Semester 1-UE1: Quantum mechanics

A--Quantum physics
I. 2-state system

II. 1D wave mechanics

III. 3D wave mechanics, applications to spectroscopy

IV. Spins addition, applications to atomic and sub-atomic physics

Semester 1-UE2: Electromagnetism and radiation

A--Radiation
I. Fields created by particles in motion (synchrotron, bremsstralung)
II. Dipolar emission (spontaneous emission, radiation source, antenna,...)
III. Interaction atom and radiation (polarizability, diffusion, absorption)
IV. Thermal emission (black body, electron source,...)
V. Stimulated emission (Einstein coefficient, laser, coherence)

Semester 1-UE3: Statistical Physics

I. Mathematical tools:
Method of the Lagrange multiplicators and central limit theorem (notion of independent variables, conditional probability).
II. Random walk (discrete and continuous)
Limitations of the binomial, Poisson and normal laws
Notions of statistics, mean and mean deviation
Application to diffusion and advection phenomena

III. Statistical sets:
Postulates of statistical physics
– microcanonical sets – partition function - mean value and fluctuations - thermodynamic limit - derivation of classical thermodynamics - equipartition theorem – canonical and grand canonical sets, T-p – sets equivalence

IV. Gas kinetic theory :
Maxwell-Boltzmann distribution – state density of the mono atomic perfect gas – -

velocity distribution – mean velocity –pressure and state equation – mean free path – mean time of flight

V. Motion:
Fourier laws – Fick – Ohm- balance equations – microscopic and macroscopic views – diffusion coefficients (relation to the mean free path) 0 relation with the random walk
Out-of-equilibrium systems, linear response, fluctuation-dissipation theorem

Semester 1-UE4: Experimental and numerical physics

Semester 1-UE5: Initiation to Astrophysics

Motivation: the goal of this optional lecture is to introduce the main themes of modern astrophysics, insisting in the various physical processes at work.

I. The birth of modern astrophysics
- a brief history of astronomy and cosmology
- from astronomy to astrophysics
II. Sources of information in astronomy
- the different part of the electromagnetic spectrum
- the main emission processes
- measurements : photometry and spectroscopy, ground and space measurements
III. Scale and measurement of astronomical distances
- Stellar distances
- the scale of cosmic distances
- cosmological distances, redshift
- observational biases
IV. Stars, a dense medium
- stellar spectra and classification, HR diagram
- basics of stellar evolution
V. The interstellar medium, matter-radiation interaction
- basics of radiative transfert : definitions and basic equations
- the different phases of the interstellar medium
- continuous and nebular emission

VI. Galaxies and matter distribution in the Universe
- introduction to galaxies

- galaxies spatial distribution
- galaxies formation: the present paradigme

VII. Introduction to high-energy phenomena
- Introduction to X-rays and gamma-rays astronomy
- Quasars and galaxy active nuclei
- Gamma burst

VIII. Star companions, planetary systems
- the Solar system
- exo---planets

References:

*Astrophysics, decoding the cosmos:
Judith Irwin, Wiley
*Astrophysics in a nutshell, David Maoz, Princeton University Press
*Astrophysical Processes: the physics of astronomical phenomena, Bradt, Cambridge University press

Semester 2-UE1: Advanced statistical and quantum physics

I. Reminders of Maxwell-Boltzmann statistics
II. Quantum statistics and their classical limits
III. Bose-Einstein statistics and its applications (condensation, gas of photons, black body)
IV. The Fermi-Dirac statistics and its applications (white dwarf, gas of electrons and conduction)

Semester 2-UE2: Relativity, high energies, sub-atomic physics

A-Special relativity:
1. Galileo and Einstein relativity principles, Lorentz transformation, Minkowski space, quadrivectors
2. Cinematics and relativistic dynamics :
Energy and momentum, forces in relativity
3. Applications of energy and momentum conservation:
desintegrations, relativistic collisions, high-energy collisions

4. Additional mathematics :
Metric tensors, Lorentz group

5. Electromagnetism in the covariant formalism. Fields transformation.

B. Sub-atomic physics:

1. Summary of particle physics:
Fundamental interactions, elementary constituents of matter,
The main conservation laws
2. Atomic nucleus physics (basis): description of the nuclei, energetical aspects
3. The alpha, beta and gamma radioactivities. Reminders on radioactive decay laws.
4. Description of few nuclear reactions (fission, fusion), astrophysical and cosmological aspects (nucleosynthesis).

Semester 2-UE3: Atomic and molecular physics, spectroscopy

1. Introduction
a. Electromagnetic spectrum
b. Structure of the matter
c. Discrete processes, continuous processes
d. Few recent development of atomic and molecular physics
(lasers, astrophysics, harsh environments, NMR, atomic clocks, GPS,
Ultra-cold atoms, …)
2. Emission and absorption spectra
a. Line profiles
b. Optical spectroscopy, magnetic resonances,…
3. Spectral analysis of atoms
a. the hydrogen atom and hydrogenoid atoms
b. Many electrons atoms
c. Intensities and selection rules. Fine and hyperfine structures.
4. Molecular physics
a. the Born-Oppenheimer approximation
b. symmetry point groups theory
c. rotation, nuclear spin statistics
d. vibration of polyatomic molecules
e. electronic structure
5. Spectral analysis of molecules

Semester 2-UE4: Experimental and numerical physics

Semester 2--UE5: Initiation to astrochemistry, physical chemistry and reactivity

Motivations: This class proposes a physical chemical approach of reaction mechanism and deals with the kinetics of these reactions. Examples from astrochemistry are used throughout the lectures.

I. Thermochemistry
First principle
Entropy and second principle
Entropie and «third principle»
Free energy and free enthalpy
Chemical equilibrium and phase transitions

II. Chemical kinetics:
Chemical kinetics and rate laws
Reactional mechanisms
Catalysis

III. Reactivity
Main chemical functions
Main reaction classes (acide-base, nucleophilic addition, nucleophilic substitution,…)
Radical reactions and polymérisation
Photochemistry
Solids and surface chemistry
Problems of interstellar chemistry

V. Quantum calculations in chemistry
Reaction structures
Molecular dynamics

Bibliography:
Physical chemistry, Atkins et de Paula, 9th edition, Oxford press
Chimie Physique, Paul Arnaud, Dunod

Semester 2-UE6: Introduction to cosmology

Motivation: the goal of this optional lecture is to introduce general relativity and the subsequent main models of the Universe and tests in observational cosmology.

I. The main observations of the Universe.

1. Radiation and observations. The observables and their interpretation.
2. Distribution of the observed matter in the Universe.

The baryonic matter: direct and indirect observations

3. The dark matter and the dark energy
4. The three pillars of cosmology : galaxies recession, cosmological radiation, elementary particles and primordial nucleosynthesis

II. General relativity

1. Tensors calculations

Operators, frame transformations, Christoffel symbols, differential

2. Curve spaces

Metric tensors, geodesic tensors, curvature tensors, Einstein tensors

3. Einstein equations

The principles (equivalence, cosmological, Mach, general relativity, covariance).

Tensor

Energy-momentum

Complete formulation of the Einstein equations

III. The Friedmann--Lemaître models

1. Expression of the four-dimension metric dimension
2. Christoffel symbols. Ricci tensor. Scalar curvature.
3. Energie-momentum tensor and Einstein equations
4. Expression of the general relativity equations in the Robertson-Walker metric
5. Unvarying models at null cosmological constant

IV. Properties of the Friedmann--Lemaître models

1. Observational tests and evolution of the Universe

distances, age, Hubble constant, spectral shifts, deceleration parameters, scaling factors, time, energy density, temperature, entropy.

2. The standard model : successes and difficulties
3. Inflationary models

V. Introduction to the standard model

1. The new cosmological tests :anisotropy and cosmological background, baryonic acoustic oscillations, far supernova and gravitational shear
2. The cosmological parameters and precision cosmology.

Acceleration of the Universe.

3. The Universe contents :

baryons, dark matter, dark energy

4. Structure of the Universe:

Amplitude of fluctuations, spectral index, reionization epoch.

5. Formation of the first stars and galaxies.

Bibliography :

Astrophysique, physique des étoiles et évolution de l'univers, J. Heyvaert

Cosmologie primordiale, P. Peter & Jean-Philippe Uzan, Initiation à la cosmologie par Marc Lachièze-Rey

Introduction to Cosmology by Barbara Ryden.

Principles of Physical Cosmology by P. J. E. Peebles.

Observational cosmology by Stephan Serjeant

Cosmology by Michael Rowan-Robinson.

Spacetime and Geometry:

An Introduction to General Relativity by Sean Carroll