Thermodynamics and Statistical Mechanics—Content(64 hours)
(SJTU Zhiyuan College Physics Major Undergraduate)

Part one: Framework of equilibrium stat. mech. (26-28 hours)

Chapter 1 Thermodynamics (4-5 hours)

1) Large systems, small systems, macroscopic states and microscopic states, thermodynamic equilibrium
2) Zeroth laws of thermodynamics, equivalence class, definition of temperature
3) First law, conservation of energy, heat, work, conjugate variables, perpetual motion of first kind
4) Second law, heat engine, Carnot theorem, Entropy, Principle of maximum entropy,
5) Arrow of time, paradox of irreversibility, perpetual motion, absolute temperature
6) Third law and its quantum mechanical origin

Selective topic: Cooling techniques, history and status quo

Chapter 2 Ensemble theory (10-12 hours)

1) Microcanonical ensemble, isolated systems, fundamental postulate of equal a priori probability, Boltzmann Entropy, principle of maximum entropy
2) Conditions of equilibrium, condition of stability, temperature, pressure, chemical potential
3) Canonical ensemble, Gibbs distribution, partition function, Helmholtz free energy, thermodynamic relations, fluctuations, central limit theorem, equivalence of ensembles
4) Grand canonical ensemble, grand potential, Gibbs Duhem relation
5) Principle of maximal entropy revisited, principle of minimal free energy, and equivalence with the fundamental postulate, Lagrange multiplier.

Selective topic: Variational principle in theoretical physics

Chapter 3 Description and evolution of many body states (10-12 hours)

Quantum systems (6-8 hours)

1) Manybody states, mixed state, density matrix
2) Evolution of density matrix, Von Neumann entropy, Von Neumann equation, evolution of entropy, quantum entanglement
3) Quantum ensembles, theorem of spin-statistics, Pauli's exclusion principle, Slater determinant
4) Fermi-Dirac statistics, Bose-Einstein statistics,
5) High temperature limit, Maxwell-Boltzmann statistics

Classical systems (4 hours)

1) Hamiltonian equation, Liouville equation, Poisson Bracket
2) Liouville theorem, Gibbs entropy and its evolution
3) Poincare's recurrence theorem, ergodicity, mixing, chaos

Selective topics: Entropy, information entropy, quantum entanglement entropy

Part two: Applications of equilibrium statistical mechanics (26 hours)

Chaper 4 Non-interacting systems (12 hours)

Classical systems (3-4 hours):

1) Ideal gas, gas mixture, Gibbs paradox, Maxwell's demon, mixing entropy
2) 2) Equipartition and its failure, poly-atomic molecular gas.
3) Two level systems, negative temperature,
4) paramagnetism, Curie's law, Ising model

Quantum systems (8-10 hours):

1) Density of states, one, two, three dimensional cases, boundary conditions
2) Fermi gas, Sommerfeld expansion, high T expansion, low T expansion
3) White dwarf, neutron star, black hole
4) Bose gas, BEC, Debye theory for lattice vibration,
5) Black body radiation, Johnson noise, cosmic microwave background
6) Bose-Einstein condensation

Chapter 5 Interacting many body systems (6 hours)

1) Interacting gas, Mayer's cluster expansion, van der Waals equation
2) Hard sphere gas, Onsager;s theory for nematic liquid cystals
3) Coulomb gas, Poisson-Boltzmann theory, Debye Hucke theory

Chapter 6 Phase transitions (6-8 hours)

1) Classification of phase transition, phase diagram, Ising model, Mean field theory
2) 2nd order phase transition, Landau theory, order parameter, symmetry breaking
3) Critical phenomena, scaling law, renormalization group, soft modes, fluctuations, topological defects
4) 1st oder phase transition, coeixtence, domain wall, binary systems, phase separation

Selective: topics: Spinodal decomposition, generalized elasticity, quantum phase transitions

Part Three: Non-equilibrium statistical mechanics (8 hours)

Chapter 7 Non-equilibrium Phenomena (4-6 hours)

1) Linear response theory
2) Fluctuation-dissipation theorem, Onsager's reciprocal relations
3) Brownian motions, Langevin equation

Selective topics: Fluctuation theorem, Jarzynski equality

Chapter 8 Paradox of irreversibility revisited (2 hours)

Selective: topics: Irreversibility of classical systems, ergodicity, recurrence, chaos
Selective: topics: Irreversibility of quantum systems, measurement, collapse of wave functions, many universe, decoherence,
Selective: topics: Second law, arrow of time

Review and Summary (2 hours)

Student Presentation (2-4 hours)

Topics of Essays:

1) Cooling techniques, history and status quo
2) Variational principle in theoretical physics
3) Thermodynamic entropy, Gibbs entropy, information entropy, and quantum entanglement entropy
4) Poincare's recurrence theorem, ergodicity, chaos, arrow of time, second law
5) Quantum mechanical irreversibility, collapse of wave function, multi-universe, decoherence
6) Cosmic microwave background, big bang, origin and destiny of universe
7) Phase transition, symmetry breaking, Ising model, critical phenomena
8) Symmetry breaking and generalized elasticity
9) Liouville theorem and Jarzynski equality, fluctuation theorems
10) Random walk and statistics of polymers
11) Any other interesting topics related to statistical physics (need consensus from the intructor)