Physics 136 Caltech
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Important Concepts
Chapters 1 through 11

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. *Newtonian mass conservation and force balance: Sec. 11.2*
  4. *Equations of elasticity;*
     - a. expansion, rotation and shear: Sec. 10.2
     - b. Elastic stress tensor and force balance: Secs. 10.4, 11.2
- ***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 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
      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, Box 11.1

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, Ex. 11.3
   b. Caustics: Secs. 6.6, 7.6

6. *Application to seismic waves in Earth: Sec. 11.5.1, Fig. 11.5*

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 = l gamma_perp l: Sec. 8.2.2
        iii. degree of temporal coherence = degree of longitudinal coherence, gamma_ll: 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. Continuum Mechanics in General

A. Fundamental Concepts

1. *Mass conservation: Sec. 11.2*
2. *Momentum conservation: Sec. 11.2*
3. *Wave equations: Box 11.1*

VIII. 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*
6. *Boundary conditions on displacements and stresses: Sec. 11.5.1, Ex. 11.6*
7. *Green's functions: Sec. 11.5.3*

B. Elastostatic Equilibrium

1. *Rods, Beams, Fibers*
    a. Longitudinal compression; Young's modulus, Poisson ratio: Sec. 10.4.5
    b. Torsion pendulum: Ex. 10.5
    c. Linear pendulum - bending of support wire: Ex. 10.10
    d. Bending of cantilever beam under own weight: Sec. 10.6, Ex. 10.8
    e. Elastica (large deformations away from straightness): Ex. 10.9
    f. Bifurcation of equilibria for stressed beam: Sec. 10.8
2. *Plates*
    a. Deformation of plate under applied forces: Sec. 10.7
    b. Stress polishing of mirrors: Sec. 10.6, Ex's: 10.11, 10.12

C. Bifurcation of Equilibria

1. *Example of compressed beam or playing card: Secs. 10.8, 11.4.5*
2. *List of other examples: Sec. 10.8*

3. *Relationship to onset of intabilities: Sec. 11.4.5*

D. *Elastodynamics*

1. *Wave equation for displacement: Sec. 11.3.1*
2. *Waves in a homogeneous, isotropic medium*
   a. Longitudinal waves (P-waves) and transverse waves (S-waves): Secs. 11.3.2, 11.3.3, 11.3.4
   b. Wave energy: Sec. 11.3.5
   c. Scalar and vector potentials: Ex. 11.1
   d. Junction conditions at a boundary: Sec. 11.5.1, Ex. 11.6
   e. Wave-wave mixing at a boundary: Sec. 11.5.1, Fig. 11.4
   f. Edge waves: Rayleigh waves and Love waves: Sec. 11.5.2
3. *Waves in rods, strings and beams: Sec. 11.4*
   a. Compression waves, torsion waves, and flexural waves: Secs. 11.4.1-11.4.4, Exs. 11.3, 11.4
   b. Relationship to buckling and bifurcation of equilibria: Sec. 11.4.5
4. *Seismic waves in the earth: Sec. 11.5*
   a. Earth's elastostatic structure: Table 11.1, Fig. 11.5
5. *Normal modes of a solid: Sec. 11.5.4*
   a. xylophone: Ex. 11.5

IX. 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*

X. 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*

E. *Green's functions:*

1. *In elasticity theory: physicists' and Heaviside: Sec. 11.5.3*