COURSE GUIDE

Statistical Physics (2671134)

Approval date:
Departamento de Física Aplicada: 19/06/2023
Departamento de Electromagnetismo y Física de la Materia: 21/06/2023

Grado (Bachelor's Degree)	Grado en Física	**Branch**	Sciences
Module	Termodinámica y Física Estadística	**Subject**	Física Estadística

Year of study	3º	**Semester**	2º	**ECTS Credits**	6	**Course type**	Compulsory course

PREREQUISITES AND RECOMMENDATIONS

Having completed the courses of Thermodynamics, Mathematical Methods of Physics, Mechanics and Waves, and Quantum Physics. Prior knowledge of Analytical Mechanics is recommended.

BRIEF DESCRIPTION OF COURSE CONTENT (According to the programme's verification report)

1. Fundamental postulates of Statistical Physics.
2. Gibbs ensembles.
3. Statistical models and thermodynamic properties of gases, paramagnetic systems, and radiation.
4. Fermi and Bose gases

SKILLS

GENERAL SKILLS

- CG01 - Skills for analysis and synthesis
- CG02 - Organisational and planification skills
- CG03 - Oral and written communication
- CG06 - Problem solving skills
- CG07 - Team work
- CG08 - Critical thinking
- CG10 - Creativity
- CG13 - Knowlegde of a foreign language

SUBJECT-SPECIFIC SKILLS

- CE01 - Knowing and understanding the phenomena of the most important physical

theories
- CE02 - Estimating the order of magnitud in order to interpret various phenomena
- CE05 - Modelling complex phenomena, translating a physical problem into mathematical language
- CE07 - Transmitting knowledge clearly, both in academic as in non-academic contexts
- CE09 - Applying mathematical knowlegde in the general context of Physics

LEARNING OUTCOMES

The course objectives and learning outcomes are:

1. To assimilate the distinctive features of microscopic and macroscopic levels of description.
2. To develop a deep understanding of the fundamentals of Statistical Physics.
3. To use probability, ensembles, and partition function concepts proficiently.
4. To understand the different statistical ensembles and their connections with thermodynamic potentials.
5. To obtain thermodynamic properties of gases and solids from simple classical and quantum microscopic models.
6. To learn basic computational techniques for the study and analysis of particle systems in thermodynamic equilibrium, either through laboratory practices or by conducting projects (seminars).

PLANNED LEARNING ACTIVITIES

THEORY SYLLABUS

Lesson 1: INTRODUCTION, FUNDAMENTALS, AND POSTULATES. Introduction and brief historical notes. Classical microscopic description. Macroscopic description and observables. Concept of ensemble and Liouville's theorem. Quantum formulation and quantum Liouville's theorem. Postulates of statistical physics. **Appendices**: Irreversibility: the arrow of time. Dynamical systems and ergodic theory. Construction of ensembles: Boltzmann's statistical physics. Statistical physics out of equilibrium.
Lesson 2: THEORY OF ENSEMBLES. Microcanonical ensemble and entropy. Canonical ensemble. Partition function. Stability. Grand canonical ensemble. **Appendices**: Quantum effects in the classical limit.
Lesson 3: FLUCTUATIONS, EQUIVALENCE OF ENSEMBLES, AND THERMODYNAMIC LIMIT. Motivation. Canonical fluctuations of energy. Grand canonical fluctuations in the number of particles. Thermodynamic limit. **Appendices**: Grand canonical fluctuations of energy.
Lesson 4: CLASSICAL IDEAL SYSTEMS. Definition. Boltzmann gas. Canonical partition function and thermodynamics of the Boltzmann gas. Molecular structure: rotational, vibrational, and electronic degrees of freedom. **Appendices**: The rigid rotor in quantum mechanics.
Lesson 5: INTRODUCTION TO THE IDEAL QUANTUM GAS. Introduction. Quantum indistinguishability: bosons and fermions. Ideal quantum systems. Equation of state of the ideal quantum gas. Weakly degenerate quantum ideal gas.
Lesson 6: DEGENERATE FERMIONIC SYSTEMS. Degenerate ideal fermion gas: Fermi energy. Equation of state at low temperatures. Specific heat. Relativistic degenerate fermion gas: Chandrasekhar model of white dwarf stars. Statistical model of the atom: Thomas-Fermi model. Completely degenerate relativistic fermion gas. Electronic gas in metals. Validity range of the ideal fermion gas.

Lesson 7: DEGENERATE BOSONIC SYSTEMS. Degenerate ideal boson gas. Bose-Einstein condensation. Statistical physics of photon gas: thermal radiation. Superfluidity of liquid helium.
Lesson 8: SOLIDS. Small oscillations. Normal modes. Phonons. Systems of independent harmonic oscillators. Specific heats. Dulong-Petit law. Debye model. Born-Karman model.
Lesson 9: MATTER AND MAGNETIC FIELD. Introduction. Diamagnetism and paramagnetism. Bohr-van Leeuwen theorem. Paramagnetism: dipoles in a magnetic field. Paramagnetism: Pauli's fermion model. Landau diamagnetism. Ferromagnetism: mean-field Ising model. Introduction to critical phenomena.
Proposed Seminars:

- Introduction to the statistical physics of liquids.
- Stability of matter.
- Superconductivity.
- Computational techniques in statistical physics: molecular dynamics and Monte Carlo method.
- Boltzmann equation.
- Takahashi gas.
- Kac gas. Deduction of the van der Waals equation.
- Magnetism in metals.
- Negative temperatures.
- Yang-Lee theory.
- 1D and 2D Ising model. Critical point, scale invariance, critical exponents. Universality.

In addition to the theoretical syllabus, students may be proposed to undertake practical or specific tasks with a significant computational component. In these tasks, students will have to carry out a study (preferably in teams) of a particle system in equilibrium, applying the theoretical techniques acquired during the course.

PRACTICAL SYLLABUS

RECOMMENDED READING

ESSENTIAL READING

Theory Books

1. PATHRIA, R.K., Statistical Mechanics (2nd edition), Butterworth-Heinemann, Oxford (1996).
2. BALESCU, R., Equilibrium and Non-equilibrium Statistical Mechanics,Wiley & Sons, New York (1975).
3. McQUARRIE, D.A., Statistical Mechanics, Harper & Row, New York (1976).
4. LE BELLAC, M., MORTESSAGNE, F. y BATROUNI, G.G., Equilibrium and non-equilibrium statistical thermodynamics, Cambridge University Press, Cambridge (2004).
5. BREY ABALO, J.J., DE LA RUBIA PACHECO, J. y DE LA RUBIA SÁNCHEZ, J., Mecánica Estadística, UNED, Madrid (2001).
6. CHANDLER, D., Introduction to Modern Statistical Mechanics, Oxford University Press, Oxford (1987).

Problem Books

1. DALVIT, D.A.R., FRASTAI, J. y LAWRIE, I.D., Problems on Statistical Mechanics, Institute

of Physics Publishing, Bristol (1999).
2. YUNG-KUO, L., Problems and Solutions on Thermodynamics and Statistical Mechanics, World Scientific Publishing, Singapur (1990).
3. FERNÁNDEZ TEJERO, C. y RODRÍGUEZ PARRONDO, J.M., 100 problemas de Física Estadística, Alianza, Madrid (1996).
4. KUBO, R., Statistical Mechanics: an Advanced Course with Problems and solutions, 2ND edition, North-Holland, Amsterdam (1999).

COMPLEMENTARY READING

Additional complementary bibliography:

1. VINAY AMBEGAOKAR, Reasoning About Luck: probability and its uses in physics,Cambridge University Press (1996).
2. Daniel J. Amit and YOSEF VERBIN, Statistical Physics,World Scientific (1999). ISBN: 981-02-3476-7.
3. P. W. ATKINS, The Second Law,W. H. Freeman (1984).
4. RALPH BAIERLEIN, Thermal Physics,Cambridge University Press, New York (1999). Hardback: ISBN 0-521-59082-5; Paperback: ISBN 0-521-65838-1; Solutions Manual (for instructors): ISBN 0-521-65860-8.
5. RALPH BAIERLEIN, Atoms and Information Theory: An Introduction to Statistical Mechanics,Freeman (1971).
6. David S. Betts and Roy E. Turner, Introductory Statistical Mechanics,Addison-Wesley (1993).
7. R. BOWLEY AND M. SANCHEZ, Introductory Statistical Mechanics, second edition, Oxford University Press (2000). ISBN: 0-19-850576-0.
8. ANATOLY I. BURSHTEIN, Introduction to Thermodynamics and Kinetic Theory of Matter,Wiley (1996).
9. ASHLEY H. CARTER, Classical and Statistical Thermodynamics,Prentice Hall (2001). ISBN: 0-13-779208-5.
10. TEUNIS C. DORLAS, Statistical Mechanics, IOP Publishing (1999). ISBN: 0-7503-0540.
11. J. S. DUGDALE, Entropy and its Physical Meaning,Taylor & Francis (1996).
12. J. B. FENN, Engines, Energy and Entropy,W. H. Freeman (1982).
13. C. B. P. FINN, Thermal Physics,second edition, Chapman & Hall (1993).
14. ROBERT P. H. GASSER AND W. GRAHAM RICHARDS, Statistical Thermodynamics,World Scientific (1995).
15. GARROD, C., Statistical Mechanics and Thermodynamics, Oxford University Press, Nueva York (1995).
16. GREINER,W. NEISE, L. y STÖCKER, H., Thermodynamics and Statistical Mechanics, Springer, Nueva York (1995)
17. T. Guenault, Statistical Physics,second edition, Chapman & Hall (1995).
18. HILL, T.L., An introduction to Statistical Thermodynamics, Addison-Wesley, Massachusetts (1960).
19. HUANG, K., Statistical Mechanics 2nd edition, John Wiley & Sons, 1987, Nueva York.
20. E. ATLEE JACKSON, Equilibrium Statistical Thermodynamics(1968).
21. C. KITTEL AND H. KROEMER, Thermal Physics,second edition, W. H. Freeman (1980).
22. F. MANDL, Statistical Physics,second edition, John Wiley & Sons (1988).
23. THOMAS A. MOORE, Six Ideas That Shaped Physics: Unit T: Some Processes Are Irreversible,WCB/McGraw-Hill Paperback (July 1999). ISBN: 007043056X.
24. G. MORANDI, E ERCOLESSI, AND F NAPOLI, Statistical Mechanics: An Intermediate Course,2nd Edition, World-Scientific (2001),
25. GEORGE PHILLIES, Elementary Lectures in Statistical Mechanics,Springer-Verlag (2000).

26. F. REIF, Fundamentals of Statistical and Thermal Physics,McGraw-Hill (1965).
27. F. REIF, Statistical Physics, (Vol. 5 of Berkeley Physics Course),McGraw-Hill (1967).
28. W. G. V. ROSSER, An Introduction to Statistical Physics,John Wiley & Sons (1982).
29. DANIEL V. SCHROEDER, An Introduction to Thermal Physics,Addison-Wesley (2000).
30. F. W. SEARS AND G. L. SALINGER, Thermodynamics, Kinetic Theory and Statistical Thermodynamics,Addison-Wesley (1975).
31. M. SPRACKLING, Thermal Physics,AIP (1992). ISBN: 0-88318-919-4
32. KEITH S. STOWE, Introduction to Statistical Mechanics and Thermodynamics,John Wiley & Sons (1984).
33. FERNÁNDEZ TEJERO, C., y BAUS, M., Física Estadística del equilibrio. Fases de la materia, Aula documental de investigación. Madrid (2000).
34. CHANG L. TIEN, Statistical Thermodynamics,Hemisphere Publications (1985).
35. TODA, M., KUBO, R. y SAITO, N., Statistical Physics I. Equilibrium Statistical Mechanics, 2nd edition, Springer-Verlag, Nueva York (1995).
36. THOMPSON, C.J., Mathematical Statistical Mechanics, Princeton University Press, New Jersey (1972).

Research papers (for seminar preparation)

1. J.G. Kirkwood, Quamtum Statistics of Almost Classical Assemblies. Phys. Rev. 44, 31 (1933).
2. Elliot H. Lieb, The stability of matter, Rev. of Mod. Phys. 48, 553 (1976).
3. C.N. Yang y T.D. Lee, Statistical Theory of Equations of State and Phase Transitions. I. Theory of Condensation.Phys. Rev. **87**, 404 (1952).
4. T.D. Lee and C.N. Yang, Statistical Theory of Equations of State and Phase Transitions. II. Lattice Gas and Ising Model. Phys. Rev. **87**, 410 (1952).
5. D.A. Kurtze y M.E. Fisher, Yang-Lee edge singularities at high temperatures. Phys. Rev. B **20**, 2785 (1979).
6. T.D. Schultz, D.C. Mattis and E.H. Lieb, Two dimensional Ising Model as a Soluble Problem of Many Fermions. Rev. of Mod. Physics, 856 July (1964).
7. Elliot H. Lieb, Thomas-fermi and related theories of atoms and molecules. Rev. Mod. Physics, **53**, 603 (1981); ibid Rev. Mod. Physics, **54**311 (1982).
8. R.J. Tayler, Stellar Evolution, Rep. on Progr. in Physics, **31**, 167 (1968).
   H.A. Bethe, Supernova Mechanicsms, Rev. of Modern Physics, **62**, 801 (1990).
9. Corak et al., Atomic Heats of Cooper, Silver, and Gold from 1K to 5K Phys. Rev. 98, 1699 (1955).
10. P.C. Hohenberg, Existence of Long Range Order in One and Two Dimensions Phys. Rev. **158**, 383 (1967).
11. A.Widom, Superfluid Phase Transition in One and Two Dimensions, Phys. Rev. **176**, 254 (1968).
12. W.E. Lamb and A. Nordsieck, On the Einstein Condensation Phenomenon. Phys. Rev. **59**, 677 (1941).
13. J. Wilks, The Theory of Liquid He, Rep. on Progr. in Physics **20**, 38 (1957).

RECOMMENDED LEARNING RESOURCES/TOOLS

http://www.sc.ehu.es/sbweb/fisica/ Physics with Computer. Interactive Physics Course on the Internet. This website in Spanish provides a section dedicated to Statistical Physics, which includes 10 sections with their respective theoretical content. The most interesting feature of this website, however, is the ability to conduct virtual experiments (Java applications) to verify the validity of some laws of Statistical Physics.
http://stp.clarku.edu/simulations/ This website offers a collection of 28 Java applications on

Statistical Physics. It includes Monte Carlo simulations, Molecular Dynamics simulations, animations, and calculations that illustrate a wide range of physical principles and phenomena (particle motion, equilibrium, Boltzmann distribution, entropy, Lennard-Jones fluids, diffusion in solids, etc.)
https://ocw.mit.edu/courses/#physics This is a place to find undergraduate and graduate courses in Statistical Physics. It includes courses, lecture notes, solved problems, and a list of exams from previous years with their solutions.

TEACHING METHODS

- MD01 - Theoretical classes

ASSESSMENT METHODS (Instruments, criteria and percentages)

ORDINARY EXAMINATION DIET

ORDINARY EXAMINATION (continuous assessment mode)

- Students will take one or more exams, which may include theoretical, quantitative and problem-solving questions as well as demonstrations. The weighting corresponding to this exam-style assessment is 70%.
- The remaining 30%, corresponding to the student's autonomous work, may consist of resolution and submission of proposed problems, practical tests, development of individual or group projects, submission of reports/memos, or, if applicable, personal interviews with students, delivering short seminars, etc.
- A minimum grade of 3.5 out of 10 in the exam-style assessment (theoretical-practical exams) is required. The overall grade will therefore correspond to the weighted sum of the grades obtained in the two separate pieces of assessment (exams and homework) as long as the minimum grade is achieved.

All aspects related to evaluation will be governed by the regulations on teaching planning and examination organization in force at the University of Granada.
The grading system will be expressed using numerical grades in accordance with the provisions of Article 5 of Royal Decree 1125/2003, of September 5, which establishes the European credit system and the grading system for official university degrees valid throughout the national territory.

EXTRAORDINARY EXAMINATION DIET

RE-SIT EXAMINATION

- The re-sit examination will consist of a single piece of assessment. The exam may consist of theoretical, quantitative and problem-solving questions as well as demonstrations. The final grade will be equally split between fundamentals (50%) and applications (50%).

All aspects related to evaluation are determined by the regulations on teaching planning and examination organization in force at the University of Granada.
The grading system will be expressed using numerical grades in accordance with the provisions of Article 5 of Royal Decree 1125/2003, of September 5, which establishes the European credit system and the grading system for official university degrees valid throughout the national territory.

SINGLE FINAL ASSESSMENT (evaluación única final)

Following the protocol and within the strict deadline set by the University of Granada, students who wish to do so may choose the single evaluation model. This evaluation will consist of a theoretical-practical exam, which may include theoretical questions, demonstrations, and problem-solving, with a 100% grade (50% for the fundamentals part and 50% for the applications part).
All aspects related to evaluation will be governed by the regulations on teaching planning and examination organization in force at the University of Granada.
The grading system will be expressed using numerical grades in accordance with the provisions of Article 5 of Royal Decree 1125/2003, of September 5, which establishes the European credit system and the grading system for official university degrees valid throughout the national territory.