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.

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. 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.
Politics of the Ecological Mutation HSS211
A. Hardy

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.
HUMANITIES AND SOCIAL SCIENCES FALL OFFERING

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 civilizations. 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.

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HUMANITIES AND SOCIAL SCIENCES SPRING OFFERING

French Identity HSS151
P.-M. Renaudeau

ECTS Credits: 2

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.
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.

Major Issues in Today’s World and the Place of France HSS101
N. Rousselier
ECTS Credits: 2
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
ECTS Credits: 2
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.
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
D. Izquierdo

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.
MATHEMATICS

Asymptotic Statistics MAA304
E. Moulines

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.

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

ECTS Credits: 3
At least 1 Mandatory course to choose between MAA303, MAA304 and MAA305 for the double major Math/CS.

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.
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

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.

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
E. Challe

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

Textbooks:

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

J.E. 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.

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.
ELECTIVES

Biology Practicals BIO301
H. Myllykallio

Prerequisite: BIO201, BIO202

ECTS Credits: 3
Required for the Biology minor

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

ECTS Credits: 3
Required for the Chemistry minor

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.
TRANSVERSE 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.

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.
YEAR 3
COURSE OFFERING
Spring Semester

The semester begins by 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.
MATHEMATICS

Measure and Integration – Condensed MAA310
I. Pasquinelli
ECTS Credits: 2
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
ECTS Credits: 2
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.
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.

Computer Graphics CSE306
N. Bonneel

ECTS Credits: 4

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.

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

ECTS Credits: 2

Prerequisite: ECO201

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. Cripo

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)

International Trade ECO306
G. Corcos

ECTS Credits: 2

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

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

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.

**PHYSICS**

Thermodynamics and Statistical Physics PHY305  
L. Palencia-Sanchez

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.

At least 12 ECTS to choose between ECO303 to ECO309 for the double major Math/Economics

ECTS Credits: 4  
Mandatory for the double major Math/Physics
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 a 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; isotropic 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.
ELECTIVES

Biomedicine BIO302  
A. Gautreau  
ECTS Credits: 3  
Required for the Biology minor

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  
ECTS Credits: 3  
Required for the Chemistry minor

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.

Seminar: Mathematical Models MAA313  
N. Spillane, L Gérin  
ECTS Credits: 3

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.
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 understand business situations and to understand typical human and organizational problems in various industries.

Course materials include written case studies, videos and simulations.

ECTS Credits: 2

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.

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