

Important Concepts
Chapters 1 through 10

- 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
 3. Equations of elasticity;
 - a. expansion, rotation and shear: Sec. 10.2
 - b. Elastic stress tensor and force balance: Sec. 10.4
 - 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**
 - D. **Elasticity: irreducible tensorial parts of strain tensor: expansion, shear and rotation: Sec. 10.2, Box 10.1**
- 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 representation: 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
 - i. Phase transitions: Secs. 4.4 & 4.6, Ex. 4.4 & 4.7
 - ii. 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 [extended to complex random processes in multiple dimensions: Ex. 8.7]

- 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
 - i. white, flicker, random-walk: Sec. 5.4
 - ii. shot noise: Sec. 5.5
- 3. *Theorems*
 - a. Central limit theorem [many influences \rightarrow Gaussian]: Sec. 5.2
 - i. and shot noise: Sec. 5.5
 - b. Wiener-Khinchine [correlation \leftrightarrow spectral density]: Sec. 5.3
 - i. van Cittert-Zernike theorem in optics as a special case: Ex. 8.7
 - c. Doob's theorem [Gaussian & Markoff \rightarrow 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
 - i. example of thermelastic noise: Secs. 10.5, 5.10, Ex. 10.6
 - f. Fokker-Planck equation: Sec. 5.6.2
 - i. 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-Kirchoff 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. Finite-Wavelength Effects in the Mixing of a Few Wave Beams: Chap. 8:**
1. *Coherence*: Sec. 8.2
 - a. degree of coherence:
 - i. degree of spatial coherence == degree of lateral coherence == complex fringe visibility, γ_{\perp} : Secs. 8.2.2 - 8.2.4
 - ii. fringe visibility, $V = |\gamma_{\perp}|$: Sec. 8.2.2
 - iii. degree of temporal coherence == degree of longitudinal coherence, γ_{\parallel} : Sec. 8.2.6
 - b. coherence time (Sec. 8.2.3), coherence length (Sec. 8.2.6), volume of coherence (Sec. 8.2.8)
 - c. interferogram and spectrum: Sec. 8.2.7
 - d. intensity coherence and correlations: Sec. 8.6
 2. *Van Cittert-Zernike Theorem (coherence as Fourier transform of angular intensity distribution and spectrum)*: Sec. 8.2.2
 - a. as special case of Wiener-Khintchine Theorem: Ex. 8.7
- E. 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
 - b. as Fabry-Perot interferometer: Sec. 8.4.2
 - c. in interferometric gravitational-wave detector: Sec. 8.5
 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
- 8. *Young's slits*: Sec. 8.2.1
- 9. *Michelson interferometer*: Sec. 8.2.7
- 10. *Michelson stellar interferometer*: Sec. 8.2.5
- 11. *Fourier transform spectrometer*: Sec. 8.2.7
- 12. *Radio interferometer*: Sec. 8.3
 - a. earth-rotation aperture synthesis: Sec. 8.3.1
 - b. closure phase: Sec. 8.3.3
- 13. *Interfaces, mirrors, beam splitters*:
 - a. Reciprocity relations for transmission and reflection: Sec. 8.4.1, Ex. 8.9
 - b. Antireflection coating: Ex. 8.10
- 14. *Etalon*: Sec. 8.4.1
 - a. finesse: Sec. 8.4.1
- 15. *Fabry-Perot interferometer*: Sec. 8.4.2
- 16. *Fabry-Perot spectrometer*: Sec. 8.4.2
 - a. chromatic resolving power: Sec. 8.4.2
- 17. *Sagnac interferometer*: Ex. 8.11
- 18. *Interferometric gravitational-wave detector*: Sec. 8.5
- 19. *Hanbury-Brown-Twiss intensity interferometer*: Sec. 8.6
- 20. *Hologram and holography*: Sec. 9.3
 - a. Compact disks: Ex. 9.3
- 21. *Frequency doubling crystals*: Secs. 9.5.4, 9.6.1; Ex. 9.8
- 22. *Phase Conjugating mirrors*: Secs. 9.4, 9.6.2; Fig. 9.10, Ex. 9.9
- 23. *Light Squeezing device*: Ex. 9.10

VII. Elasticity

A. Fundamental Concepts

- 1. *Strain; expansion, rotation and shear*: Sec. 10.2
 - a. Irreducible tensorial parts of strain: Box 10.1
- 2. *Cylindrical and spherical coordinates and bases; connection coefficients*: Sec. 10.3, Box 10.2
- 3. *Bulk and shear moduli; elastic stress tensor*: Sec. 10.4.1, 10.4.2
 - a. Atomic-scale origin of moduli: Sec. 10.4.4, Ex. 10.15
 - b. Numerical values: Table 10.1
- 4. *Elastic force on a unit volume; elastic stress balance*: Sec. 10.4.2
 - a. Biharmonic equation for displacement; harmonic equation for expansion: Ex. 10.13
- 5. *Elastic energy (energy of deformation)*: Sec. 10.4.3

B. Elastostatic Equilibrium of Rods, Beams, Fibers

- 1. *Longitudinal compression; Young's modulus, Poisson ratio*: Sec. 10.4.5
- 2. *Torsion pendulum*: Ex. 10.5
- 3. *Linear pendulum - bending of support wire*: Ex. 10.10
- 4. *Bending of cantilever beam under own weight*: Sec. 10.6, Ex. 10.8
- 5. *Elastica (large deformations away from straightness)*: Ex. 10.9

C. Elastostatic Equilibrium of Plates

- 1. *Deformation of plate under applied forces*: Sec. 10.7
- 2. *Stress polishing of mirrors*: Sec. 10.6, Ex's: 10.11, 10.12

D. Bifurcation of Equilibria

1. *Example of compressed beam or playing card: Sec. 10.8*
2. *List of other examples: Sec. 10.8*

VIII. Nonlinear Physics

A. Resonant Wave-Wave mixing: Chap 9

1. *Via nonlinear dielectric susceptibilities: Sec. 9.5*
2. *Use of anisotropy to counteract dispersion: Sec. 9.5.4, Ex. 9.6*
3. *Holography: Sec. 9.3*
 - a. *Use in compact disks: Ex. 9.3*
4. *Phase Conjugation: Secs. 9.4, 9.6.2; Fig. 9.10, Ex. 9.9*
5. *Frequency doubling: Sec. 9.5.4, 9.6.1; Ex. 9.8*
6. *Light Squeezing: Ex. 9.10*

IX. 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*
3. *In orthogonal curvilinear coordinates with orthonormal bases: Sec. 10.3*
 - a. *Connection coefficients: Sec 10.3, Ex. 10.1, Box 10.2*

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*