Fundamentals of Spectroscopy for Optical Remote Sensing

Course Outline 2009

Part I. Fundamentals of Quantum Mechanics

Chapter 1. Concepts of Quantum and Experimental Facts

1.1. Blackbody Radiation and Planck's Radiation Law

[Textbook "Laser Spectroscopy" Sections 2.1 – 2.4, Corney's book Section 1.1]

1.2. Photoelectric Effect and Quantized Energy

[Textbook Section 4.5.4, Corney's book Section 1.2]

1.3. Compton Effect and Quantized Momentum

1.4. Hydrogen Spectra and Discrete Energy Levels

[Textbook Section 4.1, Corney's book Section 1.3]

1.5. Bohr's Model [Corney's book Sections 1.4-1.8]

Chapter 2. Wave-Particle Duality

[Dirac's The Principles of Quantum Mechanics, and
Cohen-Tannoudji's Quantum Mechanics, vol. I and II]

2.1. Wave Behavior of Light

2.2. Single Photon Experiment

2.3. Wave-Particle Duality of Light

2.4. Wave-Particle Duality of Material Particles

2.5. de Broglie Relationship

Chapter 3. Quantum Mechanics Postulates, Principles, and Mathematic Formalism

[Cohen-Tannoudji's Quantum Mechanics, vol. I and II]

3.1. Postulates of Quantum Mechanics

3.2. Principle of Superposition of States

3.3. Principle of Motion – Schrödinger Equation

3.4. Principle of Uncertainty – Indeterminacy

3.5. Dirac Notation and Representations

3.6. Solutions to Eigenvalue Equation and Schrödinger Equation

Part II. Fundamentals of Atomic Spectroscopy

Chapter 4. Introduction to Atomic Structure and Atomic Spectra

Chapter 5. Atomic Structure

5.1. Atomic Structure Overview

5.2. Atomic Structure for Hydrogen Atom and Hydrogen-like Atoms

1. Hydrogen energy eigenvalues and eigenstate in Coulomb Potential
2. Electron Spin-Orbit Interaction and Energy Fine Structure
3. Nucleus Influences and Hyperfine Structure
4. Influence of External (Static) Magnetic Field
5. Influence of External (Static) Electric Field

5.3. Atomic Structure for Many-Electron Atoms

1. Central Field Approximation
2. Electron Spin Quantum Number
3. Pauli Exclusion Principle and Atomic Shell Structure
4. Electron Configuration and Periodic Table of Elements
5. Shielding, Penetration, and Atomic Core Polarization Effects
6. Alkali Atomic Structure
7. Noncentral Electrostatic Interaction and Spin-Orbit Splitting in the LS Coupling Approximation
8. jj Coupling
9. Helium Energy Levels and Applications in Remote Sensing

Chapter 6. Radiative Transitions

6.1. Introduction

6.2. Absorption, Stimulated Emission, and Spontaneous Emission

6.3. Transition Probabilities: Statement of the Problem

6.4. Semi-Classical Description of Transition Probabilities for Two-Level System

1. Semiclassical description
2. Weak-field approximation for 2-level system
3. Transition probabilities with broad-band excitation
4. Phenomenological inclusion of decay phenomena

5. Interaction with strong fields

6.5. Transition Probabilities for General Case: Time-Dependent Perturbation Theory

1. Time-dependent perturbation theory
2. Radiative transition under periodic perturbation
3. Uncertainty relationship
4. Large time case
5. Limits of the first-order calculation
6. Non-monochromatic radiation field excitation

6.6. Full Quantum Treatment of Radiative Transitions

1. Quantization of the Radiation Field
   - (1) Potential theory for the classical EM field
   - (2) Coulomb gauge
   - (3) Free classical field
   - (4) Quantum-mechanical harmonic oscillator
   - (5) Quantization of the field
2. Radiative Transition Probability
3. Electric Dipole Radiation
   - (1) Selection rules derived from 3j-symbols and reduced matrix elements;
   - (2) Intensity, polarization and angular distribution of Zeeman spectral lines;
   - (3) ΔJ transition probabilities and Einstein coefficients;
   - (4) Oscillator strength, line strength, and A_{ki}
4. Magnetic Dipole Transition and Electric Quadrupole Transition
   - (1) Magnetic dipole transition; (2) Electric quadrapole transition;
   - (3) Example for E2 and M1 transitions (atomic O);
   - (4) Example for Na 3S → 3P transition probability;
   - (5) Example for H ground-state hyperfine transition probability

Chapter 7. Spectral Linewidth and Lineshape

7.1. Introduction

7.2. Natural linewidth and lineshape

7.3. Absorption and dispersion versus refraction index

(1) Classical model of the refraction index

11.3. Raman scattering: selection rules

Chapter 12. Electronic Spectroscopy

12.1. Electronic energy and total energy of a molecule

12.2. Quantum numbers for molecular spectroscopy

12.3. Selection rules for electronic spectroscopy

Part IV. Fundamentals of Laser Spectroscopy

Chapter 13. Laser Spectroscopy Basics

13.1. Basic setup for spectroscopy experiment

13.2. Basic questions in spectroscopy

13.3. Basic effects in spectroscopy

(absorption, fluorescence, photoacoustic, optothermal, optogalvanic & ionization)

Chapter 14. Doppler-Limited Absorption and Fluorescence Spectroscopy

14.1. General absorption spectroscopy

14.2. Cavity ring down, frequency modulation, and intracavity spectroscopy

14.3. Optical pumping and double resonance

Chapter 15. Sub-Doppler (Doppler-free) Spectroscopy

15.1. Saturation absorption and polarization spectroscopy

15.2. Molecular beam and two-photon spectroscopy

15.3. Ramsey fringes

Chapter 16. Time-Resolved Spectroscopy

Chapter 17. New Developments in Laser Spectroscopy

17.1. Laser cooling and trapping and ion trap

17.2. Optical Ramsey and atom interferometry

17.3. Quantum beat

Concluding Remarks