Statistical Physics
2021

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Course materials: An Introduction to Thermal Physics by Daniel V. Schroeder.

Tutorials: There will be tutorial lectures twice a week in smaller working groups lead by teaching assistants. These tutorials will cover a range of assignments to practice and discuss key problems. See the tentative schedule of assignments in the weekly program below. Once every two weeks, we will assign a set of problem sets that will be handed in and graded.

Assessment: Homework assignments are graded as follows: An *A* will be assigned for a good effort to solve all problems and demonstrate a basic understanding of key concepts. A *B* indicates clear deficiencies, which is a signal to the students that they need to work on certain things. Finally, a *C* indicates insufficient work with major issues, a signal that a serious effort is required to catch up. We will add a bonus of up to 0.5 points (depending on your average homework grade) to your final grade. The bonus only applies if you get a passing exam grade.

The exam is broken down into two: Deeltoets 1 on Chapters 4&5 on 16-4-21 and deeltoets 2 focused on Chapters 6-9 on 27-5-21. Deeltoets 1 counts for 40% to your final grade and deeltoest 2 counts for 60%. We offer a retake exam on 1-7-21.

Learning goals: The overall goal for this course is to introduce students to the foundational topics and calculation methods of thermodynamics and statistical physics. This provides an essential basis for the students to be able to take more advanced theoretical and practical courses in physics over a broad range of disciplines.

1. Grasping and relating **key thermodynamics concepts** Explain key concepts such as entropy, free energies and thermodynamics potentials, and describe how they are related and under which conditions they are relevant. Students can interpret the laws of thermodynamics. They can apply all these key thermodynamics concepts to calculate properties of simple examples like ideal gasses.

2. Applying thermodynamics to heat engines and refrigerators Students are able to use basic thermodynamic concepts to analyze warming and cooling cycles, and they are able to understand what determines their optimal efficiency. Students can analyze idealized cases such as the Carnot cycle using PV and TS-diagrams, and compute their efficiency. They will then also be able to apply these ideas to real-life engines and refrigerators.

3. Describing phase transitions using thermodynamics Understand how to use concepts such as heat, entropy, latent heat and heat capacity to describe the thermodynamics of first-order phase transitions. They will be able to apply these ideas to key examples such as the van der Waals gas and de-mixing transitions in mixtures.

4. Deriving and applying Boltzmann statistics Students can use concepts such as microstates and the postulate of equal probability to describe the statistical physics of systems at fixed energy or at fixed temperature. An important step will be to learn how to make approximations when dealing with large numbers (Stirling's approximation). They will be able to relate the number of microstates to entropy, and discuss the concept of a heat bath. From the maximum entropy principle, students can derive a definition of temperature and the Boltzmann distribution.

5. Distinguishing and employing Statistical Ensembles Students know the difference between distinct statistical ensembles, which to apply under which condition, and how these ensembles are related to the thermodynamics potentials. They will also be able to determine the partition function and know how to use it to determine important thermodynamic characteristics of a system. Using this statistical physics approach, the students can derive basic results like the gas law and the properties of simple non-interacting systems like a paramagnet.

6. Understanding the basics of Quantum statistics, properties of quantum gasses, and interacting systems Students can describe and apply concepts such as Density of States, the Bose-Einstein Distribution and the Fermi-Dirac Distribution. They can use this theory to understand examples such as Blackbody Radiation, the Debye Model of Vibrations in a Solid and Bose-Einstein Condensation. Finally, students will be able to apply mean-field theory to analyze simple interacting systems, like the Ising model.

7. Logic of key derivations, applications, and connections between thermodynamics and statistical physics Students can indicate the key logical steps in the derivations of the main results in this course. They know the central equations and can apply them to simple examples. Students can describe the relation between the phenomenological thermodynamic approach and statistical physics.

Weekly Program

Week	Date	Subject	Readings
1 HC 1	Tue 30.03.21 11-13h	Thermodynamic efficiency and cycles	Schroeder, 4.1-4.2
WC 1	Wed. 31.03.21	Examples: Carnot cycle, car	P: 4.3, 4.6, 4.14, 4.16
HC 2	Thur 01.04.21 9-11h	Steam engine, real Refrigerators, Thermodyn. potentials	Schroeder, 4.3-5.2
WC 2	Goede vrijdag	Stirling engine, Refrigerator ΔH, ΔG in chem. reaction	4.21, 4.30, 5.6
2 HC 3	Tue 06.04.21 11-13h	Thermodyn. Potentials Ext. & int. variables Phase transformations	Schroeder, 5.3-5.4
WC 3	Wed 07.04.21 13-15h, 15-17h	Maxwell relations, Simple phase diagrams	5.11, 5.12, 5.23, 5.27
HC 4	Thur 08.04.21 9-11h	Clausius Clapeyron Van der Waals model, Phase transformation of mixtures	Schroeder 5.4
WC 4	Fri 09.04.21 13-15, 15-17h	Clausius Clapeyron applied, VdW model, Real mixing energy	5.32, 5.35, 5.48+5.51, 5.58
3 HC 5	Tue 13.04.21 11-13h	Eutectic mixtures Chemical equilibrium Osmotic pressure	Schroeder 5.5-5.6
WC 5	Wed 14.04.21 13-15h, 15-17h	Examples: entropy of mixing, entropic systems	5.62, 5.67, 5.77, 5.46
HC 6	Thur 15.04.21 9-11h	Boltzmann factor, Canonical and Microcanonical ensemble, Partition function and averages	Schroeder 6.1-6.2
Deel-toets	**Fri 16.04.21 15-18h**	**About chapters 4 and 5**	
4 HC 7	Tue 20.04.21 11-13h	Equipartition theorem, Maxwell distribution, Free energy	Schroeder 6.3-6.5
WC 6	Wed 21.04.2113-15h, 15-17h	Applying Boltzmann statistics to idealized and real atoms	6.5,6.8, 6.16-6.18, 6.20
HC 8	Thur 22.04.21 9-11h	Composite systems, (In)distinguishable particles, Ideal gas	Schroeder 6.6-6.7

WC 7	Fri 23.04.21 13-15, 15-17h	Equipartition in practice, Velocity distributions of atmospheric particles	6.31, 6.32, 6.33, 6.39, 6.43
5	Tue 27.04.21 11-13h	*Koningsdag*	
WC 8	Wed 28.04.21 13-15h, 15-17h	Statistics of gasses	6.44, 6.47, 6.49, 6.50
HC 9	Thur 29.04.21 9-11h	Grand canonical ensemble and the Gibbs factor, Quantum statistics for Bosons and Fermions: Bose-Einstein and Fermi-Dirac distribution	Schroeder 7.1-7.2
WC 9	Fri 30.04.21 13-15, 15-17h	Langmuir adsorption, applications of quantum statistics for Bosons and Fermions.	7.1, 7.5, 7.6, 7.9, 7.12, 7.16, 7.17
6 HC 10	Tue 11.05.21 11-13h	Fermi gas and degeneracy pressure, Density of states, Black body radiation and the Planck distribution	Schroeder 7.3-7.4
HC 11	**Wed** 12.05.21 13-15h	Entropy of photon gas, Debije solid Debye solid, Bose-Einstein condensation	Schroeder 7.5-7.6
WC 10	**Wed** 12.05.21 15-17h	Conduction in metal, Atoms in thermal radiation field, photon gas, applications in astronomy	7.19, 7.20, 7.23, 7.25, 7.28 7.41, 7.43, 7.44. 7.45
7 HC 12	Tue 18.05.21 11-13h	Interacting systems: the Ising model and critical phenomena	Schroeder 8.2
WC 11	Wed 19.05.21 13-15h, 15-17h	Properties of Debye solids, heat capacity of Bose gas, Exploring the Ising model	7.58, 7.59, 6.67, 7.70, 8.17, 8.18
HC 13	Thur 20.05.21 9-11h	(continued) The Ising model and critical phenomena, Mean field approximation	Schroeder 8.2
WC 12	Fri 21.05.21 13-15, 15-17h	Lattice gas and critical exponents	8.19, 8.22, 8.23, 8.24
Deel-toets	Thur 27.05.21 14-17	**Focus on chapters 6-9**	
Hertentamen	Thur 01.07.21 13-16		