Northeastern University

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

ME 7280 Statistical Thermodynamics

Spring Semester 2011 Professor Cipolla 247 Snell Engineering Center 617-373-3805

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GENERAL COURSE INFORMATION

Introduction: *Statistical Thermodynamics* is part of a broader subject called Statistical Mechanics, but is restricted to systems in equilibrium, as is Classical Thermodynamics. The objective of a statistical approach to thermodynamics is to develop the theory of macroscopic thermodynamic properties using a suitable microscopic model of molecular interactions.

In this course we will use a quantum mechanical description of the motion of the individual constituents of which systems are comprised. We will begin by using elements of probability to develop the properties if systems composed of non-interacting, independent particles. Later in the course we will introduce the theory of ensembles to find the probability that systems of the ensemble are in particular quantum states. With these probabilities we can then determine theoretical expressions for thermodynamic properties in terms of molecular parameters. It will turn out that the macroscopic thermodynamic of greatest utility will be the Helmholtz free energy, in terms of which all other properties may be found either directly or by differentiation. The Helmholtz free energy will be found in terms of a new quantity, unique to statistical thermodynamics, called the partition function, or sum over states.

Once the basic theory is compete, we will look at cases of particular interest; ideal and non ideal gases, thermal radiation (an ideal gas of photons), lattice vibrations in a solid (an ideal gas of phonons) and the free electron theory of metals.

Relevance: Because statistical thermodynamics results in theoretical expressions for thermodynamic properties, it is an aid to correlating measurements of properties and for developing predictive tools for use in the design and analysis of thermal systems. For example we will be able to derive expressions for the specific heat of substances as a function of temperature, based on a molecular model of the molecules of which the substance is composed. This is not possible to do simply using classical thermodynamics. In addition, systems with chemical reactions, or in which the relaxations of internal excitations is relevant, will benefit from a statistical approach. We will be able to derive the equilibrium constants for ideal gas chemical reactions using this approach.

Another current area of importance for mechanical engineers lies in the increasing interest in the development of nanoscale mechanical and thermal systems. This has led to a resurgence of interest in energy transport at microscopic scales, requiring knowledge of the fundamentals of statistical thermodynamics. Although transport processes themselves are a non-equilibrium phenomenon, we normally assume such processes to occur in a condition of local equilibrium. This assumption underlies all of fluid mechanics and heat transfer, where it is essential to be able to define properties such as temperature, pressure, internal energy, enthalpy and entropy at a point in a system where there are macroscopic gradients.

Microscale phenomena frequently occur on such short length and time scales that the principle of local equilibrium can no longer be assumed to hold, but must be tested in each application. Knowledge of microscopic transport becomes essential to a proper understanding of the phenomena. This course is the first step in developing such an understanding. If time permits, the course will conclude with a brief introduction to non-equilibrium transport, with a focus on the kinetic theory of gases.

Who Should Take This Course: This is a course for anyone seeking to expand their understanding and knowledge of thermodynamics. If you wish to develop credible

understanding of entropy then this is the course for you! Since the course is specifically geared to mechanical engineers, it is assumed that everyone has a good background in thermodynamics that would come, for example, from a graduate level course that included topics such as fundamental equations, Maxwell relations, entropy, internal energy, equations of state and the laws of thermodynamics. No knowledge of quantum mechanics is assumed, but students are expected to be familiar with Lagrangian and Hamiltonian dynamics. Mathematical preparation is confined to knowledge of what would be called Advanced Calculus, such as is taught in the first Math Methods course in this program, including solving partial differential equations using separation of variables.

The Text: We are using **Statistical Thermodynamics: Fundamentals and Applications by Normand M. Laurendeau.** Professor Laurendeau is a mechanical engineering professor at Purdue University he has structured the text from the viewpoint of modern applications of Statistical Thermodynamics to systems of current interest in research. The level of preparation in thermodynamics and mathematics is about what most mechanical engineers would normally have. The fundamentals are nicely done and relevant material from classical thermodynamics is integrated into the text. The book's strength is the depth to which it explores the use of spectroscopy in developing molecular properties of interest in thermodynamics and in analyzing measurement techniques of interest in combustion.

Course References

Books by mechanical engineering professors:

- Tien and Lienhard: **Statistical Thermodynamics.** This book takes an approach that is closest to that we will follow in this course.
- Carey: Statistical Thermodynamics and Microscale Thermophysics
- Kestin and Dorfman: A Course in Statistical Thermodynamics
- Van Wylen and Sonntag: Fundamentals of Statistical Thermodynamics

Other References mainly by physicists and chemists:

- Lee, Sears and Turcotte: Statistical Thermodynamics.
- Mc Quarrie: **Statistical Mechanics.** This is an excellent text by a physical chemist with applications to systems of interest in that field. The fundamentals are terse, but clean.
- Schroedinger **Statistical Thermodynamics.** This is the classic book that lays out the fundamentals of ensemble theory in a succinct way.
- Hill **Introduction to Statistical Thermodynamics.** An excellent and readable account. Topics similar to McQuarrie.
- Mayer and Mayer **Statistical Mechanics.** A classic.
- Pathria **Statistical Mechanics**.
- Schiff **Quantum Mechanics.** Excellent physical discussion of the physical basis of quantum mechanics. Any other more modern book will do as well for our purposes.