| 科目名　Course Title | |
|---|---|
| 統計物理学2(Statistical Physics II) | |
| **学科・専攻　Department/Program** | **受講年次　Grade** |
| G30 Physics | 3rd |
| **授業形態　Class style** | **必修・選択の別　Compulsory or Elective** |
| 講義 | * See "Remarks" |
| **時間割コード　Registration code** | **開講期・曜日・時限　Semester,Day & Period** |
| 0680170 | Fall semester Fri：5 |
| **単位数　Credit** | **科目区分　Course type** |
| 2 | Specialized Courses |

| | |
|---|---|
| **担当教員　Instructor** | WOJDYLO John Andrew(WOJDYLO John Andrew) |
| **所属研究室　Laboratory** | S-Lab |
| **連絡先　Contact** | john.wojdylo@s.phys.nagoya-u.ac.jp |
| **居室　Room** | ES035 |

## 講義の目的とねらい　Course purpose

This unit is the first half of a full-year course. After learning the mathematical structure of thermodynamics and why thermodynamics works – with many examples of systems beyond the ideal gas -- students are introduced to equilibrium statistical mechanics, which describes the equilibrium conditions of systems consisting of a large number of particles. Applications are considered in condensed matter physics, solid state physics, cosmology, chemistry, materials science and biology. Problem-solving is an integral part of the course: students should attend fortnightly tutorials (Physics Tutorial III) where they will discuss many of the assignment questions and receive hints for solutions. Weaker students are particularly encouraged to attend tutorials and submit assignments. This semester students are thoroughly prepared for quantum statistical mechanics in SP3 next semester. It is recommended that students take Quantum Mechanics II concurrently.

At the end of Statistical Physics III next semester students will be adequately prepared with regards to their knowledge of statistical mechanics and thermodynamics to undertake further studies in S-lab, R-lab, TB-lab, E-lab, H-lab, QG-lab and other, including experimental, labs in both the Department of Physics and Department of Applied Physics, as well as chemistry and computational biology labs at Nagoya University. A knowledge of statistical mechanics (quantum and classical) is essential for students interested in experimental physics, theoretical physics, chemistry and mathematical biology.

## 履修要件　Prerequisite

Calculus I; Calculus II; or Consent of Instructor

## 履修取り下げの方法について　How to Apply for Course Withdrawal

<「履修取り下げ届」提出の要・不要 Necessity/Unnecessity to submit "Course Withdrawal Request Form">
Necessary
<条件等 Conditions>
Withdraw by the official deadline in November.

## 成績評価　Grading

Attendance: 5%; Weekly quizzes or other written assessment: 30%; Midterm exam: 32.5%; Final Exam: 32.5%

**不可（F）と欠席の基準　　Criteria for "Absent" &"Fail" grades**

The “ Absent ” grade is reserved for students who withdraw by the official deadline in November. Unless there are exceptional circumstances, after that day, a letter grade will be awarded based on marks earned from all assessment during the semester.

**関連する科目　　Related courses**

Quantum Mechanics II; Physics Tutorial III; Statistical Physics III (next semester). It is strongly advised that students concurrently enroll in Physics Tutorial III.

**教室　　Class room**

Check the Course Timetable.

**授業内容　　Content**

Course Contents Callen Chapts 1-8, 15-17, 21 (some parts omitted); Reif Chapts 1-3, 6-7, Appendix A12. Some topics are more fully explored in tutorials. Lectures are recorded on video and will be available on Youtube (private channel).

Lecture 1. Fundamental Relation, Entropy Representation; Postulates of the Entropy. Partial derivatives and experiments. Thermodynamic coordinates. Existence of the internal energy thermodynamic potential. Existence of an entropy function of state -- proof from within thermodynamics. Basic postulates of thermodynamics. Nernst Postulate (3rd Law of Thermodynamics.) Fundamental relation in the Entropy representation. Based on Callen Chapter 1; and Zemansky and Dittman Chapter 2.

Lecture 2. Top-Down Approach: Equations of State from the Fundamental Relation. Examples. Extensive parameters are homogeneous order 1. Intensive parameters are homogeneous order 0. Thermal and Mechanical Equlibrium. Euler relation. Gibbs-Duhem relation. Based on Callen Chapter 2.

Lecture 3. Bottom Up Approach: Fundamental Relation from the Equations of State. Mathematical theorems underlying thermodynamics. Examples of applying compatibility condition, Gibbs-Duhem Relation, Euler Relation, 1st Law in molar form. 2nd Equation of State from van der Waals Equation of State. Example: rubber band; photon gas; Fundamental Relation for one-component ideal gas. Ideal gas: "Gibbs Paradox"? Entropy of a mixture: “ entropy of mixing ” . Molar heat capacity and other derivatives. Based on Callen Chapter 3.

Lecture 4. The Maximum Work Theorem. Possible and impossible processes. Quasistatic and reversible processes – how can temperature be increased reversibly? Heat flow and coupled systems. The maximum work theorem (proof without using Carnot cycle). Carnot Efficiency. Carnot cycle: why is it necessary? Carnot cycle for a photon gas.

Lecture 5. Thermodynamic potentials and their physical interpretation. The Legendre transform. Thermodynamic potentials: internal energy, Helmholtz free energy, Gibbs free energy, enthalpy. Based on Callen Chapter 5.

Lecture 6. The Extremum Principle in the Legendre Transformed Representations. Physical meaning of the potentials: a first look. Minimum principles. Applications of thermodynamics. How to measure the entropy. How to liquefy gases -- throttling (Joule-Thompson process). Based on Callen Chapter 6.

Lecture 7. Maxwell's relations and applications. Algorithm for reducing thermodynamic derivatives to a combination of easily-measurable quantities. Applications: adiabatic compression; isothermal expansion; free expansion. Based on Callen Chapter 7.

Lecture 8. Introduction to Statistical Mechanics: the “ flavour ” of SM. Intuitive introduction to the SM of “ isolated ” systems: i.e. entropy representation – microcanonical ensemble (semi-classical treatment). Why are predictions possible at all? Central Limit Theorem. Postulate of equal a priori probability. Importance of the number of accessible states Omega. Some examples of counting Omega: Einstein model of a crystalline solid; the “ two-state model ” and the Schottky Hump. Entropy and Omega. Equilibrium conditions. Combinatorial methods for counting Omega are usually difficult and of limited use – two ways to overcome this: 1) take advantage of high dimensionality [today]; 2) use Legendre transformed representations [later]. Based on Callen Chapter 15.

Lecture 9. Basic Facts About the Binomial Distribution. How a Gaussian emerges from the binomial distribution; mean, variance, standard deviation, etc. Reif Chapter 1. NONEXAMINABLE: Theory of the Classical Microcanonical Ensemble: Gibbs Ensemble; Classical Liouville Theorem; role of symmetry in Statistical Mechanics. Classical microstates. The density function and thermodynamic averages. Classical Ergodic Theorem. (Huang p. 52-54; 62-65; 127-135). The density function is a conserved quantity, therefore it must be expressible as a linear combination of fundamental additive conserved quantities. (Lifshitz and Pitaevski p. 11.)

Lecture 10. Evolution of an Isolated System to Equilibrium – Entropy. Why do isolated systems tend to equilibrium; why do systems evolve out of equilibrium states? Why do systems in an ensemble want to occupy each possible state equally; why do probability distributions want to be flat, thus maximizing our ignorance of the system state? Why does entropy increase in a spontaneous process? Why is entropy maximum at equilibrium? Why S=k Log(Omega)? Why S=-k Sum{pr Log pr}? Principle of Detailed Balance; Boltzmann ’ s H-Theorem. (Reif A12.)

Lecture 11. Statistical Mechanics in the Helmholtz Representation: Canonical formalism. Canonical partition function. Boltzmann probability distribution derived for a system in contact with a heat reservoir. Connection with thermodynamics. Weakly-interacting systems: additivity of energies and factorizability of the partition function. Basic examples. (Callen 16-1, 16-2.)

Lecture 12. Canonical Partition Function cont ' d. Fluctuations. Adiabatic work. Microscopic effect of work and heat. In equilibrium, energy probability distribution is Gaussian: overwhelming probability that the system is within 1 std dev of the mean. 3rd Law of Thermodynamics. If mean energy of a system is known then the canonical ensemble applies (temperature is fixed). Proof: allow energy of the system to fluctuate and use Method of Lagrange Multipliers to find the MOST PROBABLE probability distribution, which is Boltzmann's distribution. (Reif Chapter 6.)

Lecture 13. Paramagnetism. NONEXAMINABLE: 1st Law of Thermodynamics for Magnetic Systems: role of a pair of intensive and extensive parameters is swapped (Kittel Chapt. 18; Callen Appendix B). Examinable: We solve the problem of paramagnetism first for spin-1/2 case then for the arbitrary spin case. (Reif p. 206-208; 257-262.)

Lecture 14. The Classical Limit via Classical Counting. Why is our approach classical, even when using energy eigenvalues from QM? What characterizes the classical limit? Example: internal modes of a gas (Callen 16-3). DENSITY OF STATES (important for next semester) (Callen 16-6). The classical density of states (Callen 16-9). How the classical partition function emerges from the semi-classical partition function. Classical ideal gas: equations of state, entropy (Reif 7.2, 7.3 p 239-246). The classical equipartition theorem (Reif 7.5 p 248-250).

Lecture 15. 1. Kinetic Theory of Dilute Gases in Equilibrium. Maxwell velocity distribution. Distribution of a component of velocity. Speed distribution: mean, rms, most probable speeds. (Reif 7.9, 7.10). NONEXAMINABLE: 2. Fundamental Postulates of Quantum Statistical Mechanics: in an isolated system, equal a priori probabilities and the postulate of random phase. The operation of taking a statistical average and quantum average simultaneously: the density operator. Properties of the density operator. Canonical partition function in terms of the density operator. Why the off-diagonal entries of the density operator must be zero – this leads to random phase postulate. Meaning of the de Broglie wavelength in a gas in equilibrium at temperature T.

## 教科書　　Textbook

1. Callen, H., Thermodynamics and an Introduction to Thermostatistics, 2nd ed.,Wiley, 1985. (The central textbook in this course. Japanese translation has fewer typographical errors.)

2. Reif, F., Fundamentals of Statistical and Thermal Physics, McGraw-Hill, 1965.

Many copies of the textbooks are available in the G30 section of the Science Library.

## 参考書　　Recommended reading

1. Kittel, C., Elementary Statistical Physics, Dover, 2004. Highly recommended. Cheap to buy.

2. Kittel, C. and Kroemer, H., Thermal Physics, W.H. Freeman. (Try as alternative.)

3. Zemansky, M.W. and Dittman, R.H., Heat and Thermodynamics, An Intermediate Textbook, McGraw-Hill, 1992. (Excellent for empirical basis of thermodynamics.)

4. Blundell, S. and Blundell, K., Concepts in Thermal Physics, 2nd Ed., Oxford University Press, 2010. (Elementary explanations. Try this as an alternative. Many copies available in the library.)

5. Huang, K., Statistical Mechanics, Wiley. (Advanced reference.)

6. Landau, L.D. and Lifshitz, E.M., Statistical Physics, Part I, by E.M. Lifshitz and L.P. Pitaevskii, Pergamon Press. (A classic book: thorough, advanced treatment.)

## 連絡方法　　Contact method

## その他　　Remarks

*See Course List and Graduation Requirements for your program for your enrollment year.

- Students taking Statistical Physics II should also take Physics Tutorial III.

- Students taking this course must be confident in multivariate calculus.

- Concurrent enrolment in Quantum Mechanics II is advised.