Statistical Physics

Code: 100174
ECTS Credits: 6

2024/2025

Degree	Type	Year
2500097 Physics	OT	4

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Teachers

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Teaching groups languages

You can view this information at the end of this document.

Prerequisites

There are no official prerequisites. However, it is assumed that students have knowledge in Thermodynamics and notions of Statistical Mechanics, especially the concepts and methods of ensemble theory, and basic knowledge of quantum mechanics and electromagnetism.

Objectives and Contextualisation

The overall objective of the course is to present different methods of statistical physics and show a wide range of applications. It gives the students an interdisciplinary view of Statistical Physics, with applications ranging from elementary particles to astrophysics, through materials physics, and areas outside the classical realm of Physics, such as biological and social systems.

• Specific objectives:
1) To know ensemble theory and be able to apply it to the study to ideal and interactive systems, including phase transitions and critical phenomena.
2) To know the basic theory of stochastic processes and be able to apply it to simple cases
3) Understanding the elementary kinetic theory of transport processes and be able to apply it to dilute gases and quantum gases
4) To know simulation methods for the analysis of complex systems: Monte Carlo (Metropolis), Brownian dynamics, Langevin dynamics

Competences

- Apply fundamental principles to the qualitative and quantitative study of various specific areas in physics
- Be familiar with the bases of certain advanced topics, including current developments on the parameters of physics that one could subsequently develop more fully
- Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, and before both specialist and general publics
- Develop the capacity for analysis and synthesis that allows the acquisition of knowledge and skills in different fields of physics, and apply to these fields the skills inherent within the degree of physics, contributing innovative and competitive proposals.
- Formulate and address physical problems identifying the most relevant principles and using approximations, if necessary, to reach a solution that must be presented, specifying assumptions and approximations
- Know the fundamentals of the main areas of physics and understand them
- Make changes to methods and processes in the area of knowledge in order to provide innovative responses to society's needs and demands.
- Take account of social, economic and environmental impacts when operating within one's own area of knowledge.
- Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
- Use mathematics to describe the physical world, selecting appropriate tools, building appropriate models, interpreting and comparing results critically with experimentation and observation
- Work independently, have personal initiative and self-organisational skills in achieving results, in planning and in executing a project
- Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

Learning Outcomes

1. Analyse biological systems using techniques of statistical physics.
2. Analyse interacting particle systems through simple models and simulation techniques.
3. Analyse random paths and use them to model real systems.
4. Analyse simple stochastic equations.
5. Analyse stochastic processes and use them to model physical systems and in other ambits.
6. Apply Fermi statistics to a degenerate gas of relativistic particles.
7. Apply different techniques of simulation for the study of systems with interaction to simple cases: Monte Carlo, molecular dynamics, Brownian dynamics and Langevin dynamics.
8. Apply statistical physics to interacting particle systems.
9. Apply the concept of frozen and wake degrees of freedom to predicting the heat capacity of gases.
10. Apply the kinetic theory of quantum gases and predict the thermal conductivity of metals and insulators.
11. Applying the tools of kinetic theory to describe transport processes.
12. Communicate complex information in an effective, clear and concise manner, either orally, in writing or through ICTs, in front of both specialist and general publics.
13. Correctly apply the theory of ideal systems for groups of distinguishable and indistinguishable particles.
14. Deduce classical and quantum statistics and apply them correctly to different systems.
15. Define characteristic magnitudes to discern the relevance of different mechanisms.
16. Describe and Analyse the Bose-Einstein condensation.
17. Describe and analyse the models of Weiss, Landau and Ising for magnetic systems with interaction.
18. Describe and quantify Brownian motion.
19. Describe biological systems using techniques of statistical physics.
20. Describe ion transport in passive and active membranes, quantifying it for certain simple models.
21. Describe the basis of Brownian motors.
22. Describe the concept of stochastic process and apply their basic techniques to the description of physical systems.
23. Describe the most important statistical groups and the assumptions underlying the theory of groups.
24. Describe the thermal denaturation of DNA and quantify it for certain simple models.
25. Determine the fraction of molecules adsorbed on a macromolecule in simple models.

26. Determine the magnetic response of a superparamagnetic nanoparticle and the behaviour in a dispersion of these particles.
27. Distinguish between mean-field models and those that are not.
28. Identify situations in which a change or improvement is needed.
29. Identify the social, economic and environmental implications of academic and professional activities within one's own area of knowledge.
30. Qualitatively and quantitatively describe the behaviour of system close to critical points and the concept of universality.
31. Qualitatively and quantitatively predict the macroscopic behaviour of ideal magnetic systems for classical and quantum moments.
32. Quantify the contribution of each internal degree of freedom in the heat capacity of a gas in diatomic molecules.
33. Reason the temperature dependence of heat capacity for electrons and the crystalline network.
34. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
35. Use mean-field approaches to describe physical systems.
36. Work independently, take initiative itself, be able to organize to achieve results and to plan and execute a project.
37. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

Content

1. Stochastic processes
1.1. Introduction. Brownian Motion
1.2. Random Walks
1.3. Langevin equation
1.4. Fokker-Planck equation
1.5. Brownian motors

2. Summary of statistical mechanics
2.1 Ensemble theory. Postulates
2.2 Microcanonical ensemble
2.3 Canonical ensemble.
2.4 Continuos and discrete energy spectra.
2.5 Classical and quantum limits. Thermal wavelength
2.6 Maxwell-Boltzmann statistics
2.7 Theorem of equipartition of energy

3. Ideal gas of diatomic molecules
3.1 The problem of heat capacity in gases
3.2 Internal degrees of freedom
3.3 Contribution of each degree of freedom to heat capacity
3.4 Poliatomic molecules

4. Magnetic systems
4.1 Spin ½ systems
4.2 Quantum paramagnetism
4.3 Classical paramagnetism
4.4 Superparamagnetism

5. Biological systems
5.1 Saturation curve of myoglobin. Langmuir isotherm
5.2 DNA denaturation

6. Interacting systems
6.1 Solid, liquids, gases.
6.2 Magnetic systems. Ferro-paramagnetic transition
6.3 Weiss model
6.4 Landau model
6.5 Ising model
6.6 Critical points. Universality
6.7 Monte Carlo methods. Metropolis algorithm

7. Ideal quantum gas
7.1 Distinguishable and indistinguishable particles
7.2 Microstates in quantum statistical mechanics
7.3 Calculation of grand canonic partition functions in an ideal gas
7.4 Quantum Statistics: Bose-Einstein and Fermi-Dirac Statistics
7.5 Bosons and fermions ideal gases

8. Bosons and fermions ideal gases
8.1 Bosons gases.
Photons. Black-body radiation
Phonons. Heat capacity of the crystal lattice
Bose-Einstein condensation
8.2 Fermion gases.
Heat capacity of electrons
Degeneration pressure of fermions

9. Elementary kinetic theory of gases
9.1. Gas diluted in equilibrium
9.2. Transport coefficients
Thermal conductivity of the crystal lattice and electrons

Activities and Methodology

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Exercises classes	16	0.64	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36
Theory Classes	33	1.32	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 35
Type: Supervised			
Delivery activities	10	0.4	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 37
Type: Autonomous			
Group work	25	1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35, 37

Personal work	57	2.28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 37

Master classes
The teacher will explain the content of the syllabus with the support of audiovisual material that will be available to students in the Virtual Campus web in advance, at the beginning of each course topic. It is recommended that students have this material at hand in order to follow the classes more easily. Classes combine the use of slides with developments on the board. Student participation in class will be promoted. The teacher will solve some practical examples to illustrate the theory.

Problem Classes
The teacher will solve selected problems from the list that they will find on the Virtual Campus and students will solve in class some problems in groups. In previously established dates, students in groups of 3 students will deliver resolved problems (one delivery per group).

Some sessions will be devoted to the use of simulation tools. Students will make a simple code and analyze simulation results.

If a group believes that there is a participant who has not worked reasonably equitable, it can be expelled from the group.

Annotation: Within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

Assessment

Continous Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Exercises and projects delivery	25%	0	0	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37
Partial Exams	75%	6	0.24	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35, 36
Resit Exam	75%	3	0.12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35, 36

1. Group work. It consists of solving selected exercises (in groups of 3 students) and some numerical simulations (in groups of 2 students). The score in this evaluation group represents 25% of the final (individual) grade

2. Individual assesment: this part assess individually scientific and technical knowledge of the subject achieved by the student, as well as its capacity for analysis, synthesis and critical reasoning. It will consist of:
Partial exams: 75%.
Resit exam: 75%. It includes all the syllabus of the course (not each partial separately).

Important: In order to average the grade of the exam with the other 25%, the average score of the exams must be greater than or equal to 4 in a scale of 10.

Resit exam: in order to attend the retake exam the student must have attended the two partial exams.

Those students who pass the partial tests can attend the resit exam to improve the grade. If the score got in the resit exam is up to 1.5 points lower than the average partials score, it is kept the average partials score (unless it is less than 4). If you think you will not upgrade the score, you may not deliver the exam.

Not Assessable: The Not Assessable qualification will be obtained if the student does not attend any exam.

UNIQUE ASSESSMENT

Students who have accepted the single assessment modality will have to take a final test which will consist of a written exam that including problem solving and some theoretical questions. This test will take place on the same day as the second continuous assessment exam. Upon completion, students will deliver all deliverables and simulation reports.

The final grade is obtained in the same way as the continuous assessment: the exam weighs 75% of the final grade and the deliveries 25%.

Important: To average with the other 25% of the grade, the score of the exam must be 4 out of 10 or higher.

If the exam grade does not reach 4 or the final grade does not reach 5, the student has another opportunity to pass the subject through the recovery exam that will be held on the date set by the coordination of the qualification. The same recovery system will be applied as for the continuous assessment: the part of the grade corresponding to theory and problems (75%) can be recovered, the deliveries do not.

Bibliography

Basic
- R.K. Pathria, Statistical Mechanics, (3rd Ed), Academic Press, 2011.
- K. Huang, Introduction to statistical physics,Boca Raton, CRC Press, 2001
- F. Reif, Física estadística. Barcelona, Reverté, 1969
- J. Ortín, J.M. Sancho, Curso de Física Estadística, Barcelona, Publicacions i Edicions de la Universitat de Barcelona, cop. 2006

Advanced
- D. A. McQuarrie, Statistical Mechanics. University Science Books, cop. 2000.
- D.J. Amit and Y. Verbin, Statistical Physics: An introductory course. Singapore, World Scientific, 1995.
- D. Chandler, Introduction to Modern Statistical mechanics. Oxford, New York, 1987
- C. Fernandez, J.M. Rodríguez Parrondo, 100 problemas de Física Estadística, Madrid, Alianza, 1996
- R. Kubo. Statistical Mechanics: an advanced course with problems and solutions. Amsterdam, North-Holland, 1990.
- K.A. Dill and S. Bromberg. Molecular driving forces: Statistical Thermodynamics in Biology, Chemistry, Physics, and Nanoscience. Garland Science; 2nd edition, 2010.

Specialized articles and Web links
You will find them in the Virtual Campus

Software

There is no specific software for the subject

Language list

Name	Group	Language	Semester	Turn
(PAUL) Classroom practices	1	Catalan/Spanish	first semester	afternoon
(TE) Theory	1	Catalan/Spanish	first semester	afternoon