offer a lot of aspects that lend themselves to computer experimentation. Topics may include: graphs and adjacency matrices, number theory, logic, analysis of algorithms, dynamical systems, elementary probability…

The course will mainly consist of practical labs in Python.
Logic and Proofs CSE203
D. Rohmer

Logic and Proofs (CSE203) 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.
TRANSVERSE COURSES

Overall presentation

Transverse teaching in the bachelor program includes courses in humanities and social sciences, foreign languages, personal development and sports, for a total of 5 ECTS per semester. In the first four semesters, a student must follow a foreign language class counting for 2 ECTS, for 2 ECTS again either a course in Humanities and Social Sciences if the student has followed a seminar on personal development for the previous semester or a seminar on personal development if he had not, and two hours of monitored sport activities per week counting for 1 ECTS. The courses in humanities and social sciences, were described above, those or in foreign languages are to be chosen within a global catalog of classes provided by the corresponding department. The seminars on personal development for the spring semester of year 1 are described hereafter.
A Healthy Mind in a Healthy Body PDV201
C. Destremau

In this unit, students will focus on health (sports, diet, sleep, mental preparation via the TOP…) During several sessions, students are given some theoretical and practical tools about the four pillars: physical activity including sports; diet and nutrition; sleep and alertness; mental preparation via the Tactics to Optimize the Potential. These tools will enable them to improve their health, to manage their stress in their current life or before/during an exam.

ECTS Credits: 2

Group Volunteering PDV202
C. Destremau

In this unit, students will be involved as a group, volunteering to meet and work with all kind of partners outside the university context. The aim is to undertake collective action and develop one’s personal skills, all outside of lecture halls. This unit will allow students to strengthen their skills in terms of group work but also to develop strong values such as open-mindedness, generosity and self-confidence.

ECTS Credits: 2
YEAR 2
COURSE OFFERING
Spring Semester
Quadratic Forms and Applications MAA206

Prerequisite: MAA201

Quadratic forms and applications (MAA206) is a continuation of Euclidian and Hermitian spaces (MAA201) 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.

Series of Functions, Differential Equations MAA207

Prerequisite: MAA202

Series of functions, differential equations (MAA207) builds upon the topology notions studied in Topology and multivariable calculus (MAA202) 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.
Numerical Linear Algebra MAA208
T. Pichard

Prerequisite: MAA201

Recommended previous course: MAA106

MAA208 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 their project presentation, a report, and coursework.

ECTS Credits: 3
Mandatory for the double major Math/CS
COMPUTER SCIENCE

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

Machine Learning CSE204
J. Read

ECTS Credits: 5

Prerequisites:
CSE101, CSE102 and CSE201

Machine Learning (CSE204) 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.

Computer Architecture CSE205
F. Zappa Nardelli

ECTS Credits: 5

Prerequisite: CSE201

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.
Introduction to Formal Languages CSE206
E. Haucourt

**Prerequisites:** CSE203

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.

ECTS Credits: 3

Introduction to Networks CSE207
T. Clausen

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.

ECTS Credits: 3
**ECONOMICS**

**Introduction to Econometrics ECO203**
A. Simoni, A.Uhrendorff

**ECTS Credits:** 5  
**Mandatory for the double major**  
**Math/Economics**

**Prerequisite:** ECO101, ECO102

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:
- *Basic Econometrics* by Damodar N. Guarati and Dawn C. Porter

**Introduction to Finance ECO204**
L. Schilling

**ECTS Credits:** 5  
**Mandatory for the double major**  
**Math/Economics**

**Prerequisite:** ECO101, ECO102

Introduction to Finance (ECO204) 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
ECO205
B. Cherrier

Prerequisite: ECO101, ECO102

The Economics Workshop (ECO205) 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 PHY204
A. Couairon

Prerequisites: PHY104, PHY105

Classical electrodynamics is an important pillar of physics given that it led to numerous scientific and technological developments since the 19th century. PHY204 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.
Introduction to Quantum Physics **PHY205**

A. Specka

**Prerequisites:**
PHY101, PHY104, PHY105, PHY202

**Recommended previous courses:**
PHY103, PHY106, PHY107, PHY201

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 PHY205, 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.

**ECTS Credits:** 5

**Mandatory for the double major Math/Physics**
Waves and Heat Transfer in Geophysics PHY206

R. Plougonven

Prerequisites:
PHY101, PHY102, PHY201, PHY202

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.
Advanced Lab II  PHY207
F. Cadiz

**Recommended previous course:** PHY203

In Advanced Lab II, students have the opportunity to apply the physics knowledge they have acquired in 7 distinct lab sessions of 4 hours each. PHY207 provides an in-depth study of a wide range of physical phenomena such as fundamental and applied wave-optics (Fourier optics, Michelson interferometry), atomic physics (the Balmer series), thermodynamics (the Rührardt experiment, the Stirling engine) as well as fluid mechanics. 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.

**ECTS Credits:** 3

**Mandatory for the double major Math/Physics**
Atoms and Lasers **PHY208**
D. Suchet, E. Johnson

**Recommended previous course:** PHY202

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, Schrödinger 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.
ELECTIVES

Molecular Genetics BIO202
PA. Defossez

Prerequisite: BIO201

Molecular Genetics (BIO202) 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.

ECTS Credits: 3
Required for the Biology minor
Environment and Energy CHE202
A. Auffrant, A. Guell

Prerequisite: CHE201

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.
A First Step in Numerical Optimization MAA209
B. Bogosel

Prerequisites: MAA202, MAA208

Numerical optimization concerns the minimization or maximization of an objective function. It often relies on the computation of the gradient of this function. MAA209 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. MAA209 follows MAA208, 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.
TRANSVERSE COURSES

Overall presentation

Transverse teaching in the bachelor program includes courses in humanities and social sciences, foreign languages, personal development and sports, for a total of 5 ECTS per semester. At each of the first four semesters, a student must follow a foreign language class counting for 2 ECTS, either a course in Humanities and Social Sciences or a seminar on personal development counting for 2 ECTS each, and two hours of monitored sport activities per week counting for 1 ECTS.

The courses in humanities and social sciences, were described above, those in foreign languages are to be chosen within a global catalog of classes provided by the corresponding department. The seminars on personal development for the fall semester of year 2 are described hereafter.
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 in front of a jury.

A group of students, eager to take action autonomously in a school-wide team project, will be able to organize the show during the Final (planning, setting up, conducting the event).

ECTS Credits: 2
YEAR 3
COURSE OFFERING
Fall Semester
MATHEMATICS

Measure and Integration MAA301

Y. Martel

Prerequisite: MAA202

MAA301 proposes an introduction to the modern theory of integration. The first part of this course is focused on the construction of the Lebesgue integral, an extension of the Riemann integral to a class of functions much larger than the set of Riemann-integrable functions. With the Lebesgue theory of integration, passing to the limit in integrals of sequences of functions is an easy task which rests on the verification of a few essentially optimal assumptions. The end of the course offers an introduction to Lebesgue spaces and the Fourier transform, with applications to physics. The abstract theory of integration discussed at the beginning of this course provides the setting used in probability theory and stochastic analysis.

Topology and Differential Calculus MAA302

K. Carrapatoso

Prerequisite: MAA202

MAA302 is devoted first to the theory of metric and topological spaces in an abstract setting, including numerous examples of function spaces. We will then shift our focus towards Banach spaces, motivated by applications in optimization. Following this, the course will examine differentiable functions, smooth functions, and their local properties. Restricting our attention to finite dimensional spaces, the course will conclude with an abstract theory of optimization, with applications in economics and physics: optimization without constraints and with constraints, and the well-known Lagrange multiplier theorem will all be studied in detail.
Algebra and Arithmetics MAA303
M. Rosenbaum

Prerequisite: MAA104

MAA303 mainly focuses on general group theory. The first part of the course will be dedicated to the basic notions that one uses to study groups: normal subgroups, quotient group, simple groups... The second part of the course will focus on group actions. After introducing them, we will see a number of interesting applications in algebra, geometry and arithmetic, such as the so-called Sylow theorems.

At the very end of the course, we will move on from groups to other usual algebraic structures, such as rings and fields. This part of the course will only be a short introduction to ring and field theory. Extra material not covered during the course itself will be provided for those students who would like to go further and understand how groups, rings and fields are deeply related through the study of algebraic equations and Galois theory.

ECTS Credits: 3

At least 1 Mandatory course to choose between MAA303, MAA304 and MAA305 for the double major Math/CS.
Recommended for the double major Math/Economics
MATHEMATICS

Asymptotic Statistics **MAA304**

*E. Moulines*

First half of the semester  
**Prerequisite:** MAA203, MAA204

MAA304 will open with a recap of convergences of random variables and convergences of distributions. The class will then investigate asymptotic statistics (asymptotic properties of MLE, asymptotic confidence intervals, asymptotic test theory etc.) and information theory for statistics (efficiency, Cramer-Rao theory etc.). Finally, students will be given an introduction to Bayesian statistics.
Probability: Stochastic Processes MAA305
T. Mastrolia

Second half of the semester
Prerequisites: MAA203

This course introduces some fundamental properties on stochastic processes (in a discrete time framework), illustrated with examples in biology, economics and finance. We investigate the behavior of systems evolving step by step. As a guideline for this course, the random walk is introduced first to emphasize fundamental interesting long time behavior properties. We then introduce the notion of conditional expectations and study two particular theories: martingales and Markov chains. The course concludes with the Brownian motion as a scaling limit of a random walk in continuous time.

ECTS Credits: 3

At least 1 Mandatory course to choose between MAA303, MAA304 and MAA305 for the double major Math/CS.
COMPUTER SCIENCE

Functional Programming CSE301
X. Rival

First half of the semester

Prerequisites: CSE201 and CSE203

In this course, we will study functional Programming, and will learn how to take advantage of the features of modern functional programming languages. We will study in depth the notions of functions (higher-order functions, closures), module systems (signatures, functors), and iterators. The practice sessions will be done in OCaml (but concepts presented in the course can be applied in many other languages such as Haskell, SML or JavaScript).

Compilers CSE302
K. Chaudhuri

Prerequisite: CSE201

Recommended previous course: CSE206

Compilation is the process of transforming high-level programs and abstractions into the binary machine code used in computer processors. This course introduces the principles and techniques of compilation, with parsers, interpreters, and translators, as well as topics in code optimization and semantic analysis. Students will build a compiler for a simple programming language.
Computer Science Project CSE303
A. Couvreur

This course will give to the students the opportunity to design and implement a significant CS project.

In that perspective, the students will have to work in an organized and professional manner from conception to delivery, giving them the opportunity to apply all the knowledge they got from the previous courses.

Constraint Logic Programming CSE307

Second half of the semester
Prerequisite: CSE203

The course will present the paradigm of Constraint Logic Programming from its logical foundations for programming with relations, to its current applications. From logic programming and the early days of artificial intelligence, towards the holy grail of programming simply by modelling, the students will learn how to use a recent dialect of Prolog for relational databases, knowledge representation, automated deduction and combinatorial problem solving. The balance between declarative programming and efficiency, between clean semantics and expressiveness will be of particular interest, and will lead us into looking at how things work internally in a Prolog bytecode compiler (Warren Abstract Machine, indexing...) on practical examples.
Advanced Microeconomics ECO301
J. Combe, Y. Le Yaouanq

Prerequisite: ECO201

In Advanced Microeconomics (ECO 301), we build on the ECO 201 course to go beyond the competitive equilibrium setting and elicit new causes of market failures. We aim to study how the presence of incomplete and asymmetric information affects the standard analysis of microeconomic theory. The starting point is that the presence of asymmetric information leads to market failures and open the question of how to regulate and appropriately design markets to solve or reduce these failures. We will present the basics of two important theories and methods which have been the core of the modern microeconomic analysis since 1970: the signaling games and the mechanism design. The students will learn the tools to analyze markets and interactions in the presence of incomplete and asymmetric information. They will learn how to develop policy tools and how to design markets to mitigate the issues induced by the information structure.

More specially, we will cover the following topics:

- Chapter 1: Game theory under incomplete information (1)
- Chapter 2: Asymmetric Information, Signaling and Application to the Insurance Market (2)
- Chapter 3: The Principal Agent Model (3)
- Chapter 4: Auctions and Mechanism Design (4)
- Chapter 5: Market Design and Matching

The mathematical treatments are rigorous but not as much as at the graduate level. This course will be thus most useful as a preparation for formal graduate studies in Economics.

Textbooks:

Advanced Macroeconomics ECO302
N. Lisack, M. Senouci

Prerequisite: ECO202

This course builds on the Intermediate macroeconomics course (ECO202) and will cover both the short run (business cycles, crises, and stabilization policies) and the long run (the determinants of long-run economic growth). To be more specific, the course will cover the following topics:

Part I: Business cycles and stabilization policies (7 lectures)
- The New Keynesian model of aggregate demand and supply
- The propagation of business cycle shocks
- Conventional monetary and fiscal policies
- The liquidity trap and unconventional policies

Part II: Economic Growth (7 lectures)
- Growth facts and Solow reminder
- Immediate causes of economic development: human capital, physical capital, and technology
- The deep causes of economic development: geography, institutions, and culture

- Innovation and economic growth
- Economic growth and the environment

Textbooks:

A complementary reading list of policy and accessible research papers will be provided in due time.

ECTS Credits: 5
Mandatory for the double major Math/Economics
Advanced Quantum Physics PHY301
M. Ferrero

This course is a sequel to PHY205 «Introduction to Quantum Physics». It will expand our view on three-dimensional quantum mechanical problems, by applying the formalism to the description of atoms and particles in a magnetic field.

This includes also a deeper analysis of angular momentum, and its relation to rotational symmetry. We will discover approximation techniques for time-independent and time-dependent phenomena, and apply them to the detailed description of the hydrogen atom. Furthermore, we will study the notion of entanglement which is fundamental to quantum cryptography and quantum computing. The description of identical particles in quantum mechanics will build the bridge to the Pauli exclusion principle and the spin-statistics connection.

The following subjects are expected to be treated:
› The addition of angular momenta
› The notion of spin and magnetic resonance
› The hydrogen atom
› Approximation methods and time-independent perturbation theory
› Entangled states, the EPR paradox and quantum information
› Particles in a magnetic field, Landau levels
› Identical particles and the spin-statistics connection
› Time-evolution and time-dependent perturbation theory.
Introduction to Condensed Matter Physics PHY302
JE. Wegrowe

Recommended previous courses:
PHY107, PHY201, PHY204, PHY205, PHY206

Condensed matter physics deals with the description of the physical properties of matter when the interaction between its constituents are very strong. This is typically the case for materials and devices. It covers a very large field of knowledge that encompasses electric, thermal, chemical, magnetic, and mechanical properties, and all the combinations of these properties, in solids.

From the technological point of view, condensed matter physics have brought some major discoveries and new developments: electronic devices, sensors, actuators, transducers, power generation devices, energy storage, to name but a few.

This domain of physics is based on two different and complementary approaches. A first approach starts from the quantum microscopic constituents and describes statistically the macroscopic consequences. The second is a phenomenological macroscopic description based on general principles of thermodynamics and symmetries.

The goal of this lecture is to give an overview of the concepts, methods and applications, with a particular emphasis on the non-equilibrium thermodynamic approach of transport phenomena (electric, thermal, thermoelectric, magnetic...). The lectures are focused on the understanding of technologically important problems.

The following topics will be covered:
- Crystal structures and symmetries. Structural characterization of solids.
- Introduction to quantum theory of solids.
- Electric transport properties in metal and semiconductors. Thermoelectric effects. Hall effects, Nernst effects, magnetoresistance.
- Kinetics of magnetization: the Landau-Lifshitz-Gilbert equation, hysteresis loops and thermal activation.
- Kinetics of defects in solids.
- Standard anelastic solids (viscoelasticity).
Advanced Lab III PHY303
Y. Laplace

**Recommended previous courses:**
PHY203, PHY207

In Advanced Lab III, students have the opportunity to apply the physics knowledge they have acquired over the course of 6 lab sessions of 4 hours each. In PHY303, the students will discover a more autonomous style of experimentation. The lab sessions will be centered on modern physics and are expected to address several among the following subjects: quantum physics (e.g. Nuclear magnetic resonance), condensed matter physics (e.g. crystallography), modern optics (e.g. lasers) as well as solid and fluid mechanics (e.g. 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.
Solid Mechanics PHY304
M. Jabbour

Prerequisite: PHY101

Recommended previous course: PHY201

Some knowledge of ordinary differential equations would be helpful.

We are surrounded by natural and man-made structures that deform when subjected to loadings. These structures span a wide spectrum of length scales, from suspension bridges and aircrafts all the way down to spider webs, human hair, micro-electro-mechanical systems, and cell membranes. In this course, we will focus on slender bodies, which by virtue of their elongated aspect can be modeled as curvilinear media. This simplified geometry allows us to present the fundamental concepts of the mechanics of deformable solids without recourse to the tensor formalism that is intrinsic to three-dimensional continuum mechanics. We will then solve problems and comprehend phenomena (such as the buckling of elastic beams) involving geometric and/or material nonlinearities that, in three dimensions, do not lend themselves to analytical treatment.

We will cover the following topics:

- Geometry, deformation, and kinematics of curvilinear media
- External and internal forces and couples, equilibrium equations
- Constitutive relations, including rigid bars, extensible strings, and elastic rods
- Boundary value problems associated with various models: elastic strings, beams, and arcs
- Euler’s elastica (and, time permitting, its boundary layer)
- Linear elasticity of slender bodies and its applications
- Stability of conservative systems (both discrete and continuous)
- Dynamics: wave propagation in elastic beams, forced and free vibrations of elastic rods.

ECTS Credits: 5
1 Mandatory course to choose between PHY302 and PHY304 for the double major Math/Physics
**ELECTIVES**

**Biology Practicals BIO301**

*H. Myllykallio*

**ECTS Credits:** 3  
**Required for the Biology minor**

**Prerequisite:** BIO201, BIO202  

The primary goal of the Biology practicals is to provide an overview of the most recent techniques to complement the practicals of BIO201 and BIO202. During this course, students will participate in research projects in the École Polytechnique laboratories where they will learn some of the most advanced techniques in biology under the supervision of researchers.
Technological Tools for Chemistry **CHE301**
A. Guell

**Prerequisite:** CHE101

Chemistry strongly benefits from technological advances that accelerate the progress in the design and development of new compounds and materials, understanding their composition, properties and behavior. In this course, students explore the scientific basis and the technological features of the techniques/instruments employed on a daily basis in any cutting edge chemistry laboratory. Among these techniques, students review a set of spectroscopic tools (*e.g.*, IR and Raman spectroscopy, Mass spectroscopy, Nuclear Magnetic Resonance), nanocharacterization microscopes (*e.g.*, Scanning Electron Microscopy, Scanning Probe Microscopy), separation techniques (*e.g.*, HPLC), and analytical tools (*e.g.*, X-Ray diffraction). The course includes a significant amount of experimental time in the laboratory where the techniques will be employed to resolve interesting and exciting chemical problems. A visit to the Synchrotron radiation facility Soleil may also be planned.
TRANVERSE COURSES

Foreign languages and sports remain mandatory. Students may choose, at most, one other course in the following list or from the HSS course offering.
Diversity Report PDV301
B. Destremau

This course unit is designed to allow students to reflect upon their experience of diversity on campus. It includes reading and communicating on the students' experiences and reflections through a written report.

ECTS Credits: 2

Active Volunteering PDV302
B. Destremau

This course unit is designed to allow students to acquire personal skills they will use in their future professional life. Since responsibility is paramount in professional life, the unit fosters and rewards community spirit as well as the students' commitment for the public good. Students will learn through experience how to contribute to society. Being third year students, they will be expected to make personal choices and to take actions autonomously. The unit includes reflection and communication on the students' practices and experiences through a written report.

ECTS Credits: 2
YEAR 3
COURSE OFFERING
Spring Semester

The semester begins with a mandatory Bachelor Thesis prepared during a research internship of 8 weeks minimum. The subsequent classes have a shorter duration.
MATHEMATICS

At least 2 Mandatory course to choose between MAA306, MAA307, MAA308 and MAA312 for the double majors Math/CS and Math/Physics

Algebra and Geometry MAA306
E. Balzin

Prerequisite: MAA206

The course “Topics in Differential Geometry” introduces basic and important objects which are widely used in mathematics and physics: vector fields and differential forms.

Firstly, we propose a geometric point of view on differential equations using the language of vector fields, their integral curves and their flows. Secondly, we define differential forms and the exterior differentiation of such forms.

Many formulas used in physics (Gauss-Green-Riemann-Ostrogradski-Stokes) are naturally expressed and unified in those terms and will illustrate the course.

Convex Optimization and Optimal Control MAA307
S. Amstutz

Prerequisite: MAA202

MAA307 is composed of three connected parts. The first one lays the foundation of convex analysis in Hilbert spaces, and covers topics such as: convex sets, projection, separation, convex cones, convex functions, Legendre-Fenchel transform, subdifferential. The second part deals with optimality conditions in convex or differentiable optimization with equality and inequality constraints, and opens the way to duality theory. The last part is an introduction to the optimal control of ordinary differential equations.
Image Analysis MAA308
S. Allassonnière

When several pictures (obtained from a camera, a CT scan, etc.) of an object are available, registration refers to mathematical methods to combine those images. Registration is then an important first step to extract information from those images. This will introduce variational methods that play a central role in many scientific problems and in particular in image analysis.

Next, we will consider the problem of partitioning an image into different segments. These segments should be meaningful: an organ in a CT scan, an object in a picture. The lecture will cover a range of mathematical models and methods, such as regularization or level set methods.

Numerical Methods for ODEs MAA312
N. Spillane

In MAA312 “Numerical Methods for ODEs”, we will introduce numerical scheme to simulate ordinary differential equations.

We will start by Euler schemes (explicit and implicit) and understand how the notions of stability and consistency can be used to study these methods. We will then consider Runge-Kutta schemes and apply the different methods to particular applications, e.g. the N-body problem.
Measure and Integration – Condensed MAA310
I. Pasquinelli

First half of the semester
MAA310 is the condensed version of the course MAA301, devoted to the modern theory of integration.

Mandatory and only open to students who have not followed MAA301 or an equivalent course.
This course can replace two of the mandatory ECTS in Maths or in Economics.
Topology and Differential Calculus – Condensed MAA311

Second half of the semester
MAA311 is the condensed version of the course MAA302, devoted mostly to the theory of metric and topological spaces in an abstract setting.

Mandatory and only open to students who have not followed MAA301 or an equivalent course.

This course can replace two of the mandatory ECTS in Maths or in Economics.

ECTS Credits: 2
COMPUTER SCIENCE

At least 2 courses to choose between CSE304, CSE305 and CSE306 for the double major Math/CS

Complexity CSE304
O. Bournez

ECTS Credits: 4

Prerequisites:
CSE202, CSE203, CSE206

Theoretical Computer Science has shown that computational problems can be classified according to how difficult they are to solve. We now know that some problems are intrinsically impossible to solve in a reasonable amount of time, or with a reasonable amount of resources. This course describes the rigorous model of computation required to compare and classify computational problems and their difficulty, giving an introduction to the theory of computational complexity and the standard complexity classes.

Concurrent and Distributed Computing CSE305
E. Goubault

ECTS Credits: 4

Prerequisite: CSE201, CSE202

Today’s programs and calculations operate not on one computer at a time, but rather on groups of processors or machines working together in concert. But ensuring efficiency and cooperation among the threads of a program is a deeply subtle, and fascinating, problem.

This course aims to provide the techniques required to master efficient distributed programming, avoiding the many pitfalls that arise when computations share their resources.
Computer Graphics CSE306
N. Bonneel

Prerequisite: CSE201, CSE202

This course explores fundamental concepts in 2D and 3D computer graphics, including digital images, 2- and 3-dimensional geometry, curves and surfaces, perspective, ray tracing, filtering and antialiasing, the graphics pipeline, and human visual perception.
ECONOMICS

Health and Development Economics ECO303
P. Rossi

ECTS Credits: 2

Prerequisite: ECO201

This course is an introduction to development economics with a specific focus on the relationship between health and development. To what extent do differences in the disease environment explain differences in economic performance? Which policies are effective at improving health in developing countries? We will study these questions from an empirical perspective and review recent evidence to shed light on important policy debates.

We will touch upon the two main views on fundamental causes of economic growth: endowments and institutions.

Reading list:


Industrial Organization ECO304
R. de Nijs

Prerequisite: ECO201

This course provides students the ability to analyze the behavior and performance of firms in markets, with a particular focus on strategic interactions. Topics include monopoly power, behavior of firms in oligopoly markets, static and dynamic measurement of market performance, pricing and product choice decisions, advertising, research and development, and theory of the firm.

Textbook:
› Introduction to Industrial Organization by Luis M.B. Cabral
› The Theory of Industrial Organization by Jean Tirole
Social and Environmental Responsibility of Business ECO305

P. Crifo

ECTS Credits: 2

Prerequisite: ECO201, ECO202

This course introduces the economics of corporate social responsibility (CSR), and the determinants for businesses, acting on a voluntary basis, to incorporate social, environmental, and ethical concerns into their economic activities and interactions with their stakeholders. It consists in three parts. The first part presents the basic stylized facts about CSR and the role of governments and investors in promoting responsible behaviors. The second part presents the three main models which explain CSR decisions. The third part covers the data and impact analysis of CSR.

Textbook:

› Corporate Environmentalism and Public Policy by Thomas P. Lyon & John W. Maxwell (Cambridge University Press)

› The Market for virtue: the potential and limits for CSR by David Vogel (Brookings institution press)
Prerequisite: ECO201, ECO202

This course introduces students to the economics of international trade. It consists of three parts. The first part presents facts about trade flows and trading firms and introduces the widely-used gravity equation. The second part covers three standard trade theories which explain trade patterns. The last part presents trade policy, with some focus on recent trade disputes.

Textbook:
- *International Economics*, Krugman, Obstfeld & Melitz (Pearson)
- *International Economics*, Feenstra & Taylor (Worth Palgrave MacMillan)

Introduction to Research Frontiers A, B (ECO307, ECO308)
ECONOMICS

Introduction to Research Frontiers A, B
ECO307, ECO308
G. Corcos

ECTS Credits: 2+2

This course introduces students to the research frontiers in economics. Each week, a researcher from the laboratory CREST would present a central topic of his/her research. Students are expected to see how researchers tackle problems using the tools and concepts developed in economics. Topics include traditional microeconomics, macroeconomics, and econometrics, as well as recent interdisciplinary developments such as blockchain technology, and machine learning.

Computational Economics ECO309
M. P. Winant

ECTS Credits: 4

This course is designed to provide economists with elements of modern scientific computing using the open-source Julia language. It covers several topics in numerical analysis and programming, and applies them to several economic modeling fields (dynamic programming, macro modeling, IO models). Special emphasis is given to performance and reproducibility. Approximately half of the sessions will consist in hands-on tutorials.

At least 12 ECTS to choose between ECO303 to ECO309 for the double major Math/Economics
Prerequisites: 
PHY101, PHY201, PHY205 

Recommended previous course: PHY301

The most dramatic success of thermodynamics is to provide us with a universal description of macroscopic physical systems. It equally applies to systems as various as molecular gases, magnetic materials, stellar systems, and electromagnetic radiation to name a few. It was later realized that the laws of thermodynamics can be established from a statistical description. The statistical approach represented a genuine paradigm shift in our understanding of physical systems and paved the way to major advances in many fields. The aim of this course is to give a theoretical background to thermodynamics and statistical physics, as well as applications in a variety of contexts, from classical to quantum.

The following subjects are expected to be treated:

- Axiomatic thermodynamics (reminder and complements; laws 0-3, energy, entropy, universality)
- Phase transitions
- Statistical description of isolated systems
- From isolated to open systems: The canonical Gibbs ensembles
- Statistical physics of the ideal classical gas
- Ideal quantum gases: fermions and bosons (Bose-Einstein condensation and Fermi seas)
- Other applications of thermodynamics and statistical physics.
Fluid Mechanics PHY306
S. Michelin

Prerequisite: PHY101, PHY102, PHY105

Recommended previous course:
PHY201, PHY206

The motion of fluids plays a critical role in many phenomena or processes that are the center of our daily life or engineering systems, ranging from the flight and/or propulsion of aircrafts and vessels, the generation of electricity from wind-turbines, the flow of blood in our arteries, the atmospheric and ocean circulations guiding our climate or microscopic flows in lab-on-a-chip systems. This course will provide the students the fundamental tools to model, understand and analyze the motion of such fluid flows in three dimensions, and evaluate the resulting forces on the bounding surfaces.

The material covered in this course will build upon several courses of the program including Mechanics and Heat (PHY101), Mathematical Methods for Physicists I and II (PHY102 and PHY105), Classical Mechanics (PHY201) and Waves and Heat Transfer in Geophysics (PHY206).

The following subjects are expected to be treated:
- Eulerian description of motion of 3D flows
- Mass and momentum conservation
- Hydrostatic pressure
- Viscosity and viscous stresses
- Motion of a Newtonian fluid: Navier-Stokes equations
- Non-dimensional analysis and scalings
- Parallel and weakly-non parallel flows
- Inviscid flows and potential flow theory
- Vorticity
- Introduction to boundary layers.
Introduction to Subatomic Physics PHY307
E. Maurice

Prerequisites: PHY204, PHY205

Recommended previous courses: PHY106, PHY301

The quest for finding the ultimate constituents of matter has revealed that matter has a nested structure: quarks at scales that differ by many orders of magnitudes; atoms contain electrons and nuclei; nuclei are made up of nucleons, which in turn are composed of. Nowadays, particle physicists are more concerned with the fundamental laws that govern the interactions of elementary particles. The most emblematic question is “how do particles acquire mass”; and the discovery of the Higgs boson in 2012 is an important clue that we are on the right path to answering this question.

This course will give a pedestrian introduction to nuclear and particle physics, illustrating in a balanced fashion theoretical underpinnings, experimental activities and technological aspects of subatomic physics. The basis for this course will be the PHY205 and PHY301 (introductory and advanced quantum physics) as well as PHY204 (theoretical electrodynamics). The following subjects are expected to be treated:

❯ the big picture of the structure of matter and the great discoveries
❯ nuclear binding energy; nuclear models (droplet model; fermi-gas model); isotopic spin
❯ particle accelerators and colliders
❯ decay of elementary and subatomic particles decay
❯ scattering experiments: nucleus, nucleons, quarks
❯ the nonrelativistic quark-model and the magnetic moment of the nucleons
❯ neutrino oscillations.

ECTS Credits: 4
One course to choose between PHY306 and PHY307 for the double major Math/Physics
ELECTIVES

Biomedicine BIO302  
A. Goutéraux

The biomedicine course will include a series of lectures covering the molecular and cellular mechanisms of diseases and therapeutic strategies to treat them. In parallel, students will actively participate to research performed in laboratories of École Polytechnique on campus. All research topics are related to biomedicine.

Mastering the Synthesis and Transformation of Molecules CHE302  
T. Cantat

Prerequisite: CHE201

Mastering the transformation of organic matter is key to tackle societal challenges such as the synthesis of new pharmaceutical drugs, the design of functional polymers and the recycling of wastes to value-added products. CHE302 is an intermediate-level chemistry course that introduces the reactivity and transformation of organic chemicals, based on quantum chemistry. From the description of the electronic structures and bonding interactions in molecules (using molecular orbitals and Hückel theory), the transformation of organic and inorganic compounds is introduced, as well as the reactivity of organic functionalities (carbonyls, alkenes and aromatics) and the concepts of catalysis. This interactive course explores these topics through lectures, tutorials and labs.
The course Seminar: Mathematical Models (MAA313) covers simulation and statistics, while introducing students to PDEs and numerical optimization. During this course, students are asked to present scientific papers on different problems of mathematical modeling. Each presentation requires not only a deep understanding of the considered paper, but also a practical implementation of the numerical method proposed in the article. Students are free to focus on some more specific part or even to explore different ideas that might be of their own. This therefore requires a lot of autonomy, clarity, imagination and personal investment.
TRANSVERSE COURSES

Foreign languages and sports remain mandatory. The students may choose at most one other course in the following list.

Fundamentals of Organizations MIE301
C. Chamaret

This course covers the concepts and theories related to the management of organizations (culture, power, innovation...). The course includes a discussion of the main theories, which are useful to understand business problems and empirical situations. Upon completion of this course, students will demonstrate their ability to apprehend business situation and to understand typical human and organizational problems in various industries.

Course materials include written case studies, videos and simulations.
Diversity Report PDV303  
B. Destremau  

This course unit is designed to allow students to reflect upon their experience of diversity on campus. It includes reading and communicating on the students’ experiences and reflections through a written report. Only students who did not take this unit in semester 5 may register.

ECTS Credits: 2

Active Volunteering PDV304  
B. Destremau  

This course unit is designed to allow students to acquire personal skills they will use in their future professional life. Since responsibility is paramount in professional life, the unit fosters and rewards community spirit as well as the students’ commitment for the public good.

Students will learn through experience how to contribute to society. Being third year students, they will be expected to make personal choices and to take actions autonomously. The unit includes reflection and communication on the students’ practices and experiences through a written report.

Students who registered for Active Volunteering in semester 5 may register again, but for a different project.

ECTS Credits: 2