ASEN 6265
Fundamentals of Spectroscopy for Optical Remote Sensing

<u>Course Outline 2017 (Draft)</u>

Part I. Introduction to Quantum Physics

Chapter 1. Quantum Concepts 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. Basics of 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

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 $\rightarrow$ 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
- (2) Quantum mechanics correction to refraction index
- (3) Absorption and dispersion
- (4) Example for dispersion: Faraday filter

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

Chapter 18. Fascinating Applications of Laser Spectroscopy

Concluding Remarks