Syllabus
Thermodynamics and Statistical Mechanics
(Physics 4650/6650)
Spring Semester 2024

Instructor Information:

Instructor:	Prof. Jens Oberheide http://globaldynamics.sites.clemson.edu/index.html
Office:	103 Kinard Lab
Department:	Dept. of Physics and Astronomy, CU
Phone:	864-656-5163
Email:	joberhe@clemson.edu
Office Hours:	Tuesday 12:30 – 1:30 pm; I have an open door policy: I encourage you to come on an as needed basis any time.
Class Hours & Modality:	TTH 11:00 – 12:15, Long Hall 228; in-person; you may leave class if I have not arrived after 15 minutes

Course Mode of Delivery

This section gives you the big picture of how we are going to do the course. Most importantly, talk to me if anything comes up that impacts your ability to meet course expectations. I can only help if you let me know!

This is a traditional theoretical physics class. I will work out the physics on the board and will discuss its meaning with the class.

This is an in-person class and in-person attendance is expected if you don't have an online-only accommodation. The class will not be recorded, except if warranted by special circumstances. I will treat you as professionals and won't police attendance but will certainly make sure that you don't miss too many classes.

For each class, a notetaker will be assigned and the notes will be made available to the whole class through Canvas at https://clemson.instructure.com/courses/207789. ***You are still encouraged to take your own notes.*** The purpose of these notes is (i) to get some practice in professional note taking, (ii) provide a reference for students who miss a particular class, (iii) reminder of key topics when you prep for an exam.

Doing problems is critically important to understand the material (and physics in general). As such, ***weekly homework*** will be assigned and graded. You will get feedback on your assignments and (most) solutions will be made available.

There will be one midterm exam (tentatively on Tue, February 27) and one final exam (on Wed, May 1).

This Syllabus applies to all sections of PHYS 4650 and PHYS 6650, if not stated otherwise. ***See the 6000-level requirements and honors requirement for special provisions.***

Course Information

Course Rationale: The course will provide an introduction to the main principles of thermodynamics and statistical mechanics including their relationship and applications. The level will be appropriate to prepare students for graduate (PhD-level) studies in physics. You will learn how the underlying concepts explain (at a first glance vastly different) topics such as blackbody radiation, paramagnetism, the ideal gas law, and white dwarfs. The course will follow the book from Blundell & Blundell.

Objectives:

1. Advance to a basic understanding of equilibrium thermodynamics, including the 0^{th}, 1^{st} and 2^{nd} laws of thermodynamics, thermodynamic potentials and 1^{st} order phase transitions to understand things like osmotic pressure and chemical reaction rates.
2. Be able to do essential statistics and apply probably distributions to do some thermodynamical calculations.
3. Get a theoretical understanding of the concept of ensemble theory: microcanonical & macrocanonical, and to apply the ensemble concepts to get a hand on the density of states
4. Be able to apply the density of states concept to compute thermodynamics properties of a system, including the theory of paramagnetism.
5. An introduction to concepts of ideal Fermi and Bose systems, including a derivation of blackbody radiation as an ultra-relativistic Bose gas and simple Fermi systems in the low temperature limit (so: what are Bose-Einstein condensates, Fermi energy)

Learning Outcomes:

1. Essentials of equilibrium thermodynamics:
    a. Be able to apply the 0^{th} and 1^{st} laws of thermodynamics and the concept of cyclic processes to derive the 2^{nd} law and recognize (i) the resulting equilibrium condition for entropy and (ii) the importance of the fundamental relation in terms of system knowledge. This includes the concepts of reversible and irreversible processes and the 3^{rd} law.
    b. Recognize that intensive properties are derivatives of the fundamental relation with respect to the corresponding extensive quantities and apply the concept to derive the entropy of the ideal gas.
    c. Be able to identify the appropriate thermodynamic potential for a given system/process and compute intensive and extensive variables from that. This includes the computation of specific heats, the derivation of equations of state and the proper use of the Maxwell relations for thermodynamic calculations.
    d. Be able to identify the equilibrium conditions for 1^{st} order phase transitions and apply the concept to find the pressure dependence of the transition temperature and to solve standard problems such as osmotic pressure, chemical reaction rates, latent heat, etc.

2. Basic statistics and combinatorics:
    a. Be able to compute the number of permutations for various subsets of distinguishable and indistinguishable particles.
    b. Be able to derive the binomial distribution, recognize its large number approximation as the normal distribution using the Sterling approximation, and appreciate the central limit theorem to an extent that allows him/her to apply the concept to a given problem. Be able to derive the Poisson distribution.
    c. Be able to compute the mean and standard deviation of a given variable if the probability distribution is known, for both the discrete and continuous cases.

3. Foundations of statistical mechanics:
    a. Recognize the concept of microstates and the resulting fundamentally important connection between thermodynamics (entropy) and statistical mechanics (microstates).
    b. Be able to compute the number of microstates for simple systems using combinatorics and derive thermodynamics properties for these systems.
    c. Be able to explain the reason for the Gibbs paradox and generally recognize its importance for distinguishable and indistinguishable particles when computing thermodynamic properties.
    d. Recognize phase-space as the appropriate framework for ensemble theory and be able to compute the number of microstates and the density of states for standard microcanonical ensembles using phase-space considerations. Examples include 1D, 2D, 3D classical ideal and ultrarelativistic gases, classical and quantum mechanical rotator, and the harmonic oscillator.
    e. Recognize the connection between microcanonical and canonical ensemble theory, be able to identify free energy as the appropriate thermodynamic potential, and be able to compute the partition function for standard systems of distinguishable and indistinguishable particles (such as the ideal gas, the harmonic oscillator, paramagnet, etc.) and derive thermodynamic properties from that.

4. Ideal Fermi and Bose systems:
    a. The student should recognize the concept leading to Bose-Einstein and Fermi-Dirac distributions and the difference between these systems.
    b. Be able to compute blackbody radiation from the ultra-relativistic Bose gas; and Fermi energy and occupation numbers for simple Fermi systems in the low temperature limit.

Course Outline: The book from Blundell & Blundell includes 37 chapters and it is impossible to cover all of them in one semester. Chapters 31-37 are special topics that you can study on your own based on what you will learn in class. However, we should be able to cover the remaining chapters – as some are rather short and closely related to other chapters. So, I will go over some chapters quickly and rather spend more time on others.

- ***Class:*** In each lesson, you will learn the key topics from the course material in the book by Blundell & Blundell. You are expected to read the relevant text ***before each class***.
- ***Lecture notes:*** As the **assigned notetaker** (at least once but perhaps twice per semester), you will learn to professionally summarize the relevant material of the lecture such that a student who could not attend the class will be able to understand what was being taught. This is also an important training in scientific writing and professional note taking, an important skill for every professional.

  Notes are due (per email in pdf format) the day of the next class until 9 am: on Thursday at 9 am for a Tuesday class, and on Tuesday at 9 am for a Thursday class. I will then check –and grade– these notes and ask the assigned notetaker for revisions, if needed. Revisions must be provided the following business day until 9 am. **The (revised) lecture notes will be provided to <u>all</u> students via Canvas, with the name of the assigned notetaker printed on top of the notes.** The lecture notes will count toward the final grade. General instructions re the structure and expectations for the lecture notes will be posted on Canvas. It is your responsibility to be aware of your assignment to take notes for a particular class. Failure to submit notes and/or revisions on time will result in an 0% grade for the assignment in question.
- ***Homework:*** These assignments will give you the chance to apply what you have learned and to demonstrate development of your skills related to the course content. You will turn in a ***handwritten*** solution during class. Typed homework solutions are a waste of time and will not be accepted. Each assignment will include questions related to the textbook material. These assignments will be your homework grade and will be done ***once a week.*** To truly learn physics, you need to do many more problems – there's no substitute for that. You are thus encouraged to attack problems in Blundell & Blundell not given as a homework – and I will be happy to help you if you are stuck.
- ***Canvas:*** We are not going to use Canvas a lot but I will post homework solutions and other docs (like the syllabus or notetaking instructions) there.

Method of Teaching: This is a lecture course based upon a textbook. You should prepare by reading the chapters and try to solve as many problems as possible. Exams will be administered in class.

Grading: Assignments in this course are divided into these general categories, which carry the following weight in your final grade calculations:

Category	Weight
Written Homework	40%
Class Notes	5%
Midterm exam	25%
Final exam	30%

There will be ***one midterm exam*** (tentative date: Tue, February 27 during class) and one ***final exam*** (Wed, May 1). Exams are closed book and no notes. However, you will be allowed to prepare your own equation sheet (1 page, front and back, handwritten) for the exams.

The ***two lowest homework scores will be*** dropped for the final grade calculation. ***Late homework won't be accepted*** if you do not give me a very good reason.

You are treated as a professional in the course. Accordingly, the grading is strict, but fair. Reading the directions and grading criteria provided for each assignment is the key to understanding how you will be graded.

Letter grade: A: 85-100%; B: 70-85%; C: 50-70%; D: 40-50%; F:<40%

Required Textbook:

Concepts in Thermal Physics (2nd Edition) by Stephen J. Blundell and Katherine M. Blundell; Oxford University Press, ISBN 978-0-19-956210-7, 493 pages; ~$40. **The lecture will follow this book!**

Recommended Textbook:

Another good book is *An Introduction to Thermal Physics* by Daniel V. Schroeder; Addison-Wesley, ISBN 9-780-201-38027-7, $69. But this is not required.

Web Sites: The course web site is on Canvas, accessible at https://clemson.instructure.com/courses/207789. There is only one Canvas site for all sections of PHYS 4650 and PHYS 6650. It will be used to post homework solutions, class notes, and some needed material such as the syllabus – so, essentially a file repository.

Honors Section Requirements

If you're in the honors section, you are required to complete **one** longer assignment towards the end of the semester. This will be an approximately 5-page comprehensive summary of a topic not covered in class. I may ask you for minor/major revisions as needed. The assignment counts toward the written homework result and will be graded as unsatisfactory, satisfactory after major revision, satisfactory as is/after minor revision. For an unsatisfactory assignment, 10% will be deducted from your written homework result (e.g., 90% in the written homework will be downgraded to 80%). For a satisfactory after major revision assignment, the deduction will be 5%. A satisfactory as is/after minor revision assignment will result in no deduction.

6000-level Requirements

If you are in the 6000-level course, you're generally expected to demonstrate a higher (MS) level of competency. As such, you will be assigned more advanced and/or additional

homework. Furthermore, you will need to complete **two** longer assignments towards the middle and the end of the semester, respectively. These will be approximately 5-page comprehensive summaries of a topic not covered in class. I may ask you for minor/major revisions as needed. The assignments count toward the written homework result and will be graded as unsatisfactory, satisfactory after major revision, satisfactory as is/after minor revision. For **each** unsatisfactory assignment, 10% will be deducted from your written homework result (e.g., 90% in the written homework will be downgraded to 80%). For **each** satisfactory after major revision assignment, the deduction will be 5%. **Each** satisfactory as is/after minor revision assignment will result in no deduction.

Course Policies

The following policies are the standard syllabus material. Please read completely.

Prerequisites: Undergraduate classical mechanics (Physics 3210 or consent of the instructor).

Attendance Policy: This course is designed for active in-person learning and engagement. Attendance and active participation in this course will provide the most benefit for learning. Since you are treated as professionals in the course, ***attendance is not required but highly recommended. I reserve the right to drop any student from the course who stops attending/participating for extended periods of time.***

Any exam that was scheduled at the time of a class cancellation due to inclement weather will be given at the next class meeting unless contacted by the instructor. Any assignments due at the time of a class cancellation due to inclement weather will be due at the next class meeting unless contacted by the instructor. Any extension or postponement of assignments or exams must be granted by the instructor via email or other means of communication within 24 hours of the weather-related cancellation.

University Policies

Academic Integrity: The Clemson University statement on academic integrity reads: "As members of the Clemson University community, we have inherited Thomas Green Clemson's vision of this institution as a "high seminary of learning." Fundamental to this vision is a mutual commitment to truthfulness, honor and responsibility, without which we cannot earn the trust and respect of others. Furthermore, we recognize that academic dishonesty detracts from the value of a Clemson degree. Therefore, we shall not tolerate lying, cheating or stealing in any form."

Student Accessibility Statement: Clemson University values the diversity of our student body as a strength and a critical component of our dynamic community. Students with disabilities or temporary injuries/conditions may require accommodations due to barriers in the structure of facilities, course design, technology used for curricular purposes, or other campus resources. Students who experience a barrier to full access to a class should let the professor know, and make an appointment to meet with a staff member in Student

Accessibility Services as soon as possible. You can make an appointment by calling 864-656-6848 or by emailing studentaccess@lists.clemson.edu. Students who receive Academic Access Letters are strongly encouraged to request, obtain and present these to their professors as early in the semester as possible so that accommodations can be made in a timely manner. It is the student's responsibility to follow this process each semester. You can access further information here: http://www.clemson.edu/campus-life/campus-services/sds/.

Clemson University Title IX Statement: Title IX Policy: Clemson University is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, religion, sex, sexual orientation, gender, pregnancy, national origin, age, disability, veteran's status, genetic information or protected activity (e.g., opposition to prohibited discrimination or participation in any complaint process, etc.) in employment, educational programs and activities, admissions and financial aid. This includes a prohibition against sexual harassment and sexual violence as mandated by Title IX of the Education Amendments of 1972. The University is committed to combatting sexual harassment and sexual violence. As a result, you should know that University faculty and staff members who work directly with students are required to report any instances of sexual harassment and sexual violence, to the University's Title IX Coordinator. What this means is that as your professor, I am required to report any incidents of sexual harassment, sexual violence or misconduct, stalking, domestic and/or relationship violence that are directly reported to me, or of which I am somehow made aware.

This policy is located at http://www.clemson.edu/campus-life/campus-services/access/title-ix/ . Ms. Alesia Smith is the Executive Director for Equity Compliance and the Title IX Coordinator. Her office is located at 223 Holtzendorff Hall, phone number is 864.656.3181, and email address is alesias@clemson.edu.

Clemson University is committed to providing a safe campus environment for students, faculty, staff, and visitors. As members of the community, we encourage you to take the following actions to be better prepared in case of an emergency: (a) Ensure you are signed up for emergency alerts (https://www.getrave.com/login/clemson), (b) Download the Rave Guardian app to your phone (https://www.clemson.edu/cusafety/cupd/rave-guardian/), (c) Learn what you can do to prepare yourself in the event of an active threat (http://www.clemson.edu/cusafety/EmergencyManagement/)