# COURSE DATA

| Data Subject | |
|---|---|
| **Code** | 34246 |
| **Name** | Statistical physics |
| **Cycle** | Grade |
| **ECTS Credits** | 4.5 |
| **Academic year** | 2023 - 2024 |

**Study (s)**

| Degree | Center | Acad. year | Period |
|---|---|---|---|
| 1105 - Degree in Physics | Faculty of Physics | 3 | Second term |
| 1928 - D.D. in Physics-Mathematics | Double Degree Program Physics and Mathematics | 5 | First term |
| 1929 - D.D. in Physics-Chemistry | Double Degree Program Physics and Chemistry | 4 | Second term |

**Subject-matter**

| Degree | Subject-matter | Character |
|---|---|---|
| 1105 - Degree in Physics | 7 - Thermodynamics and statistical physics | Obligatory |
| 1928 - D.D. in Physics-Mathematics | 5 - Quinto Curso (Obligatorio) | Obligatory |
| 1929 - D.D. in Physics-Chemistry | 4 - Cuarto Curso (Obligatorio) | Obligatory |

**Coordination**

| Name | Department |
|---|---|
| CERVERA MONTESINOS, JAVIER | 345 - Earth Physics and Thermodynamics |
| MAFE MATOSES, SALVADOR | 345 - Earth Physics and Thermodynamics |

# SUMMARY

This document is a guide to the *Statistical Physics* course, a third-year, 4.5-credits core course of the *Physics* degree and the Double Degrees in Physics-Chemistry and Physics-Mathematics, which is taught in the second quarter of the academic year. The subject has strong links with other courses of the degrees,

especially with *Thermodynanics* (*Statistical Physics* and *Thermodynamics* constitute the *Thermal Physics* core of the *Physics* degree), but also with *Mechanics*, *Waves*, *Atmospheric Physics*, *Quantum Physics* and *Solid State Physics*.

*Statistical Physics* has one primary objective: to show how the macroscopic properties of systems with many particles can be related to the microscopic characteristics of these particles making use of statistical methods. A strong emphasis will be placed on understanding the relationship between macroscopic behavior and microscopic characteristics.

The course is based on the Gibbs ensemble theory and the Boltzmann entropy. The applications covered include classical (Maxwell-Boltzmann) and quantum (Fermi-Dirac and Bose-Einstein) ideal gases as well as an introduction to systems of interacting particles and phase transitions based on the mean field approach.

No matter what area of physics you pursue in your career, the concepts (entropy, temperature, chemical potential, etc.) and tools (the partition function formalism, computer simulations, etc.) in this course are core knowledge for any physicist. Indeed, *Statistical physics* finds application in Nuclear Physics, Nanotecnology, Molecular Biophysics, Condensed Matter Physics, Quantum Optics, Earth Physics and Astrophysics.

The fundamental nature and applicability of statistical physics have been emphasized throughout the course. The concepts and tools developed are immediately applied to a broad range of multidisciplinary problems. This applied focus is expected to encourage the study of the subject and facilitate further application of the concepts to other fields of physics.

## PREVIOUS KNOWLEDGE

### Relationship to other subjects of the same degree

There are no specified enrollment restrictions with other subjects of the curriculum.

### Other requirements

Because Statistical Physics is a subject taught in the third, fourth or fifth year, the student is expected to be familiar with:

1. Fundamental concepts of Mechanics (phase space, equipartition theorem, etc.), Thermodynamics (macroscopic entropy, temperature, and chemical potential; thermodynamic equilibrium and processes; phase transitions, etc.) and Quantum Physics (quantum states and energy levels of simple systems, identical particles: fermions and bosons, etc.); basic concepts of Optics and Electromagnetism in condensed matter;

2. Introductory Applied Mathematics (elementary probability and combinatorics; basic elements of algebra and calculus) and simple Numerical Methods.

A brief mathematical review will be provided at the beginning of the course.

## OUTCOMES

### 1105 - Degree in Physics

- Knowledge and understanding of the fundamentals of physics in theoretical and experimental aspects, and the mathematical background needed for its formulation.
- To know how to apply the knowledge acquired to professional activity, to know how to solve problems and develop and defend arguments, relying on this knowledge.
- Problem solving: be able to evaluate clearly the orders of magnitude in situations which are physically different, but show analogies, thus allowing the use of known solutions in new problems .
- Theoretical understanding of physical phenomena: have a good understanding of the most important physical theories (logical and mathematical structure, experimental support, described physical phenomena).
- Be able to understand and master the use of the most commonly used mathematical and numerical methods.
- Modelling & Problem solving skills: be able to identify the essentials of a process / situation and to set up a working model of the same; be able to perform the required approximations so as to reduce a problem to an approachable one. Critical thinking to construct physical models.
- Basic & applied Research: acquire an understanding of the nature and ways of physics research and of how physics research is applicable to many fields other than physics, e.g. engineering; be able to design experimental and/or theoretical procedures for: (i) solving current problems in academic or industrial research; (ii) improving the existing results.
- Foreign Language skills: Have improved command of English (or other foreign languages of interest) through: use of the basic literature, written and oral communication (scientific and technical English), participation in courses, study abroad via exchange programmes, and recognition of credits at foreign universities or research centres.
- Learning ability: be able to enter new fields through independent study, in physics and science and technology in general.
- Communication Skills (written and oral): Being able to communicate information, ideas, problems and solutions through argumentation and reasoning which are characteristic of the scientific activity, using basic concepts and tools of physics.
- Students must have acquired knowledge and understanding in a specific field of study, on the basis of general secondary education and at a level that includes mainly knowledge drawn from advanced textbooks, but also some cutting-edge knowledge in their field of study.
- Students must be able to apply their knowledge to their work or vocation in a professional manner and have acquired the competences required for the preparation and defence of arguments and for problem solving in their field of study.

- Students must have the ability to gather and interpret relevant data (usually in their field of study) to make judgements that take relevant social, scientific or ethical issues into consideration.
- Students must be able to communicate information, ideas, problems and solutions to both expert and lay audiences.
- Students must have developed the learning skills needed to undertake further study with a high degree of autonomy.

## LEARNING OUTCOMES

Upon completion of the course, the students will understand and apply the basic principles and methods of *Statistical Physics* to problem solving in this and other related subjects. In particular, we will address the following objectives:

i) to describe the macroscopic behaviour of many particle systems in terms of the microscopic characteristics of these particles making use of *Gibbs' ensembles* and *Boltzmann entropy*;

ii) to develop problem solving procedures for *ideal classical and quantum gases* as well as for *systems of interacting particles*; and

iii) to understand the *connection between Statistical Physics and the other subjects taught in the Physics degree* as well as to know the basic syllabus in this field of Physics.

Other methodological objectives are:

i) to make assumptions and develop simple skills to solve practical problems;

ii) to know the order of magnitude and units characteristics of *Statistical Physics* as well as to present graphically the results;

iii) to recognise the multidisciplinary nature of most current problems in physics; and

iv) to use intuition and creativity, as well as to perceive the aesthetic dimension of physics (mathematical nature of the physical laws, role of geometry and symmetries, interconnections between apparently different problems, etc.), in the study of nature.

According to the above objectives, the student should achieve the following skills by the end of the course:

i) given a real problem, the student should construct a bridge between macroscopic properties and microscopic characteristics by using statistical methods. This bridge will be based on Gibbs' ensembles (partition function formalism) and Boltzmann entropy;

ii) when faced to a problem, the student should make simple assumptions, use order of magnitude tools, and identify the key characteristics of the system. To this end, the student should use intuition and creativity, subjected to experience and critical reasoning, in order to develop simple molecular models;

iii) the student should know the Fermi-Dirac and Bose-Einstein statistics, as well as the classical limiting case (Maxwell-Boltzmann), and their applications. The student should also be familiar with simple sytems of interacting particles, with emphasis on the mean field method and network models (Ising);

iv) the student should be ready to apply the general concepts to different systems allowing a simple statistical description as well as to recognise the connections of the subject with the other fields of physics.

Finally, other skills common to most subjects in the degree are: the use of physical units and approximation tools, the understanding of graphical information, the use of simple computer simulations, and, in general, the critical analysis of all physical problems.

## DESCRIPTION OF CONTENTS

### 1. Statistical description of macroscopic systems.

Combinatorial mathematics. Probability and distributions. Spin Systems. Phase space. Ensembles and basic postulates of Statistical Physics. Microcanonical ensemble: entropy and temperature. Boltzmann entropy. Entropy and irreversibility.

### 2. Partition function.

Boltzmann factor and partition function. Canonical ensemble, average values and fluctuations. Application to the ideal gas. The equipartition theorem. Classical limit. Gibbs factor and grand partition function. Grand canonical ensemble, average values and fluctuations. Statistical ensemble equivalence.

### 3. Ideal gases. Classical and quantum study.

Fermi-Dirac and Bose-Einstein distributions. Bose-Einstein Condensation. Classical limit: Maxwell-Boltzmann distribution. Electron gas. Photon gas.

### 4. Particle interactive systems.

The configurational partition function. Real gases and interaction potentials. The mean field approach: van der Waals fluid. The Ising Model. Monte Carlo simulations.

## WORKLOAD

| ACTIVITY | Hours | % To be attended |
|---|---|---|
| Theory classes | 38,00 | 100 |
| Tutorials | 7,00 | 100 |
| Study and independent work | 37,50 | 0 |
| Preparation of practical classes and problem | 30,00 | 0 |
| **TOTAL** | **112,50** | |

## TEACHING METHODOLOGY

**Classroom activities: 40%**

**Theoretical and practical lectures** address the conceptual and formal aspects of the subject and present a set of problems as applications of the theoretical concepts. They are based mainly on classroom lectures allowing continuous dialogue with students and make use of teaching tools as experimental demonstrations, animations or videos, graphical representation of the solutions to problems, projections and other presentations.

**Tutorial sessions** in small working groups are focused on student individual work and require his/her active participation. These sessions are intended to clarify doubts concerning the theoretical concepts, problem solving, reinforcement in areas of great difficulty, and other questionnaires. Conceptually relevant experimental demonstrations can also be presented. All activities are focused on the continuous evaluation and verification of student progress in the field.

**Student's personal work: 60%**

- Study of the theoretical lectures

- Problem solving, multiple choice questions, and presentations (individually or in small groups)

- Individual tutorials are devoted to specific queries on student's doubts. Students are expected to ask help concerning any difficulty found in the study of theory and solution of the problems. Discussion of other topics of interest and queries on relevant bibliography are also possible.

You will find more specific information on the methodology of the subject in the *Aula Virtual* website.

## EVALUATION

Course evaluation and marking students work is divided in two blocks:

1. **Written examinations**: the first part will assess the understanding of the conceptual and theoretical formalism of the subject. Specific sections of the theoretical lectures as well as simple conceptual and numerical questions will be considered. The second part of the examination will verify the student ability in problem solving as well as assess his/her critical reasoning. In particular, the discussion and appropriate justification of the results obtained will be considered for full marking.

2. **Continuous progress monitoring of student work**: this part of the evaluation process will assess the personal work presented by students. Oral presentation of problems solved by students as well as other methods involving interaction between students and lecturers will be considered.

COMMENTS:

The student is offered two routes to pass the course:

1. Assessment of continuous monitoring plus examination: it is based on the two evaluation blocks mentioned above. In accordance with the criteria established by the Bachelor's Degree in Physics Committee (CAT), the student’s final mark will be the maximum between:

    a. 70% examination mark + 30% continuous monitoring mark (provided that the examination mark is not lower than 4 out of 10).

    b. 100% examination.

2. Examination: the final mark will be that obtained in the examination.

The student will find more detailed information on the evaluation of the subject in the Aula Virtual website.

## REFERENCES

### Basic

- S. Mafé y J. Cervera, Apuntes + Problemario de Física Estadística, Aula Virtual de la Universitat de València.
- S. Mafé; J. de la Rubia, Manual de Física Estadística, Servei de Publicacions de la Universitat de València, 1998.
- R. Baierlein, Thermal Physics, Cambridge Univ. Press, 1999.
- D. V. Schroeder, An Introduction to Thermal Physics, Addison-Wesley 2000.

### Additional

- J. L. Castillo y P. L. García, Introducción a la Termodinámica Estadística mediante problemas, Sanz y Torres, 1994.
- C. Fernández Tejero y J. M. Rodríguez Parrondo, 100 Problemas de Física Estadística, Alianza Ed., 1996.
- "http://mw.concord.org/modeler/" Molecular Workbench. Visual, Interactive Simulations for Teaching and Learning Science, The Concord Consortium, 2013.
- "http://phet.colorado.edu/" Interactive Simulations. University of Colorado at Boulder, 2017.
- H. Gould y J. Tobochnik, Statistical and thermal physics: with computer applications, Princeton University Press, 2010.
- R. K. Pathria y Beale P.D., Statistical Mechanics, Elsevier Science, 1996.