

Important Concepts
Chapters 1 through 7

- I Frameworks for physical laws and their relationships to each other
 - A General Relativity, Special Relativity and Newtonian Physics: Sec. 1.1
 - B Phase space for a collection of particles: Chap 2
 - C Phase space for an ensemble of systems: Chap 3
 - D Relationship of Classical Theory to Quantum Theory
 - 1 Mean occupation number as classical distribution function: Sec. 2.3
 - 2 Mean occupation number determines whether particles behave like a classical wave, like classical particles, or quantum mechanically: Secs. 2.3 & 2.4; Ex. 2.1; Fig. 2.5
 - 3 Geometric optics of a classical wave is particle mechanics of the wave's quanta: Sec. 6.3
 - 4 Geometric optics limit of Schrodinger equation is classical particle mechanics: Ex. 6.6
- II Physics as Geometry
 - A Newtonian: coordinate invariance of physical laws
 - 1 Idea Introduced: Sec. 1.2
 - 2 Newtonian particle kinetics as an example: Sec. 1.4
 - B Special relativistic: frame-invariance of physical laws
 - 1 Idea introduced: Sec. 1.2
 - 2 Relativistic particle kinetics: Sec. 1.4
 - 3 4-momentum conservation: Secs. 1.4 & 1.12
 - a Stress-energy tensor: Sec. 1.12
 - 4 Electromagnetic theory: Sec. 1.10
 - a Lorentz force law: Sec. 1.4
 - 5 Kinetic theory: Chap. 2
 - a Derivation of equations for macroscopic quantities as integrals over momentum space [Sec. 2.5]
 - b Distribution function is frame-invariant and constant along fiducial trajectories [Secs. 2.2 & 2.7]
 - C Statistical mechanics: invariance of the laws under canonical transformations (change of generalized coordinates and momenta in phase space): Sec. 3.2, Ex. 3.1
- III 3+1 Splits of spacetime into space plus time, and resulting relationship between frame-invariant and frame-dependent laws of physics
 - A Particle kinetics: Sec. 1.6
 - B Electromagnetic theory: Sec. 1.10
 - C Continuum mechanics; stress-energy tensor: Sec. 1.12
 - D Kinetic theory: Secs. 2.2, 2.5 & 2.7
 - 1 Cosmic microwave radiation viewed in moving frame: Ex. 2.3
- IV Spacetime diagrams
 - A Introduced: Sec. 1.7
 - B Simultaneity breakdown, Lorentz contraction, time dilation: Exercise 1.11

- C The nature of time; twins paradox, time travel: Sec. 1.8
- D Global conservation of 4-momentum: Secs. 1.6 & 1.12
- E Kinetic theory -- Momentum space: Sec. 2.2
- V Statistical physics concepts
 - A Systems and ensembles: Sec. 3.2
 - B Distribution function
 - 1 For particles: Sec. 2.2
 - 2 For photons, and its relationship to specific intensity: Sec. 2.2
 - 3 For systems in statistical mechanics: Sec. 3.2
 - 4 Evolution via Vlasov or Boltzmann transport equation: Sec. 2.7
 - a Kinetic Theory: Sec 2.7
 - b Statistical mechanics: Sec. 3.3
 - 5 For random processes: hierarchy of probability distributions: Sec. 5.2
 - C Thermal equilibrium
 - 1 Kinetic-theory distribution functions: Sec. 2.4
 - 2 In statistical mechanics; general form of distribution function in terms of quantities exchanged with environment: Sec. 3.4
 - 3 Evolution into statistical equilibrium--phase mixing and coarse graining: Secs. 3.6 and 3.8
 - D Representations of Thermodynamics
 - 1 Summary: Table 4.1
 - 2 Energy representation: Sec. 4.2
 - 3 Free-energy representation: Sec. 4.3
 - 4 Enthalpy representaiton: Ex. 4.3
 - 5 Gibbs representation: Sec. 4.4
 - E Specific statistical-equilibrium ensembles and their uses
 - 1 Summary: Table 4.1
 - 2 Canonical, Gibbs, grand canonical and microcanonical defined: Sec. 3.4
 - 3 Microcanonical: Secs. 3.5 and 4.2
 - 4 Canonical: Sec. 4.3
 - 5 Gibbs: Sec. 4.4
 - 6 Grand canonical: Sec. 3.7 and Ex. 3.6 and 3.8
 - F Fluctuations in statistical equilibrium
 - 1 Summary: Table 4.2
 - 2 Particle number in a box: Ex. 3.7
 - 3 Distribution of particles and energy inside a closed box: Sec. 4.5
 - 4 Temperature and volume fluctuations of system interacting with a heat and volume bath: Sec. 4.5
 - 5 Fluctuation-dissipation theorem: Sec. 5.6.1
 - 6 Fokker-Planck equation: Sec. 5.6.2
 - 7 Brownian motion: Sec. 5.6.3
 - G Entropy
 - 1 Defined: Sec. 3.6
 - 2 Second law (entropy increase): Secs. 3.6, 3.8
 - 3 Entropy per particle: Secs. 3.7, 3.8, Fig. 3.4, Exs. 3.5, 3.9
 - 4 Of systems in contact with thermalized baths:
 - a Summary: Table 4.1
 - b Heat & volume bath (Gibbs): Sec. 4.4

- a Phase transitions: Secs. 4.4 & 4.6, Ex. 4.4 & 4.7
 - b Chemical reactions: Sec. 4.4, Ex. 4.5 & 4.6
 - H Macroscopic properties as integrals over momentum space:
 - 1 In kinetic theory
 - a Number-flux vector, stress-energy tensor: Sec. 2.5
 - b Equations of state: Sec. 2.6
 - c Transport coefficients: Sec. 2.8
 - 2 In statistical mechanics: Extensive thermodynamic variables
 - a Grand partition function: Ex. 3.6
 - 3 In theory of random processes: Ensemble averages: Sec. 5.2
 - I Random Processes: Chap 5
 - 1 Properties of random processes
 - a Stationarity: Sec. 5.2
 - b Markov: Sec. 5.2
 - c Gaussian: Sec. 5.2
 - d Ergodicity: Sec. 5.3
 - 2 Characterization of random processes
 - a Probability distributions: Sec. 5.2
 - b Correlation functions: Sec. 5.3
 - c Spectral densities: Sec. 5.3
 - a white, flicker, random-walk: Sec. 5.4
 - b shot noise: Sec. 5.5
 - 3 Theorems
 - a Central limit theorem [many influences -> Gaussian]: Sec. 5.2
 - a and shot noise: Sec. 5.5
 - b Wiener-Khintchine [correlation <-> spectral density]: Sec. 5.3
 - c Doobs theorem [Gaussian & Markoff -> fully characterized by mean, variance, and relaxation time: Sec. 5.3
 - d Effect of filter on spectral density: Sec. 5.5
 - e Fluctuation-dissipation theorem: Sec. 5.6.1, Ex. 5.7, 5.8, 5.10
 - f Fokker-Planck equation: Sec. 5.6.2
 - a and Brownian motion: Sec. 5.6.3, Ex. 5.6, 5.9
 - 4 Filtering
 - a Band-pass filter: Sec. 5.5, Ex. 5.2
 - b Wiener's optimal filter: Ex. 5.3
- VI Optics (wave propagation) concepts
 - A Plane waves & wave packets in homogeneous media
 - 1 Dispersion relation, phase velocity, group velocity: Sec. 6.2
 - 2 Longitudinal wave packet spreading due to dispersion: Ex. 6.2
 - 3 Transverse wave packet spreading due to finite-wavelength effects: Sec. 7.2; Fig. 7.2
 - B Geometric optics approximation: Sec. 6.3
 - 1 Derivation via 2 lengthscale expansion: Sec. 6.3
 - 2 Propagation laws and their relation to Hamiltonian mechanics and quantum mechanics: Secs. 6.3 and 6.5
 - 3 Fermat's principle: Sec. 6.3
 - a Justified by Fresnel theory of diffraction: Sec. 7.4
 - 4 Paraxial optics: Sec. 6.4
 - a Paraxial ray optics: Sec. 6.4

- b Paraxial Fourier (wave) optics: Sec. 7.5
 - 5 Breakdown of geometric optics
 - a General discussion (wave packet spreading, parametric wave amplification, ...): Sec. 6.3
 - b Caustics: Secs. 6.6, 7.6
- C Finite-Wavelength Effects in Homogeneous, Dispersion-Free Media
 - 1 Helmholtz-Khirschhoff Integrals
 - a Precise version: field at point as integral over surrounding closed surface: Eq. (7.4)
 - b As integral over an aperture: Eq. (7.6)
 - 2 Fraunhofer diffraction (far from diffracting object): Sec. 7.3
 - a As Fourier transform of field leaving aperture: Eq. (7.11)
 - b Use of Convolution Theorem to compute diffraction patterns from complicated objects: Fig. 7.4
 - c Babinet's principle: Sec. 7.3.2
 - d Airy pattern for circular aperture: Fig. 7.6
 - e Caustics: Sec. 7.6, Fig. 7.13
 - 3 Fresnel diffraction (near diffracting object): Sec. 7.4
 - a Fresnel integrals and Cornu spiral: Fig. 7.8
 - b Diffraction pattern from straight edge: Fig. 7.9
 - 4 Fourier optics [Paraxial Optics with finite wavelengths]: Sec. 7.5
 - a Propagators (Point Spread Functions): Sec. 7.5
 - b Gaussian beams: Sec. 7.5.5
- D Optical Instruments
 - 1 Lens: Fig. 6.3, Fig. 6.5
 - a geometric-optics analysis: Fig. 6.3, Fig. 6.5
 - b Fourier-optics analysis: Sec. 7.5, Fig. 7.11
 - 2 Refracting telescope: Ex. 6.9
 - 3 Optical cavity:
 - a geometric-optics analysis: Ex. 6.10
 - 4 Optical fiber:
 - a geometric-optics analysis: Ex. 6.5
 - b Fourier-optics analysis - Gaussian beam: Ex. 7.8
 - 5 Diffraction grating: Sec. 7.2, Fig. 7.4
 - 6 Zone Plate, Fresnel Lens: Sec. 7.4
 - 7 Phase Contrast Microscope: Sec. 7.5, Fig. 7.12
- VII Computational techniques
 - A Tensor analysis
 - 1 Without a coordinate system, abstract notation: Secs. 1.3 and 1.9
 - 2 Index manipulations in Euclidean 3-space and in spacetime
 - a Tools introduced; slot-naming index notation: Sec's 1.5, 1.7 & 1.9
 - b Used to derive standard 3-vector identities: Exercise 1.15
 - B Two-lengthscale expansions: Box 2.2
 - 1 Solution of Boltzmann transport equation in diffusion approximation: Sec. 2.8
 - 2 Semiclosed systems in statistical mechanics: Sec. 3.2
 - 3 Statistical independence of subsystems: Sec. 3.4
 - 4 As foundation for geometric optics: Sec 6.3
 - C Matrix and propagator techniques for linear systems

1 Paraxial geometric optics: Matrix methods: Sec. 6.4

2 Paraxial Fourier optics (finite wavelengths): Propagator methods:
Sec. 7.5

D Statistical physics:

1 Computation of fundamental potentials (or partition functions) via
sum over states: Secs. 3.8, 4.3; Exercise 3.6

2 Renormalization group: Sec. 4.6

3 Monte carlo: Sec. 4.7