COURSE OUTLINE PY541

I. FUNDAMENTALS (9.5 lectures)

1) Introduction to Probability (1.5 lectures)
   (a) Motivation and basic ideas
   (b) Fundamental laws of probability
   (c) The one-dimensional random walk
      –The binomial distribution, Stirling's approximation, and the Gaussian approximation
   (d) Central limit theorem

2) Thermodynamic Equilibrium (3 lectures)
   (a) The microcanonical ensemble
      –Equal *a priori* probability principle; equivalent definitions of entropy
      –*Mathematical interlude:* method of steepest descent and application to thermodynamics
      –Sharpness of thermodynamic equilibrium in the $N \to \infty$ limit
   (b) Definition of temperature and entropy
   (c) General conditions of equilibrium
      –Role of T, p, and μ in determining equilibrium
      –Extrema principles; basic thermodynamic relations
   (d) The canonical ensemble
      –The Boltzmann factor and the Helmholtz free energy

3) Connection Between Thermodynamics and Statistical Mechanics (2.0 lectures)
   (a) Canonical ensemble
      –Relation between partition function and Helmholtz free energy
      –Equivalence to the microcanonical ensemble; the distribution of energy
      –Computation of averages; distribution of energy and energy fluctuations
      –The equipartition theorem
   (b) Grand canonical ensemble
      –Gibbs factor, thermodynamic potential, and equation of state
      –Computation of averages; distribution of particle number and its fluctuations
      –Chemical equilibrium

4) Illustrative Examples (1.5 lectures)
   (a) The paramagnet
      –Basic thermodynamic response functions – m, χ, C_H
   (b) Ideal gas in the canonical ensemble
      –Classical and quantum limits, the Maxwell-Boltzmann distribution
   (c) Elementary kinetic theory
      –Maxwell-Boltzmann distribution; molecular flux and collisions
      –Linear transport processes: electrical, heat, & particle conductivity, viscosity
   (d) Einstein model for a solid
   (e) The Langmuir adsorption isotherm

5) Thermodynamics of Homogeneous Systems and Applications (1.5 lectures)
   (a) Maxwell relations
   (b) Heat capacity
      –General relation between c_p and c_V and its physical meaning
   (c) Heat engines and refrigerators
      –Contrast between adiabatic and isothermal processes in an ideal gas

II. STATISTICAL MECHANICS OF IDEAL QUANTUM SYSTEMS (8 lectures)

1) Introduction (1.5 lectures)
   - (a) Derivation of the quantum distribution functions
     - –Qualitative role of quantum effects
     - –Fermi-Dirac, Bose Einstein, Planck distributions, and the Maxwell-Boltzmann limit
   - (b) Statistical mechanics of ideal quantum gases
     - –Equation of state and its consequences
   - (c) Classical limit of the quantum distributions
     - –the effective statistical potential

2) Fundamentals and Applications of Fermi Statistics (4 lectures)
   - (a) Screening of Coulomb interactions in condensed systems
   - (b) Thermodynamics
     - –equation of state, mean energy, and heat capacity of a Fermi gas
   - (c) Low-energy excitations
     - –Thermionic emission; photoelectric effect
   - (d) Magnetic properties
     - –Pauli paramagnetism
     - –Landau diamagnetism; de Haas-van Alphen effect
   - (e) White dwarf stars

3) Fundamentals and Applications of Bose Statistics (2.5 lectures)
   - (a) Basic thermodynamics and Bose-Einstein condensation
   - (b) Black-body radiation
     - –Thermodynamics of a photon gas
     - –Stefan-Boltzmann law and its applications
   - (c) Phonons in solids

III. STATISTICAL MECHANICS OF INTERACTING SYSTEMS (8 lectures)

1) Non-Ideal Gases (2 lectures)
   - (a) Cluster expansion for the partition function
   - (b) The virial expansion
     - –Derivation of leading corrections to ideal behavior and its physical interpretation
   - (c) Basic thermodynamic properties of non-ideal gases
     - –Van der Waals equation of state: isothermal and phase properties

2) Phase Transitions and Equilibria (2 lectures)
   - (a) Basic phenomenology and general principles
     - –First-order transitions, critical point, triple point; Lee-Yang theorem
   - (b) The Maxwell construction
   - (c) Clausius-Clapeyron equation
   - (d) Interfacial effects and metastability phenomena

3) Phase Transitions in Spin Systems (4 lectures)
   - (a) Introduction and basic phenomenology
     - –Universality and critical exponents; role of spatial dimensionality

(b) Mean-field theory
   –Self-consistent approximations and microscopic approaches
(c) Landau and Landau-Ginzburg theory of phase transitions
   –Landau expansion of the free energy; the Ginzburg criterion
(d) Exact solution of the one-dimensional Ising model
(e) Approximation methods for arbitrary spatial dimension
   –High-temperature expansion
   –Low-temperature expansion
(f) Disordered Spin Systems
   –random coupling strengths, random field systems, and spin glasses

IV. BIOPHYSICAL APPLICATIONS (2 lectures)

Topics currently in development.