PHYS 3P41 - Statistical Physics
Course outline

Instructor: E. Sternin

About this course

Brock calendar entry

Introduction to probability distribution functions, accessible states, entropy, temperature, partition functions and relations to thermodynamic functions.

Introduction

Thermal physics is the branch of science which deals with collections of large numbers of particles, on the order of 10^{23}. The properties of almost anything we can measure in our world, be it the temperature of a star or a cup of coffee, are determined by the principles that you will learn in this course.

Fundamentally, statistical mechanics starts from the ground up: from microscopic, quantum mechanical states of the particles, to the bulk properties that arise when a *very large* number of such particles come together. This "science of large numbers" offers us a powerful way of scaling up from the microscopic so that, for example, we can explain why heat flows from how to cold, and make other accurate predictions about the outside world.

Pre-requisite

PHYS 2P50

Textbook

- *Thermal Physics*, by C.Kittel and H.Kroemer, 2nd Ed., W.H.Freeman & Co., New York, 1995.

Other references

- *Introduction to Thermal Physics*, by D.V.Schroeder, Addison Wesley, New York, 2000.
- *Statistical Physics*, by F.Reif, McGraw Hill, New York, 1965.
- *Heat and Thermodynamics*, by M.Zemansky and R.H.Dittman, 6th Ed., McGraw Hill, New York, 1981.

Lectures

08:00 - 09:00 M W Th, in MC J404

Tutorials

TBA

Instructor

E. Sternin (MC B206, ext. 3414, e-mail: ed.sternin@brocku.ca)

Topics to be covered

1. **Introduction**
   - thermodynamics *vs.* statistical physics
   - states of the system are quantum states

- model spin system; the degeneracy function
- probability distribution; calculating averages

2. **Fundamental concepts of thermal physics**
   - all accessible states of a closed system are equally probable
   - systems in thermal contact; entropy and temperature
   - the second law of thermodynamics
   - Examples
     - thermal engines
     - the direction of heat flow
     - paramagnetism
     - magnetic cooling
3. **Boltzmann distribution**
   - Boltzmann factor, partition function, canonical ensemble
   - a two-state system in detail; heat capacity
   - Helmholtz free energy
   - reversible processes
   - thermodynamic identity, $dU=TdS-pdV$
   - pressure
   - first of Maxwell relations
   - Example: N atoms in a box
     - energy is a function of temperature only
     - ideal gas law
     - entropy, Cv, Cp - the hard way
     - same, using free energy
     - Sackur-Tetrode equation
   - Example: a two-level system
   - Example: a harmonic oscillator

Test 1: TBA

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4. **Planck distribution**
   - QM description of a particle in a box
     - density of states
   - photons (EM radiation in a cavity)
     - density of states
     - black-body radiation - Planck radiation law
     - Stefan-Boltzmann law
   - phonons (elastic waves in solids)
     - Debye temperature
     - low-temperature limit - Debye T^3 law
5. **Gibbs distribution**
   - systems in diffusive contact
     - chemical potential
     - direction of particle flow
     - example: ideal gas
     - entropy and chemical potential
   - thermodynamic identity, summary of thermodynamic relations
   - Gibbs factor and Gibbs sum (the grand partition function)
     - example: a two-level system
   - other distribution functions: Bose-Einstein and Fermi-Dirac
   - classical regime: ideal gas, revisited
     - chemical potential, free energy, pressure
     - entropy: Sackur-Tetrode equation, Gibbs paradox
     - energy: degrees of freedom, heat capacity of diatomic gases
   - chemical potential and potential energy
     - example: isothermal atmosphere
   - chemical potential and work
     - example: reversible isothermal expansion

        - example: reversible isentropic process
        - example: irreversible expansion into vacuum
    - experimental tests of Sackur-Tetrode equations
    - fluctuations in an ideal gas

Test 2: TBA

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6. **Fermi and Bose gases**
    - Summary: Fermi-Dirac, Bose-Einstein, and classical distributions
    - degenerate Fermi gas in 3D
        - geometry, density of orbitals, Fermi energy
        - heat capacity of N fermions
        - approximations and heat capacity in real metals
    - temperature dependence of chemical potential
    - boson gas
        - Bose-Einstein condensation, BE condensation temperature
        - phase transition to a condensed state; superfluidity of He(4)
    - fluctuations in Fermi and Bose gases
    - BE condensation temperature and separation of energy levels
7. **Thermodynamic potentials**
    - Helmholtz and Gibbs free energy
    - Maxwells' relations through cross-derivatives of G
    - intensive and extensive variables
    - Enthalpy
    - example: derivation of Cp=Cv+R
    - example: equilibrium in chemical reactions, law of mass action, Saha equation

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Test 3: TBA

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8. **Imperfect gases**
    - derivation of the van der Waals equation (approximate)
    - law of corresponding states, the critical point
    - free energy and phase equilibria; Maxwell's construction
    - van der Waals formula is [one possible] interpolation
    - proper derivation of the vdW equation (a la Landau)
9. **Kinetic theory of gases**
    - Maxwell distribution of velocities
    - Transport processes: predictions of statistical mechanics
        - mean free path
        - phenomenological transport laws
        - derivation of a transport equation: viscosity
        - experimental example: from Boyle (1660) to Maxwell (1866)
        - transport of energy: heat
        - transport of the number of particles: diffusion
        - experimental example: pore size determination by NMR
10. **Introduction to interacting systems**
    - statistical mechanics: a quantum mechanical perspective
        - stationary states; energy representation; expectation values
        - random fluctuations in wave functions; time average
        - density matrix formalism
        - thermal average is the derivative of free energy
    - example: non-interacting spins in an external magnetic field; a review
    - the Ising model of a ferromagnet
        - mean-field approximation
        - self-consistency relation; graphical and numerical solutions
        - critical exponents; predictioins of mean-field theory

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Test 4: TBA

- **Student presentations:** TBA

Grading and the grading scheme

Component	Weight	Comments
Homework	-	assigned weekly, not marked
Tutorial Tests	65%	4 in-class tests, 15%+15%+15%+20%
Term paper and oral presentation	35%	there is no final exam in the course

Academic Integrity

Academic misconduct is a serious offence. The principle of academic integrity, particularly of doing one's own work, documenting properly (including use of quotation marks, appropriate paraphrasing and referencing/citation), collaborating appropriately, and avoiding misrepresentation, is a core principle in university study. Students should consult "Academic Misconduct" section in the Undergraduate Calendar to view a fuller description of prohibited actions, and the procedures and penalties. The University takes academic misconduct extremely seriously and will follow its strict procedures to the letter in all cases.

A helpful website explains Brock's Academic Integrity Policy. Please consult it, as all students are expected to know and abide by its provisions.

Courses may use `turnitin.com`, a phrase-matching software, to verify originality of your submitted lab reports and written assignments. If you object to uploading your assignmentsr to `turnitin.com` for any reason, please notify the instructor to discuss alternative submissions.

Be aware that it is the policy of the Department of Physics that any academic misconduct including (but not limited to) possessing, using or accessing unauthorized material in any form (including online) during final exams or assessments will *automatically* result in zero grade for the exam. Since most courses require a minimum passing grade on the final exam to complete the course, this will likely lead to a failure in the course.

FMS Penalties for Academic Misconduct

Unless otherwise specified, the Department of Physics follows the following minimum penalty guidelines for cases of academic misconduct in the Faculty of Mathematics and Science (FMS). Please be aware that the Associate Dean, Undergraduate Programs, may assign different penalties than those listed here, depending on the details of individual cases. Also note that cheating on exams carries significantly higher penalties.

First offence:
: Zero grade on the assignment, additional penalty of 100% of the weight of the assignment to be subtracted from the final grade, mandatory completion of the AZLS Academic Integrity workshop

Second offence:
: Zero grade on assignment, additional penalty of 200% of the weight of the assignment to be subtracted from the final grade, 4-month suspension

Third or additional offence:
: Zero grade in the course, 1-year suspension, permanent removal from major program.

Cheating on exams:
: Zero grade in the course, including for first offenses.

FMS Academic Policies

Intellectual Property Notice

All slides, presentations, handouts, tests, exams, and other course materials created by the instructor in this course are the intellectual property of the instructor. A student who publicly posts or sells an instructor's work, without the instructor's express consent, may be charged with misconduct under Brock's Academic Integrity Policy and/or Code of Conduct, and may also face adverse legal consequences for infringement of intellectual property rights.

Important dates

Please be aware of all the important dates, such as the first/last days of classes, snow days and reading week, as well as the deadline for withdrawal without academic penalty. For the current academic term, this information can be found here.

Accommodations

The University is committed to fostering an inclusive and supportive environment for all students and will adhere to the Human Rights principles that ensure respect for dignity, individualized accommodation, inclusion and full participation. The University provides a wide range of resources to assist students, as follows:

a. If you require academic accommodation because of a disability or an ongoing health or mental health condition, please contact Student Accessibility Services at askSAS@brocku.ca or 905 688 5550 ext. 3240.
b. **Medical Self-Declaration Forms** (brief absence up to 72 hours)

   In the case of a short-term medical circumstance, if a student wishes to seek an academic consideration, please use the Medical Self-Declaration Form. The request is to be made in good faith by the student requesting the academic consideration due to a short-term condition that impacts their academic activities (e.g., participation in academic classes, delay in assignments, etc.). The period of this short-term medical condition for academic consideration must fall within a 72-hour (3 day) period. The form must be submitted to the instructor either during your brief absence or if you are too unwell, within 24 hours of the end of your 3 day brief absence.

   Medical Verification Form (extended duration)

   In cases where a student requests academic consideration due to a medical circumstance that exceeds 72 hours (three days) and will impact their academic activities (e.g., participation in academic classes, delay in assignments, etc.), or in the case of a final exam deferral, the medical verification form must be signed by the student and the health professional as per process set out in the Faculty Handbook III:9.4.1.

c. If you are experiencing mental health concerns, contact the Student Wellness and Accessibility Centre. Good2Talk is a service specifically for post-secondary students, available 24/7, 365 days a year, and provides anonymous assistance. Follow the above link or call 1-866-925-5454. For information on wellness, coping and resiliency, visit: Brock University (Mental Health).
d. If you require academic accommodation on religious grounds, you should make a formal, written request to your instructor(s) for alternative dates and/or means of satisfying requirements. Such requests should be made during the first two weeks of any given academic term, or as soon as possible after a need for accommodation is known to exist.
e. If you have been affected by sexual violence, the Human Rights & Equity Office offers support, information, reasonable accommodations, and resources through the Sexual Violence Support & Education Coordinator. For information on sexual violence, visit Brock's Sexual Assault and Harassment Policy or contact the Sexual Violence Support & Response Coordinator at humanrights@brocku.ca or 905 688 5550 ext. 4387.
f. If you have experienced discrimination or harassment on any of the above grounds, including racial, gender or other forms of discrimination, contact the Human Rights and Equity Office at humanrights@brocku.ca.

For a full description of academic policies in the Faculty of Mathematics and Science, consult brocku.ca/mathematics-science/