International Master Physics, Photonics & Nanotechnology

Definitions of the symbols:
L : Lecture, E : Exercises, P : Practical,
ECTS : *European Credits Transfer* System,
TE : Terminal exam, PaE : Partial exam, PrE : Practical exam, O : Oral exam

FIRST YEAR M1

FIRST SEMESTER S1

UE 1	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/ PrE	Total coef
Solid-state physics and soft matter	1a : Solid-state physics	26	14		40	3	TE/PaE	O	2	1	3
	1a : Soft matter	14	2	4	20	2	TE/PaE/PrE	O	1	1	2
TOTAL UE		**40**	**16**	**4**	**60**	**5**			**3**	**2**	**5**

UE 2	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Quantum physics	2a : Quantum Physics	24	10		34	6	TE/PaE	O	1,5	0,5	2
	2b : Quantum optics	10	6		16		TE/PaE	O	1,5	0,5	2
	2c : Atomic & molecular spectroscopy	12	8		20		TE/PaE	O	1,5	0,5	2
TOTAL UE		**46**	**24**		**70**	**6**			**4,5**	**1,5**	**6**

UE 3	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Signal processing	3a : Signal analysis	8	10		18	2	PaE			2	2
	3b : Data analysis	4	10		14	1	PaE			1	1
	3c : Data acquisition	4	14		18	2	PaE			2	2
TOTAL UE		**16**	**34**		**50**	**5**				**5**	**5**

UE4	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/ PrE	Total coef
Lasers	4a : Fundamentals of laser	20	10		30	3	TE	O	3		3
	4b : Gaussian optics	14	6		20	2	TE	O	2		2
TOTAL UE		**34**	**16**		**50**	**5**			**5**		**5**

UE 5	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Numerical methods for Physics	Numerical methods for Physics	10	8	12	30	4	TE/PaE	O	2	2	4
TOTAL UE		**10**	**8**	**12**	**30**	**4**			**2**	**2**	**4**

UE 6	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
French, soft skills & industry	7a : French		20		20	2	PaE	O		2	2
	7b : Soft skills		10		10	1	PaE	O		1	1
	7c : Industry seminar	10		10	20	2	PaE	O		2	2
TOTAL UE		**10**	**30**	**10**	**50**	**5**				**5**	**5**

TOTAL S1	**156**	**128**	**26**	**310**	**30**			**14,5**	**15,5**	**30**

SECOND SEMESTER S2

UE7	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Guided optics and opto-electronics	Guided optics and opto-electronics	13	12	15	40	4	PaE	O		4	4
TOTAL UE		**13**	**12**	**15**	**40**	**4**				**4**	**4**

UE 8	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Nonlinear optics	5a : Fundamentals of nonlinear optics	14	8		22	2	TE/PaE	O	1,5	0,5	2
	5b : Materials for nonlinear optics	12	6		18	2	TE/PaE	O	1,5	0,5	2
TOTAL UE		**26**	**14**		**40**	**4**			**3**	**1**	**4**

UE 9	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Microscopies	9a : Scanning probes (AFM, SNOM)	6	4	10	20	2	PaE/PrE	O		1+1	2
	9b : Electron microscopies (TEM, MEB)	6	4	10	20	2	PaE/PrE	O		1+1	2
TOTAL UE		**12**	**8**	**20**	**40**	**4**				**4**	**4**

UE 10	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/PrE	Total coef
Fiber Communications	Optical communications	22	8	10	40	4	TE/PaE/PrE	O	3	1	4
TOTAL UE		**22**	**8**	**10**	**40**	**4**			**3**	**1**	**4**

UE 11	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE/ PrE	Total coef
Micro Nano fabrication & Clean Room	Micro Nano fabrication & Clean Room	10	10	10	30	4	PrE	O		4	4
TOTAL UE		**10**	**10**	**10**	**30**	**4**				**4**	**4**

Brief overview

The nanofabrication essentially uses two ways to manufacture nano-objects: the bottom-up approach and the top-down approach. We propose to familiarize students with the top-down technique, called lithography, and used in the laboratory. This conventional manufacturing technique uses the interaction of an incident beam (e-beam or UV) with the material. The techniques of UV lithography and e-beam lithography will be presented as well as techniques of scanning electron microscopy (SEM), thin film deposition (PVD) and reactive ion etching (RIE).

Practical: PVD + SEM, e-beam litho, UV litho, RIE

UE 12	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE	Total coef
Projects			50		50	6	PaE			6	6
TOTAL UE			**50**		**50**	**6**				**6**	**6**

UE 13	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE	Total coef
Minor	Taken from the graduate school	20	10	10	40	4	TE		4		4
TOTAL UE		**20**	**10**	**10**	**40**	**4**			**4**		**4**

TOTAL S2	**118**	**108**	**54**	**280**	**30**			**10**	**20**	**30**

TOTAL M1	**274**	**236**	**80**	**590**	**60**			**24,5**	**35,5**	**60**

SECOND YEAR M2

THIRD SEMESTER S3

UE14	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE		Total coef
Ultrafast Optics	14a : Femtosecond science: from concepts to applications	18	8		26	3,5	TE	O	3,5		3,5
	14b : Femtosecond laser pulses: properties, characterization and manipulation	10	4		14	2,5	TE	O	2,5		2,5
TOTAL UE		**28**	**12**		**40**	**6**			**6**		**6**

Brief overview

The course is related to the fundamental concepts and applications of ultra-short femtosecond) lasers. In the first part, the linear and nonlinear optical phenomena encountered in the propagation of an intense and ultra-short laser pulse are described. We derive simple formulas for evaluating spatial and temporal pulse distortions depending on the input energy of the laser and the material media. We next derive simple analytical models developed within the framework of perturbation theory. They provide useful tools for the description of femtosecond processes like, for instance, wave packet analysis measured though pump-probe techniques, production of terahertz radiations, photon echoes, parametric generation of the new wavelengths, and CARS spectroscopy.
The second part deals with the characterization and manipulation of ultrashort laser pulses. It is dedicated to the characterization of femtosecond pulses and how to extract some specific and important parameters: energy, spectrum, temporal shape, and wavefront. We next focus on the shaping of laser pulses in spatial and time domain. Applications and possibilities opened in the context of coherent control will be then discussed.

UE15	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PrE	Total coef
Nano biosciences	Nanobiomodelling	20		20	40	6	TE/PrE	O	3	3	6
TOTAL UE		**20**		**20**	**40**	**6**			**3**	**3**	**6**

Brief overview

Lecture : Macromolecules (proteins & complexity of the biological nanoworld) / Atomistic modelisation (Hartree-Fock, DFT, Force Fields) / Molecular dynamics and normal mode analysis / Monte Carlo methods.

Practical : Numerical applications (Practical sessions using professional sofwares : Gaussian, Gromacs, VMD, LAMMPS) and individual project**.**

UE 16	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE		Total coef
Advanced Photonics	16a : Non-linear fiber optics	16	4		20	2,5	TE	O	2,5		2,5
	16b : Non-linear dynamics & fiber lasers	10			10	1	TE	O	1		1
	16c : Advanced nonlinear and ultrafast fibre optics	10			10	1	TE	O	1		1
	16d : Photonic glasses and optical fibers	10			10	1	TE		1		1
TOTAL UE		**46**	**4**		**50**	**5,5**			**5,5**		**5,5**

Brief overview

The first part aims at introducing the fundamental concepts governing the propagation of short pulses in dispersive and nonlinear media. In particular, it shows that the interaction between a short optical pulse and a nonlinear dielectric material gives rise to a wide variety of fascinating physical phenomena such as self-phase modulation, four-wave mixing, solitons, modulational instabilities, similaritons, rogue waves, shock waves, polarization attraction and supercontinuum. Very general concepts are mainly illustrated by examples of modern high speed optical telecommunications.
We next cover advanced topics relevant to the physics and applications of nonlinear ultrafast optics, including: Ultrashort pulses - description and techniques for characterisation, particularly frequency resolved optical gating; fibre frequency conversion processes including supercontinuum generation and applications; nonlinear localisation effects and optical rogue waves.
We highlight some of the key applications of advanced photonics for the industry, with a particular emphasis on integrated laser sources, advanced components, optical sensors, and photonic glasses.

UE 17	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE		Total coef
Quantum Technologies	17a : Quantum engineering	4		10	14	1,5	TE	O	1,5		1,5
	17b : Quantum control	10	4		14	1,5	TE	O	1,5		1,5
	17c : Quantum information	10	2		12	1,5	TE	O	1,5		1,5
TOTAL UE		**24**	**6**	**10**	**40**	**4,5**			**4,5**		**4,5**

Brief overviews

Quantum engineering and quantum information

This course studies the concepts and techniques of quantum information, quantum computation and, more generally, of quantum technologies. They encompass a family of processes that use quantum effects to produce results that are not possible or more difficult with classical physics. In quantum computation quantum mechanics is used to design algorithms that achieve certain results much faster then classical algorithms.

Program:
– Classical and quantum information, bits and qubits, entangled states
– Quantum technologies: quantum random number generators, quantum cryptography
– Quantum computation: quantum gates, quantum algorithms
– Example of physical systems: trapped ion quantum computer, superconducting quantum computing
– Quantum Network with singles photons
Practical works: Single-photon generation and detection / Hong–Ou–Mandel effect

Quantum control

We present the state-of-the-art techniques of optimal control for quantum dynamics and quantum control. We apply them in different examples coming from Nuclear Magnetic Resonance, molecular dynamics and quantum information science. This course covers all the current topics of optimal control theory such as geometric methods and numerical algorithms.

UE18	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE		Total coef
Atomic & Molecular dynamics	18a : Molecular dynamics	10			10	1	TE	O	1		1
	18b : Bose Einstein condensates	10			10	1	TE	O	1		1
	18c : Open quantum system	10			10	1	TE	O	1		1
TOTAL UE		**30**			**30**	**3**			**3**		**3**

Brief overviews

Molecular Quantum Dynamics

Time dependent quantum mechanics (superposition principles and wavepackets, example in coherent chemistry by femtosecond lasers, alignment of molecules, attospectroscopy of electronic wavepackets, condensed phase) / Molecular Hamiltonian (adiabatic representation, Born-Oppenheimer approximation, normal coordinates, photo absorption spectra, choice of the coordinates, Euler angles) / Wave packet propagation / Conical intersection (example in retinal).

Bose Einstein Condensates

The first part of this lecture demonstrates that the Gross-Pitaevskii equations that govern a non-linear two-level system describing a bath of atomic and molecular Bose-Einstein condensates can be derived exactly from the concept of 2:1 Fermi resonance usually introduces in molecular spectroscopy.
We first analyze the linear two-level system associated with the obtained non-linear one and determine exact analytical solution in the case of particular external excitation. Landau-Zener, Rosen-Zener, Demkov-Kunicke models are studied.
The non-linear two-level model is examined with a short overview of the Kerr third order nonlinearities.

Open Quantum Systems

Program: Closed and open quantum systems / The microscopic derivation of master equations / Application: quantum optical master equation for a two-level atom / Markovian vs non-Markovian dynamics / Decoherence and relaxation processes

UE 19	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE		Total coef
Nano-Optics	19a : Nano-photonics	18	6		24	3	TE	O	3		3
	19b : Nanophysics – Plasmonics	14	2		16	2	TE	O	2		2
TOTAL UE		**32**	**8**		**40**	**5**			**5**		**5**

Brief overview

1. Nano-photonics

Nano-photonics is the study of optical phenomena near or beyond the diffraction limit. The objective of this course is to present principles and applications of nano-photonics.

We first discuss light propagation in micronic and submicronic optical waveguides and give a short overview of integrated photonic devices. Next, we consider micro-optical cavities as a key concept for efficient light-matter interaction with applications such as controlled spontaneous emission, low threshold laser or sensitive biosensors.

A second part is devoted to optical nanosources. We briefly present single molecule spectroscopies methods with particular attention devoted to single photon source behavior.

We give some simple but key concepts for modelling nano-optical systems.

2. Nanophysics and plasmonics

The objective of this course is to present electron confinements effects on the optical properties of matter, mainly semi-conductor and metal materials. After a short review of the optical properties of bulk materials, we describe optical properties of their nanostructured counterparts.

In a first part, we consider semi-conductor nanocrystal (quantum dots) for which electron confinement below its mean free path (~10 nm) leads to quantum confinement effects at the origine of size-dependent optical spectra. Full engineering of quantum dots is therefore possible to achieve bright nanosources at any wavelength for various applications (biolabelling, quantum cryptography, …)

The second part of this course concerns plasmonics, or so-called optics of metal. It relies on the specific modes (surface plasmon polaritons) sustained by metallic nanoparticles (~dozens of nm) to control the light at a strongly subwavelength scale. Surface plasmon polaritons results from the coupling of a collective oscillation of the free electrons at the metal surface with an electromagnetic wave.

An important particularity of these modes is that their confinement can be down to the nanoscale (that is deeply sub wavelength) although at the price of losses. In this part, we introduce the concept of delocalized and localized plasmons as well as current (surface enhanced spectroscopies, biosensing) or expected (integrated photonics devices, optical nanoantennas,…) applications.

Related practical works: Surface plasmon waves, Optical tweezers

TOTAL S3	**180**	**30**	**30**	**240**	**30**			**27**	**3**	**30**

FOURTH SEMESTER S4

UE20	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE	Total coef
Laboratory works	20a : Spectroscopy	2		8	10	1	PaE	O		1	1
	20b : Whispering gallery mode resonators	2		8	10	1	PaE	O		1	1
	20c : Surface plasmon waves	2		8	10	1	PaE	O		1	1
	20d : Optical tweezers	2		8	10	1	PaE	O		1	1
TOTAL UE		**8**		**32**	**40**	**4**				**4**	**4**

UE 21	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE	Total coef
French	French – Language & Culture		20		20	2	PaE	O		2	2
TOTAL UE			**20**		**20**	**2**				**2**	**2**

UE 22	discipline	L	E	P	Total	ECTS	Type exam Session 1	Type exam Session 2	Coef TE	Coef PaE	Total coef
Research training in laboratory	Internship					24	PaE			24	24
TOTAL UE						**24**				**24**	**24**