**Physics 335—Thermal Physics**
**MWF 11:40 a.m. – 12:30 p.m.**
**Course Description, Fall 2024**


| | |
|---|---|
| **Instructor:** | Andrew Dougherty |
| **Office:** | HSC 031 610-330-5212 |
| **Lab:** | HSC 025 610-330-5212 |
| **E-mail:** | doughera@lafayette.edu |
| **Web Page:** | http://workbench.lafayette.edu/~doughera/ |
| **Course Web Page:** | https://moodle.lafayette.edu/course/view.php?id=27803 |


**Office Hours:** Please feel free to e-mail or call at any time and ask a question or set up an appointment. You are not limited to the listed times. I will also normally be available on most other days during the free times indicated on my schedule.

**Classes on Snow Days and Other Emergencies:** If I am unable to make it to class, I will send out an email via Moodle.

**Web Pages:** All course assignments and documents will be posted to our Moodle site https://moodle.lafayette.edu/course/view.php?id=27803.

**Description:**

This course considers the fundamental concepts of heat, temperature, work, internal energy, entropy, reversible and irreversible processes, thermodynamic potentials, etc., from both a traditional macroscopic and a modern microscopic viewpoint. Statistical thermodynamics is used primarily to study the equilibrium properties of ideal systems and simple models. This course provides the background needed to understand materials from a microscopic point of view.

**Prerequisites:** Phys 215 (Introduction to Quantum Physics); Math 263 (Calculus III).

**Texts:** The textbook for this course is *An Introduction to Thermal Physics* by Daniel V. Schroeder (Oxford University Press) (2021). The author maintains a web site https://physics.weber.edu/thermal/ describing the book and the differences from earlier editions. If you pick up an earlier edition, please *do* manually make all the corrections listed on that web site.

An additional useful site is https://www.compadre.org/stpbook/, Statistical and Thermal Physics Programs, by Jan Tobochnik and Harvey Gould.

Any additional resources needed will be linked from our Moodle site.

**Student Learning Outcomes:**

The main goal of this course is to help you understand, identify, and apply the fundamental principles of thermodynamics and statistical mechanics in a variety of situations. You should be able to use both qualitative reasoning and quantitative problem-solving skills in applying those principles. A second goal is to help you continue to grow in the *process* of doing physics, including skills such as developing and testing models, interpreting experimental data, solving problems, and communicating results.

Specifically, upon successful completion of this course, you should be able to

- Solve problems involving the macroscopic interpretation of thermodynamic concepts including temperature, heat, and entropy.
- Apply the laws of thermodynamics to a wide variety of situations, including those encountered in everyday life.

- Describe and use the principles behind the design and operation of heat engines, heat pumps and refrigerators.
- Combine the laws of quantum mechanics and the laws of statistics to predict the behavior of widely varied model systems consisting of a large number of particles.
- Use statistical mechanics to connect the macroscopic thermodynamic properties of a system to its microscopic constituents.

**Grades:** Your grade will be based on homework (40%), two tests (20% each), and the final exam (20%).

**Tests:** There will be two in-class tests on the dates indicated on the syllabus. These tests will likely consist of two parts: A short in-class section, and a longer open-book take-home portion. More details will be given closer to the test dates.

**Final Exam:** There will be a comprehensive final exam at a time to be arranged by the registrar. *Please do not make travel arrangements that may conflict with the exam before that time is set.*

**Homework:** Assignments will be given regularly and will ordinarily be due at the beginning of class on the dates indicated on the syllabus.

- You are encouraged to work together on homework assignments, but collaborations must be acknowledged and should not be one-way only. You must fully understand whatever work you turn in. See the section on Academic Honesty below for more details.

- Problems will be due at the *beginning* of class. **Late homework will normally not be accepted**.

- For written homework, I expect your work to be clearly organized and easy to follow. You should include not just numbers and calculations, but also include some text to explain *what* you are doing and *why*. This can often be quite brief, but it is *your* responsibility to make your reasoning clear; it is not the reader's responsibility to try to figure out what you meant. Homework that is incomplete or difficult to understand will not get full credit. The following guidelines are intended to help *you* present your work effectively:

  1. Be sure to include your name on each page.
  2. Each problem should be clearly labeled.
  3. It is often helpful to include figures. Any figures should have clear labels.
  4. Show your work clearly, and include all non-trivial steps. Use words to explain what you are doing and why. This can often be very brief, something like "Use conservation of energy."
  5. Allow plenty of space.
  6. Put a $\boxed{\text{box}}$ around your final solution, including correct units.

- **Illegible papers will not be accepted**. If I have difficulty reading or understanding your work, I may return it to you ungraded for re-submission. You may resubmit a legible version (along with the original) by the next class meeting, but that version must not have any new content—it must simply be a legible version of the original.

- Please look at the homework problems ahead of time and ask questions about them either in or out of class. I am happy to give whatever help you need, but it is important that you eventually learn to do these problems on your own—after all, that's what you will have to do on the tests.

- Homework will normally be due on Wednesdays. If you look at the problems ahead of time, I will be happy to spend class time on Mondays going over any difficulties that might arise.

**Computer Work:** Some of the homework assignments will involve numerical calculations or simulations. Most of these will be done in a tool such as *Mathematica* or `python`. Although I will normally use *Mathematica*, you may use whatever tool you wish. I assume you are familiar with at least the basics of *Mathematica*, but will give explicit instructions for new, novel, or advanced features that we may use. I will post any *Mathematica* notebooks or `python` programs used in the class on the course web site. Please ask if you need further help. I want you to have time to think about the physics at hand, not get held up by syntax issues.

**Presentations:** Near the end of the semester, we will have brief student presentations. These will typically be more extended explorations of textbook problems drawn from work earlier in the semester. You will propose a particular problem, and, after approval, do a 10–15 minute presentation in class. I will flag good examples as we go along, and give more details after Fall Break.

**Seminars:** Occasionally throughout the semester I hope to allow students to receive extra credit towards your homework score by attending physics department seminars (or seminars in related areas). These will be announced in advance.

**Academic Honesty:** The fabric of science, and indeed any intellectual endeavor, is built on the integrity of all involved. Accordingly, I take academic honesty very seriously. I expect that you will abide by the "Principles of Intellectual Honesty" appearing in the Lafayette College Student Handbook.

Working with others is often a helpful way to learn physics. For this course–and indeed for most advanced courses in any discipline—I believe such collaboration to be an essential element for success. I encourage you to collaborate with each other, but unless specifically directed otherwise, all work you turn in *as* your own should *be* your own. My expectation is that everyone will be open to both giving and receiving aid from their peers.

Some students also find it useful to consult other texts, friends, and even a variety of on-line sources. In all cases, though the principles of academic honesty apply: All nontrivial collaborators and external sources must be acknowledged (apart from your textbook and instructor). You may seek help understanding a problem, but all work you turn in must be your own original work. Copying an answer from another source, such as CourseHero, Chegg, Bartleby, or a generative AI source, is a violation of the Academic Honesty Policy. Although some students believe that looking up solutions as soon as they get stuck helps their learning because they get immediate feedback, I would argue that the negatives of this approach outweigh any benefits.[1] In particular, merely looking up a solution:

- Creates a false sense of security that won't be there during exams.

- Can replace other healthy learning behaviors, such as: reading through the text for missing concepts or similar examples; asking a friend; asking a professor; taking a

[1] This discussion is based on one in Prof. Boekelheide's syllabus.

break and coming back to the question later; having a "Eureka" moment when out for a walk. These are all healthy learning behaviors, and doing less of them is a negative.

- Often fails to lead to actual learning. It won't necessarily help you the next time you encounter a somewhat similar situation.
- Can lead to a culture where it feels like everyone knows the answer all the time and being unsure of a solution feels abnormal. This is exactly backwards. Being unsure of a solution is normal.

Please read the department's Academic Honesty policy for the rules regarding collaboration. Feel free to ask if you have any questions about this policy.

**Your Responsibilities:**

**Read the text.** Your text is a critical resource for this class—it is a source of definitions, facts, ideas, explanations, and derivations. I do not intend to spend class time simply repeating the text. Instead, class time will be used to elaborate those features, answer your questions, do examples, and practice applying those ideas to various physical situations.

Accordingly, you should read the text ahead of time. I have included a detailed daily syllabus so you know what the assigned readings for each day will be.

**Ask questions.** If you are confused, it is important that you stop me and try to sort it out rather than falling behind. *Please* interrupt and stop the class whenever anything isn't clear. Remember that if you are confused, there are almost certainly many others who are confused as well, and they would welcome your question.

**Keep up with assigned work.** A good rule of thumb is that you should anticipate spending approximately 12 hours a week for each college course. This means you should anticipate spending an average of 9 hours per week outside of class.

*Plan ahead.* Thermal physics problems are often *long* and complex. They challenge you to extend what you know to ever-more realistic and complex situations. When you are doing a problem, the answer is usually not immediately obvious. It is not always easy to tell whether you are on the right track or not—sometimes you have to work for a while to tell. I am here to help. If you start on your homework ahead of time, I will be available to help you if you get stuck. Don't wait until the night before an assignment is due before starting it.

**Participate in class.** Your active engagement during class can play an important part in helping you to master the material. Class time will also be used to announce changes to the syllabus. I will also post everything to our Moodle site. It is *your* responsibility to keep up.

**Inclusivity:** All students should feel welcome in Physics class. We all bring our own unique perspective to class, and it is my intention that all students feel included in the intellectual community of the classroom. Unfortunately, the history of science is full of exclusion, so it's important to be explicit about inclusion.

Please contact me if you feel your identity is not being honored in class, if you have a preferred name or pronouns that I am not aware of, you observe religious holidays which conflict with coursework, or if there is something else that I should address. I am still learning, too, and your feedback is important to me.

**Proper Usage of Course Materials:** At Lafayette College, all course materials are proprietary and for class purposes only. This includes posted recordings of lectures, examples, tests, solutions, and other course items. Such materials should not be reposted. Online discussions should also remain private and not be shared outside of the course. You must request my permission prior to creating your own recordings of class materials, and any recordings are not to be shared or posted online even when permission is granted to record. If you have any questions about proper usage of course materials feel free to ask me.

**Generative AI Statement:** See the general Academic Honesty section above.

**Class Recordings:** From time to time, it will be useful to record our classes for those unable to attend in person. I will make any such recordings available on a Google Drive shared within the class.

These recordings are for the use of this class only, and should not be shared outside of the class. If you have any concerns with being recorded during the course please let me know.

**Federal Credit Hour Statement:** The student work in this course is in full compliance with the federal definition of a four credit hour course. Please see the Registrar's Office web site https://registrar.lafayette.edu/wp-content/uploads/sites/193/2013/04/Federal-Credit-Hour-Policy-Web-Statement.doc for the full policy and practice statement.

**Andrew Dougherty Fall 2024**
**Office: Hugel Science Center 031**
**Lab: Hugel Science Center 025**
**610-330-5212 dougherа@lafayette.edu**

| **Time** | **Mon.** | **Tues.** | **Wed.** | **Thurs.** | **Fri.** |
|---|---|---|---|---|---|
| 9:30<br>10:20 | **Phys 152**<br>HSC 142 | | **Phys 152**<br>HSC 142 | | **Phys 152**<br>HSC 142 |
| 10:35<br>10:45 | | | | | |
| 11:00<br>11:25 | | **Phys 338**<br>HSC 042 | | | |
| 11:40<br>12:15 | **Phys 335**<br>HSC 017 | | **Phys 335**<br>HSC 017 | | **Phys 335**<br>HSC 017 |
| 12:30<br>12:55 | | | | | |
| 1:15<br>1:40<br>2:30 | | **Phys 152**<br>**Lab**<br>HSC 119 | | | |
| 2:45<br>3:35<br>4:00 | | | | | |
| 4:10<br>4:30 | | | | | |
| 5:00<br>5:30 | | Committee<br>Meeting | *Physics Club* | | |

**ACADEMIC HONESTY GUIDELINES**
**Department of Physics**

It is expected that each student taking courses in the Department of Physics is familiar with the statement "Principles of Intellectual Honesty" appearing in the Lafayette College Student Handbook. The following guidelines are intended to indicate how that statement pertains to your work in physics. Your instructor may have further guidelines for your specific course. We assume that students are honest; if you are not certain as to what is expected of you, consult your instructor before proceeding.

**I. EXAMINATIONS:**

1. Bring only those materials specifically authorized by your instructor. Frequently in the elementary courses, you will be permitted to bring in a formula sheet or you will be provided with one.

2. If you find that the seating arrangement is such that you can see someone else's paper, don't look! Better yet, ask if you can sit in another seat.

3. If you use a calculator, clear the answer before setting the calculator aside.

4. If you fail to hand in your paper at the end of the period you will be awarded a grade of zero for that test.

**II. TAKE-HOME EXAMINATIONS:** Take-home examinations are often assigned in some courses. Specific rules governing such tests will be announced by your instructor. The overriding principle, however, is that any work submitted be your own or be specifically credited to its source. There should be no discussion of the test questions with *anyone* other than the instructor.

**III. HOMEWORK: You must acknowledge *all* collaborators.** You are encouraged to learn from one another. You should first try to do homework problems on your own; after all you will have to do similar problems on your own in tests. However, discussion of difficult problems with others can help you to develop your own analytical skills and is encouraged, provided that, *after discussion* you write up solutions *on your own.* Do *not* borrow or lend homework papers. There is an important difference between discussing a problem with someone and copying his or her work. There have been students who have loaned papers to friends for a few minutes to "check answers", and been horrified to find themselves charged with academic dishonesty because their "friends" copied their solutions.

**Please Note:** The same ethical standards of academic integrity and honesty apply to the on-line homework as to the written homework, except that there is no place for you to specifically acknowledge collaboration. However, the same general rules apply.

**IV. LABORATORY:** Usually two or more students will work together in performing experiments and will submit reports of their work. In some courses, a single joint report may be submitted. Specific instructions will be announced by your instructor. If the words used to describe some part of the experiment are taken from some other source (such as the lab manual), then the source should be cited. (Reference to the lab manual can usually substitute for laborious copying.) If you consult with *anyone* about the experiment (e.g. students in your lab class other than your lab partner), that consultation should be acknowledged in your report. Do *not* borrow or lend a completed lab book or any portion of one.

**V. PAPERS:** Refer to the statement "Principles of Intellectual Honesty" in the Student Handbook.

| **Syllabus** | | **Phys 335** | **Fall 2024** |
|---|---|---|---|
| **Aug.** | 26 | Welcome and Introduction; Thermal Equilibrium | Ch. 1.1 |
| | 28 | Ideal Gas; Equipartition | Ch. 1.2–3 |
| | 30 | Heat and Work | Ch. 1:4–5 |
| **Sept.** | 2 | Heat Capacity | Ch. 1:6 |
| | 4 | Enthalpy; HW #1 | Ch. 1:6 |
| | 6 | Microstates | Ch. 2.1–2 |
| | 9 | Interacting Systems, 2nd Law | Ch. 2.3 |
| | 11 | Large Systems ; HW #2 | Ch. 2.4 |
| | 13 | Ideal Gas | Ch. 2.5 |
| | 16 | Entropy | Ch. 2.6 |
| | 18 | Temperature; HW #3 | Ch. 3.1 |
| | 20 | Entropy and Heat | Ch. 3.2 |
| | 23 | Paramagnetism | Ch. 3.3 |
| | 25 | Equilibrium and Pressure; HW #4 | Ch. 3.4 |
| | 27 | Chemical Potential | Ch. 3.5–6 |
| | 30 | *Problems and Review* | Chs. 1–3 |
| **Oct.** | 2 | **Hour Test I** | Chs. 1–3 |
| | 4 | Heat Engines | Ch. 4.1 |
| | 7 | Refrigerators | Ch. 4.2 |
| | 9 | Free Energy; HW #5 | Ch. 5.1 |
| | 11 | Free Energy and Equilibrium | Ch. 5.2 |
| | 14 | *Fall Break* | |
| | 16 | Phase Transformations | Ch. 5.3 |
| | 18 | Phase Transformations of Mixtures; HW #6 | Ch. 5.4 |
| | 21 | Boltzmann Factor | Ch. 6.1 |
| | 23 | Boltzmann Factor; HW #7 | Ch. 6.1 |
| | 25 | Boltzmann Factor | Ch. 6.1 |
| | 28 | Average Values | Ch. 6.2 |
| | 30 | Equipartition; HW #8 | Ch. 6.3 |
| **Nov.** | 1 | Applications | Ch. 6.3 |
| | 4 | Maxwell Speed Distribution; Free Energy | Ch. 6.4–5 |
| | 6 | Composite Systems; Ideal Gas; HW #9 | Ch. 6.6–7 |
| | 8 | Gibbs Factor | Ch. 7.1 |
| | 11 | Bosons and Fermions | Ch. 7.2 |
| | 13 | **Hour Test II** | Chs. 4–6 |
| | 15 | Degenerate Fermi Gas | Ch. 7.3 |
| | 18 | Blackbody Radiation | Ch. 7.4 |
| | 20 | *Presentations*; HW #10 | |
| | 22 | *Presentations* | |
| | 25 | *Presentations* | |
| | 27–29 | *Thanksgiving* | |
| **Dec.** | 2 | Ising Model | Ch. 8.2 |
| | 4 | *Presentations* | |
| | 6 | Ising Model (*continued*); HW #11 | |
| | | *Final Exam* (cumulative) | |

Revised November 3, 2024