Universitat Autònoma de Barcelona

2018/2019

Statistical Physics

Code: 100174
ECTS Credits: 6

Degree	Type	Year	Semester
2500097 Physics	OT	4	0

Contact

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Use of languages

Principal working language: spanish (spa)

Some groups entirely in English: No

Some groups entirely in Catalan: No

Some groups entirely in Spanish: No

Teachers

Xavier Alvarez Calafell

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.

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) Know ensemble theory and be able to apply it to the study to ideal and interactive systems, including phase transitions and critical phenomena.

2) 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 gases and dilute quantum gases

4) Know simulation methods for the analysis of complex systems: Monte Carlo, Brownian dynamics, Langevin dynamics

Skills

- 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 critical thinking and reasoning and know how to communicate effectively both in the first language(s) and others
- Develop independent learning strategies
- 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
- Generate innovative and competitive proposals for research and professional activities.
- Know the fundamentals of the main areas of physics and understand them
- Respect the diversity and plurality of ideas, people and situations
- 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. Develop critical thinking and reasoning and communicate ideas effectively, both in the mother tongue and in other languages.
28. Develop independent learning strategies.
29. Distinguish between mean-field models and those that are not.
30. Generate innovative and competitive proposals for research and professional activities.
31. Qualitatively and quantitatively describe the behaviour of system close to critical points and the concept of universality.
32. Qualitatively and quantitatively predict the macroscopic behaviour of ideal magnetic systems for classical and quantum moments.
33. Quantify the contribution of each internal degree of freedom in the heat capacity of a gas in diatomic molecules.
34. Reason the temperature dependence of heat capacity for electrons and the crystalline network.
35. Respect diversity in ideas, people and situations.
36. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments
37. Use mean-field approaches to describe physical systems.
38. Work independently, take initiative itself, be able to organize to achieve results and to plan and execute a project.
39. 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

1. 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

1. 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

1. 4.1 Spin ½ systems
   4.2 Quantum paramagnetism
   4.3 Classical paramagnetism

5. Biological systems

1. 5.1 DNA denaturation
   5.2 Biological membranes
   5.3 Saturation curve of myoglobin. Langmuir isotherm

6. **Interacting systems**

1. 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.
2. 6.7 Monte Carlo methods. Metropolis algorithm

7. **Ideal quantum gas**

1. 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**

1. 8.1 Bosons gases.
   Photons. Black-body radiation
   Phonons. Heat capacity of the crystalline network
   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 crystalline network and electrons

Methodology

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. 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.

Activities

Title	Hours	ECTS	Learning outcomes
Type: Directed			
Master Classes	30	1.2	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 37
Problems classes	15	0.6	3, 4, 5, 1, 2, 13, 9, 6, 8, 10, 11, 12, 15, 22, 21, 20, 17, 16, 18, 24, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 38, 37
Type: Supervised			
Delivery activities	10	0.4	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 38, 39, 37
Type: Autonomous			
Group work	25	1	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 15, 21, 20, 17, 16, 18, 24, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 39, 37
Personal work	61	2.44	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 38, 39, 37

Evaluation

1. Group work. It will consist 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 evaluation: 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 written tests: 75%. Those who do pass partial tests can go to the final exam to upgrade.
Retake exam: 75%

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.

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

Evaluation activities

Title	Weighting	Hours	ECTS	Learning outcomes
Exercise and projects delivery	25%	0	0	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 35, 38, 39, 37
Final Exam	75%	3	0.12	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 38, 37
Partial Exams	75%	6	0.24	3, 4, 5, 1, 2, 13, 7, 9, 6, 8, 10, 11, 12, 14, 15, 22, 21, 20, 17, 16, 18, 24, 23, 31, 19, 28, 27, 25, 26, 29, 30, 32, 33, 36, 34, 38, 37

Bibliography

· Basic

- R.K. Pathria, *Statistical Mechanics*, (2ª Ed), Oxford, Butterworth Heinemann, 1996.

- 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 mechanic*s. 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 Course