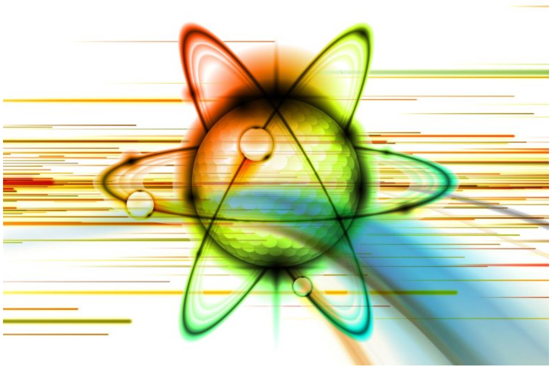
# General Physics



## OBJECTIVES

Radiation and ionization play an important role in many astrophysical situations. This course deals with two questions from theoretical physics: The first question is: 1) How do we model ionized gases, called plasmas? Students will learn to apply kinetic and fluid approaches in order to treat collective phenomena such as waves. The second question is more fundamental: 2) How do we nowadays model emission of photons by atom bounded electrons? Answering this question will lead us to quantum field theory, one of the most successful physical theories. Students will learn to quantize particle wave functions and Maxwell's equations in order to allow for quantum mechanical interactions of electrons and photons (light particles).

## EVALUATION

The main evaluation is an oral exam at the end of the lecture. During 30 minutes each student answers questions on topics discussed during the lecture and performs short computations. The second part of the evaluation consists in two short written exams that review calculations and reasoning from the lectures and the homeworks.

- Short written exam on quantum field theory (16.6%)
- Short written exam on plasma theory (16.6%)
- Oral exam on quantum field and plasma theory (66.6%)

## MAIN PROGRESSION STEPS

- `First half`: Plasma theory
- `Second half`: Quantum field theory

## BIBLIOGRAPHY & RESOURCES


- Edward G Harris, A Pedestrian Approach to Quantum Field Theory, Dover Publications, 2014
- Lancaster & S.J. Blundell: Quantum Field Theory for the Gifted Amateur, Oxford University Press 2015
- A. R. Choudhuri: The Physics of Fluids and Plasmas An Introduction for Astrophysicists, Cambridge 1998
- Dwight R. Nicholson, Introduction to Plasma Theory, Wiley, 1983


## CONTACT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# Content

The first part of this course, the plasma part, will bring us from kinetic theory to the fluid description. Kinetic theory is a statistical description of many particle systems that is directly build up on the Hamiltonian description of classical point mechanics. We will meet typical kinetic equations defined on the phase space. After that, we will derive the fluid description of a plasma from the kinetic one and discuss its approximations and limitations. The application focus will be on collective phenomena such as plasma waves and Landau damping.

The second part will bring us in touch with Quantum Field Theory (QFT). QFT is the today's best framework for modeling microscopic phenomena. It's application to electrodynamics is called Quantum electrodynamics (QED) and allows to compute phenomena such as emission and absorption of photons by atom bounded elections and pair production (interaction of a photon with matter resulting into creation of electron-positron pair). In view of the limited duration of the course and the huge complexity of QFT, a special pedagogy will be applied: Guided by one selected problem, *stimulated emission of photons*, only the necessary theory will be introduced. The focus will be on modeling. Let us sketch this approach: Stimulated emission is resulting from the interaction of photons with atom bounded electrons. We therefore need photons first. We will quantize the classical electro-magnetic field in order to find photons and reformulate (called second quantization) quantum mechanics in order to be able to create and destroy atom bounded electrons. The theoretical development will always be guided by the application necessities. In contrast to standard lectures on QFT, we will strive for the simplest model for our specific problem. For example we will mostly deal with non-relativistic quantum mechanics and only mention implications of relativistic equations. This way, we will none the less discover far reaching concepts such as Feynman diagrams and path integrals.

## Part. 1 - Plasma theory

by Holger Homann

- Kinetic description of neutral gases
  - The probability density function (PDF)
  - The Klimontovich equation
  - Collisions & the Maxwell-Boltzmann distribution
- Fluid description of neutral gases
  - Moment equations of the PDF
  - Compressible and incompressible fluids
- Introduction to plasmas
  - Single particle motion - drifts
  - Debye shielding
  - The two fluid model
  - Electromagnetic oscillations & waves
  - The Vlasov equation
  - Waves and Landau damping

## Part. 2 - Quantum field theory

by Holger Homann

- Introduction
  - Short recap of quantum mechanics: Schrödinger, Heisenberg, and the path integral formulation
  - The radiation problem
- Quantization of fields
  - Quantization of Maxwell's equations
  - Quantization of the harmonic oscillator
  - Second quantization of the Schrödinger equation
- Interaction of quantum fields
  - The interaction Hamiltonian
  - Perturbation theory
  - Emission and absorption of photons by atom bounded electrons
- Perspective on the relativistic theory