Physics 136 | Caltech
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Important Concepts

Chapters 1 through 8

- 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 equilbrium--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
      - 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 -> Gaussian]: Sec. 5.2
      - i and shot noise: Sec. 5.5
    - b Wiener-Khintchine [correlation <-> spectral density]: Sec. 5.3
      - i van Cittert-Zernike theorem in optics as a special case: Ex. 8.7
    - 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
      - 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 Propagatin 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-Khirchoff 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, gamma_perp: Secs. 8.2.2 - 8.2.4
    - ii fringe visibility, V = I gamma_perp I: Sec. 8.2.2
    - iii degree of temporal coherence == degree of longitudinal coherence, gamma_II: 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

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