# PHYS*2240 Thermal Physics
# Fall 2017 Course Outline

Department of Physics
University of Guelph

## Course Objectives

This course will introduce you to the basic ideas of thermal physics, including temperature, heat, work; and thermal, mechanical and diffusive equilibrium. We will discuss the statistical basis for entropy and thermodynamics. We will cover applications of thermodynamics to both non-interacting and interacting systems.

Courses in thermal physics (thermodynamics and statistical mechanics) form one of the core sequences in the physics undergraduate curriculum, alongside course sequences in classical mechanics, in electromagnetism, and in quantum mechanics. The objective of PHYS*2240 is to begin your journey along the thermal physics sequence (which informally includes NANO*3600, PHYS*4240, and PHYS*4150). You should enter PHYS*2240 with a standard first-year science background, including some first-year physics and calculus.

We will follow the topic selection and structure in the textbook *Thermal Physics* by Daniel V. Schroeder. We will cover Chapters 1-3 extensively; we will also discuss selected topics from Chapters 4 and 5. Please see the course outline at the end of this Syllabus for a detailed schedule of lecture topics. After introducing some basic thermodynamic language and mathematical tools, we will explore the first law thermodynamics: energy conservation. However, we will find that energy conservation is not sufficient to answer the big questions of thermodynamics. The idea of entropy and the introduction of a second law of thermodynamics is necessary to answer these big questions and describe thermal phenomena. The entropy concept originates from our lack of precise knowledge about which of the many, many microscopic states a system is actually in, despite our imposition of constraints on the system at a macroscopic level. We will discuss entropy from a statistical perspective. Having motivated the second law, we will explore its consequences for equilibrium, for phase transitions, and for various applications and measurable quantities. These examples will illustrate the general structure of the theory, and will highlight the universal scope of thermal physics.

You will refine your analytical and problem-solving skills through regular written assignments.

## Class Schedule and Location

Monday, Wednesday, and Friday 1:30 pm - 2:20 pm, MCKN 227

First Lecture: Friday, September 8th
Last Lecture: Friday, December 1st

The course runs for 12 weeks (35 lectures); there is no lecture on Thanksgiving (Monday, October 9th) or for the in-class term test 1. Friday, December 1st is a Thanksgiving make-up lecture.

## Course Instructor

Name: Rob Wickham
Office: MacNaughton 448
Phone: (519) 824-4120 ext. 53704
Email: rwickham@uoguelph.ca

## Office Hours

Usually, Monday, 2:30 pm - 3:30 pm and Tuesday, 1:00 pm - 3:00 pm. However, office hours will shift depending on whether an assignment is due on Wednesday or on Friday, or whether there is an upcoming test. Please check the course calendar on CourseLink. Please send me an email if you can't find me and wish to schedule a meeting.

## Course Website

CourseLink: Login via https://courselink.uoguelph.ca/

## Required Textbook

*An Introduction to Thermal Physics*, by D. V. Schroeder
(Addison Wesley Longman, 2000).

## Other, optional resources:

- C. B. P. Finn, *Thermal Physics*
- C. J. Adkins, *Equilibrium Thermodynamics*
- Thermal physics online resources and simulations: www.compadre.org/stp/

## Evaluation

| Assessment | % of Grade | Due Date |
|---|---|---|
| Assignments (5) | 30% | roughly every two weeks |
| Term Test 1 | 10% | Wednesday, October 11$^{th}$, in class |
| Term Test 2 | 20% | Monday, November 13$^{th}$, 7-9 pm, room TBA |
| Final Exam | 40% | December 12$^{th}$, 2:30-4:30 pm, room TBA |

A medical certificate is required if the exam is missed.

Assignment solutions that are not stapled together will receive a grade reduction of 5%. Assignments are due at the beginning of class; late assignments will receive a grade of zero.

Physics is not done in a vacuum. (OK, sometimes it is...) Students may discuss assignments amongst themselves but their written solutions must not be shared with anyone (this would be an example of plagiarism).

Plagiarism is the act of appropriating the ``*...composition of another, or parts or passages of his [or her] writings, or the ideas or language of the same, and passing them off as the product of one's own mind...*" (Black's Law Dictionary). A student found to have plagiarized will receive zero for the work concerned. Collaborators shown to be culpable will be subject to the same penalties.

## Course Evaluation

The Department of Physics requires student assessment of all courses taught by the Department. These assessments provide essential feedback to faculty on their teaching by identifying both strengths and possible areas of improvement. In addition, annual student assessment of teaching provides part of the information used by the Department’s Tenure and Promotion Committee in evaluating the faculty member's contribution in the area of teaching.

The Department's teaching evaluation questionnaire invites student response both through numerically quantifiable data, and written student comments. In conformity with University of Guelph Faculty Policy, the Department’s Tenure and Promotions Committee only considers comments signed by students (choosing "I agree" in question 14). Your instructor will see all signed and unsigned comments after final grades are submitted. Written student comments may also be used in support of a nomination for internal and external teaching awards.

Note: No information will be passed on to the instructor until after the final grades have been submitted.

## Standard Statements

### E-mail Communication

As per university regulations, all students are required to check their e-mail account regularly: e-mail is the official route of communication between the University and its students.

### When You Cannot Meet a Course Requirement

When you find yourself unable to meet an in-course requirement because of illness or compassionate reasons, please email the course instructor to make arrangements.

### Drop Date

At Guelph, the last date to drop one-semester courses, without academic penalty, is Friday, November 3rd. For regulations and procedures for Dropping Courses, see the Undergraduate Calendar.

### Copies of out-of-class assignments

Keep paper and/or other reliable back-up copies of all out-of-class assignments: you may be asked to resubmit work at any time.

### Accessibility

The University of Guelph is committed to creating a barrier-free environment. Providing services for students is a shared responsibility among students, faculty and administrators. This relationship is based on respect of individual rights, the dignity of the individual and the University community's shared commitment to an open and supportive learning environment. Students requiring service or accommodation, whether due to an identified, ongoing disability or a short-term disability should contact the Centre for Students with Disabilities as soon as possible.

For more information, contact CSD at 519-824-4120 ext. 56208 or email csd@uoguelph.ca or see the website: http://www.uoguelph.ca/csd/

### Academic Misconduct

The University of Guelph is committed to upholding the highest standards of academic integrity and it is the responsibility of all members of the University community – faculty, staff, and students – to be aware of what constitutes academic misconduct and to do as much as possible to prevent academic offences from occurring. University of Guelph students have the responsibility of abiding by the University's policy on academic misconduct regardless of their location of study; faculty, staff and students have the responsibility of supporting an environment that discourages misconduct. Students need to remain aware that instructors have access to and the right to use electronic and other means of detection.

Please note: Whether or not a student intended to commit academic misconduct is not relevant for a finding of guilt. Hurried or careless submission of assignments does not excuse students from responsibility for verifying the academic integrity of their work before submitting it. Students who are in any doubt as to whether an action on their part could be construed as an academic offence should consult with a faculty member or faculty advisor.

The Academic Misconduct Policy is detailed in the Undergraduate Calendar.

**Recording of Materials**
Presentations which are made in relation to course work—including lectures—cannot be recorded or copied without the permission of the presenter, whether the instructor, a classmate or guest lecturer. Material recorded with permission is restricted to use for that course unless further permission is granted.

**Resources**
The Academic Calendars are the source of information about the University of Guelph's procedures, policies and regulations which apply to undergraduate, graduate and diploma programs.

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### I. Equilibrium, state variables, and equations of state (6 lectures) [1.1, 1.2]

1) The microscopic world and the macroscopic world, temperature, thermal equilibrium
2) Kelvin scale of temperature, ideal gas equation of state, thermal expansion
3) Pressure; the isothermal atmosphere, Boltzmann factor
4) Differentials, partial derivatives, and the mathematics of functions of multiple variables
5) Interacting gas: the van der Waals equation of state, P-V diagram, isotherm
6) van der Waals fluid continued: isothermal compression, instability, phase transition (pp. 180 - 181)

### II. Conservation of energy: work and heat (5 lectures) [1.4 - 1.6]

7) Mechanical work; quasi-static, isothermal expansion of an ideal gas
8) Work is path-dependent, energy is a state function. What is heat? First law: energy conservation.
9) Internal energy, heat and temperature
10) Quasi-static, adiabatic expansion of an ideal gas, adiabatic atmosphere
11) Heat capacity at constant V or constant P, heat transfer example

## III. Microstates and multiplicity: the statistical origin of entropy (9 lectures) [2.1 - 2.5]

12) The big questions of thermodynamics, two-state system
13) Microvariables and microstates of the two-state system, counting microstates, constraints and the multiplicity function
14) **Test 1 (in class)**
15) Macrovariables and macrostates of the two-state system, Einstein solid
16) Multiplicity of the Einstein solid. Interacting systems: two Einstein solids in thermal contact
17) Two larger Einstein solids in thermal contact, most likely macrostate
18) Large systems, large numbers, behaviour of the multiplicity function
19) Sharpness of the multiplicity function, two macroscopic Einstein solids in thermal contact, behaviour near the peak: peak width and fractional peak width
20) Multiplicity of a monatomic ideal gas, indistinguishability, energy hyper-surface
21) Two interacting ideal gases, behaviour of multiplicity, entropy (finally!)

## IV. Entropy, second law, thermodynamic equilibrium, applications (11 lectures) [2.6, 3.1, 3.2, 3.4 - 3.6, 1.3, 1.6, 4.1]

22) Second Law: Increase of entropy following release of internal constraints
23) Entropy changes in ideal gas: isothermal expansion, adiabatic expansion, free expansion, mixing
24) Temperature, thermal equilibrium, heat flow and entropy
25) Behaviour of the heat capacity and entropy at low temperatures
26) Mechanical equilibrium, entropy and pressure, thermodynamic identity, relation between entropy and constant-pressure heat capacity
27) **Problem solving**
28) Diffusive equilibrium, chemical potential **(Test 2 in the evening)**
29) The isothermal atmosphere revisited, surface adsorption
30) Internal degrees of freedom, equipartition of energy, heat capacity data
31) Heat engines and the Carnot cycle
32) Entropy of the van der Waals fluid (pp. 180 - 186)

## V. Phase transitions and Gibbs free energy (4 lectures) [5.1 - 5.3]

33) Phase transitions, constant T, P, N, Gibbs free energy of van der Waals fluid, minimum free energy and equilibrium (pp. 170-171, 182-184)
34) Second law for constant T, P, N, thermodynamic identity, chemical potential
35) Phase transition in the van der Waals fluid, metastability and instability, jump in V and S at the liquid-gas transition
36) Slope of the phase boundary: the Clausius-Clapeyon relation
    **(Course evaluation)**