STATISTICAL MECHANICS

Text Book: R. K. Pathria, Statistical Mechanics

Reference Books:
L. D. Landau and E. M. Lifshitz, Statistical Physics, Part I
K. Huang, Statistical Mechanics
S. K. Ma, Statistical Mechanics

Course Outline

1. Brief Review of Thermodynamics: (chapter II of Landau and Lifshitz) thermal equilibrium and the laws of thermodynamics, temperature, energy, entropy and its relation to information theory, and other functions of states
2. Classical Statistical Mechanics (chapter 1,2,3,4 of Pathria): postulates, microcanonical, canonical, and grand canonical ensembles, statistical mechanics of non-interacting systems
3. Quantum Statistical Mechanics (chapter 5 of Pathria): postulates, density matrix, statistical mechanics of identical particles.
4. Ideal Fermion System (chapter 8 of Pathria)
5. Ideal Boson System and Bose-Einstein condensation (chapter 7 of Pathria)
6. Interacting Classical Systems (chapter 9 of Pathria): virial and cluster expansions, origin of van der Waals equation of state, liquid-gas transition, critical end-point, critical exponents
7. Mean field theory and phase transitions (chapter 11,12 of Pathria) Ising and related models, Landau theory, correlation functions, linear response, fluctuation-dissipation, ciritical phenomena
8. Kinetic theory and Boltzman equation, Fokker-Plank and Master equations, Langevin equation, and other related issues.

Course outcomes

understand the relation between thermodynamics of macroscopic states and statistical mechanics of classical and quantum systems with many microscopic degrees of freedom.

use statistical mechanics to describe various physical/measurable quantities of non-interacting classical and quantum systems:
classical ideal gas, non-interacting fermion and boson systems, Bose-Einstein condensation.

describe interacting systems by a perturbation theory in density of particles around the

non-interacting limit
and its relation to theory of phase transitions.

general mean field theory of interacting systems and basic understanding of the origin of phase transitions

basic theory of non-equilibrium systems and understanding of how the equilibrium is reached.

ELECTROMAGNETISM

Course Text: Jackson – 3rd Edition

Course Outline

The first three chapters are an advanced review of undergraduate E&M. Parts of the first chapter provide a complete review and allow the student to make connection with Jackson's units, vector calculus conventions and notations. We suggest incoming students read the first three chapters and perhaps complete a 'problem set' based on problems from the end of the first chapter before term starts. (although this has serious logistical problems)

Wk 1 lightening overview

Wk 2: Chapter 4 Multipole expansions
Energy distributions in an electric field
Electrostatics in dielectric media

Wk 3: Chpt 4 (cont) Boundary value problems with dielectrics
Electric susceptibility
Electrostatic Energy in dielectric media

Wk 4: Chapter 5 Magnetostatics
Biot-Savart Law
Amperes law, Magnetostatics differential equations
Vector potential

Wk 5: Chpt 5 (cont) Magnetic field of localised current distributions
Magnetic fields in macroscopic media (B and H)
Magnetised sphere in an external field
Permanent magnets

Wk 6: Chapter 6 Faraday's laws of inductions
Energy in a magnetic field
Maxwell's displacement current
Vector and Scalar potentials

Wk 7: Chpt 6 (cont) Gauge transformations (Lorentz, Coulomb gauges)
Green's functions of wave equation
Poynting's Theorem for charged particles in EM fields
Energy conservation, impedance and admittance

At this point the book becomes more “topical”. We need to select material that covers a spectrum of interests, rather than homing in on the “favourite chapter” of the lecturer!

Wk 8: Chapter 7 Plane waves in non-conducting medium
Linear and circular polarisation (Stokes parameters)
Reflection at interface between two dielectrics
Total internal reflection

Wk 9: Chpt 7 (cont) Dispersion characteristics of dielectrics, conductors
Wave propagation in ionosphere and magnetosphere
Wave propagation in conduction and dissipative media
Super-position of waves, group velocity

Wk 10: Chapter 8 Fields at the surface of a conductor
Wave guides, modes in a rectangular wave guide
Energy flow and attenuation in wave guides
Resonant cavities

Wk 11: Chpt 8 (cont) Power loss in a cavity: Q
The ionosphere as a resonant cavity
Dielectric waveguides
Impedance of a flat strip conductor pair (AKA TV antenna)

Wk 12: Chapter 9 Fields from an oscillating source
Dipole fields, radiation, magnetic dipoles/quadrupoles
Centre-fed linear antenna
Scattering at a Long waveguide

Wk 13: Chpt 9 (cont) Perturbation theory of scattering (Rayleigh Blue Sky)
Scalar diffraction theory
Babinet's principle of complementary sources
Diffraction at a circular aperture

Could also consider a briefer treatment of chapter 9, to allow a one week look at chapter 10 and EM wave propagation in a plasma. It might be nice to get to chapters 11 and 12 (relativity and propagation of charged particles in an EM field) but probably to do that one would have to skip chapters 8 and 9 or only spend one week each on 8, 9, 11 and 12.

OUTCOMES

- Knowledge of E&M
- Comfort with vector calculus and related mathematical manipulations
- Some knowledge appropriate to various research fields.

QUANTUM MECHANICS

Course Text: Cohen-Tannoudji (CT) vol's 1 & 2, and Sakurai's Advanced QM (Sa).

Reference Books:
Shankar (Sh),

Course Outline

wk 1: A quick review of math background and basic postulates + summary of simple 1D problems (wells, steps, tunneling)
Sh Ch 1-4, 9, 10.
CT II-III (AIII & NIII?)
Complement: FIII-GIII (evolution operator, Heisenberg picture,...)

wk 2: Simple harmonic oscillator (CT V) + some complements (time-dependence, quasi-classical states, and/or cetera)

wk 3: Many degrees of freedom, identical particles (bosons and fermions); exchange, Hartree-Fock,...
Sh Ch 10
CT XIV

wk 4: Path-integral formulation: deriving operator formalism from path-integral, and the other way
Sh Ch 8 & a part of Ch 21 (21.1)

wk 5: Symmetries (conservation laws and Ward identy)
Sh Ch 11 (or a better description based on path-integral)

wk 6: Angular momentum, Clebsch-Gordon, Wigner-Eckart,...
Sh Ch's 12 + 15
CT VI + X + BX + DX
Complement: EVI (Landau levels)? Selection rules?

wk 7: Hydrogen atom and spin & magnetism
Sh Ch 13 & 14
CT VII & DVII
Complement: CT EVII and molecular orbitals? FVII on molecular spectra?

wk 8: Variational methods & time-independent Perturbation theory
Sh Ch 16 & 17
CT XI

Complement: Fine & hyperfine structure as an example (CT XII)

wk 9: Time-dependent perturbation theory (sudden, adiabatic, level crossings, Fermi's Golden Rule)
Sh ch 18
CT XIII
Complement: periodic (resonant) perturbations (CT XIII-C and/or CXIII)

wk 10: Scattering theory (Born approx, partial waves, scattering phase shift, optical thm)
Sh Ch 19
CT VIII

wk 11: The Dirac equation
Sh Ch 20
SA 3

wk 12: Second quantisation
SA 2

wk 13:
Make up for overestimate in amount of material which can be covered!
And/or special topics: presumably each prof will have his/her own, but it should already be noted that the following items are absent from the above list:
WKB, instantons
Spin-1/2 specifically; double-well tunneling,...
Periodic potentials, Bloch's theorem
Entanglement, Bell's Inequalities, quantum information
Nonlinear Schrodinger equation, self-consistent (Thomas-Fermi) solutions,...
quantization of constrained/gauge systems etc, ...
{Presumably some of these topics may also fit into the "complements"}

Outcomes

The course should cover the important subjects which are sometimes omitted in undergraduate QM courses in US and Canadain Universities, but are indispensable for graduate level study and research in almost all area. They include, as the minimum set,

* path-integral formulation
* symmetries (conservation law and Ward identity)
* angular momentum and representation theory (Clebsch-Gordon, Wigner-Eckart)
* Various approximation methods such as WKB (tunneling/instantons)

* Scattering theory (partial waves, Born approx, optical theorem)
* The Dirac equation
* perturbation theory (including the adiabatic theorem, level crossings, and periodic perturbations)
* 2nd quantisation
* the density matrix
* Exchange effects, Hartree-Fock,...
* Heisenberg & Schrodinger pictures

Especially, path-integral formulation is essential in many areas but are not usually taught in Canadian/US undergraduate. Therefore it must be one of the main subjects to be taught in this course.
By the end of the course, students should be comfortable not only with the basic postulates of quantum mechanics and with undergraduate topics such as the spectrum of the Hydrogen atom, but with a range of standard techniques for dealing with problems. These will include scattering theory, perturbation theory, variational & WKB methods, the density matrix, and Hartree-Fock. Students will also be introduced to the idea and applications of path-integrals as well as relativistic quantum mechanics and 2nd quantisation.

FLUID MECHANICS

Course Text:
P.K. Kundu & I.M. Cohen: "Fluid Mechanics", 2nd ed., Academic Press, 2002 (for all but the last topic)

U. Frisch: "Turbulence", Cambridge, 1995 (for the last topic)

Reference Texts:
D.J. Tritton: "Physical Fluid Dynamics", 2nd ed., Oxford, 1988

T.E. Faber: "Fluid Dynamics for Physicists", Cambridge, 1995

Course Outline:

Basic concepts (continuum hypothesis, liquids and gases, etc) [1]

Kinematics (incl. material derivative) [1]

Derivation of the Navier-Stokes equations [3]

Conservation laws, Bernoulli theorem [5]

Viscosity-dominated (Stokes) flows [4]

Vorticity dynamics [3]

Gravity waves [5]

Instability [5]

Dynamical similarity [2]

Turbulence (similarity theory, cascades, intermittency) [10]

Outcomes:

Familiarity with Cartesian tensors, nonlinear PDEs, eigenvalue problems,

similarity theory, stochastic methods