PHYSICS - 607: **FALL - 2007**

ATOMIC AND NUCLEAR PHYSICS

- **Instructor: Dr. Igor Ostrovskii**

SYLLABUS

➢ COURSE OBJECTIVES AND GOALS

1. Introduce the physics graduate students to 20-th century atomic and nuclear physics.
2. To give main results in the atomic spectroscopy, and contemporary nuclear physics.
3. Expand an understanding of the applications of quantum physics to the atoms and nuclei.
4. Develop an understanding of the current basis of broad knowledge in atomic and nuclear physics.
5. To discuss the connections between quantum mechanics and contemporary physics problems of atoms and nuclei.
6. Enhance the critical thinking, analytical reasoning, and problem solving skills of graduate level.
7. Discuss the problems confronting physics in the 21-st century.

➢ LEARNING OBJECTIVES:

In this course, we introduce the physics graduate students to the latest achievements in Atomic and Nuclear physics.

- A. The learning outcomes for graduate students are summarized below.
  After completing this course, a graduate student should:

1. Know in detail what is today's "Modern Atomic and Nuclear Physics" including interaction of quanta with atoms, fine optical spectra of atoms, and structure of nuclei.
2. Graduates will understand the latest theoretical and experimental results along with 20th century developments in the field of "atomic spectroscopy."
3. Graduate students will be able to apply theoretical results of Quantum physics to analysis of the experimental data on atomic and nuclear structure.
4. Learners should know how to use interactive methods and Internet for their independent learning in the fields covered by this graduate course.
5. Different learning expectations for graduate versus undergraduate students will be realized (*section B below*).
6. The graduates will contribute to their field of study (*section C below*).

- B. Different learning expectations for graduate versus undergraduate students:

1. Theoretical and experimental results on "atomic and nuclear structure" will be understood at a level that helps graduate to pass a comprehensive examination.
2. In class, discussions of the Nobel Prizes in the fields specified will foster broad knowledge of the graduate students and especially will help them to pass an oral part of comprehensive examination.
3. Graduate students will be able to work out the particular problems of respectively high theoretical level that is needed to take successfully the comprehensive examinations.
4. Doctor and Master Candidates will build on their critical thinking including "how to apply contemporary results to your individual work on a dissertation/thesis."

- C. Fostering independent learning that enable the graduates to contribute to a profession or field of study:

1. Graduate students will make at least one presentation of a certain section/subsection from their textbook to foster independent learning and to train teachers' skills.
2. Graduates will have some special laboratory demonstrations fostering their practical experimental skills in the fields specified.
3. Learners will have an opportunity to present shortly their research themes, literature reviews, etc., which enable graduates to contribute to their field of study including topics of their future dissertations/theses.

- **Lecture:** TTh 11:00 am – 12:15, Room 126 Lewis Hall
- Office: Room 207 Lewis Hall; Email: iostrov@phy.olemiss.edu
- **Office Hours**: MWTh 3:00 p.m. – 4:00 p.m. (207 Lewis Hall)

- **<u>TEXT</u>**: The Physics of Atoms and Quanta, by H. Haken and H.C. Wolf, 7-th edition, Springer.

We will cover Chapters 1, 2, 3, 4, 5, 6, 8, 11 through 22.

PLEASE, READ THE BOOK

- **Additional reading**:

1) Modern Atomic and Nuclear Physics, by Fujia Yang and Joseph H. Hamilton, 2000 year edition, McGraw-Hill Companies.
2) Physics of Atoms and Molecules by B.H. Brandsen and C.J. Joachain, 2nd edition, 2003, Pearson Education Ltd., England.
3) Principles of Modern Physics, by Robert B. Leighton, McGraw-Hill Book Company.

- **<u>GRADING SCALE</u>:** A's -------------------- 90 – 100
  B's -------------------- 80 – 89
  C's -------------------- 70 – 79, Etc.

- **<u>EVALUATION</u>**: <u>Grades will be based on the home works, tests, and final examination</u>:
  Homework ----------- 20 %
  Two tests ------------- 40 % (#1=20 %, #2=20 %)
  Final exam ----------- <u>40 %</u>
  100 %

- **<u>TESTS AND FINAL EXAMINATION SCHEDULE:</u>**

Test 1 (Class # 13), Chapters 2 - 6, 8, 11, 12 ------- Tuesday, October 2.

Test 2 (Class # 25), Chapters 13 – 20 ---------- Tuesday, November 13.

<u>FINAL EXAMINATION ------------ Wednesday, December 5, Noon.</u>

- **<u>REQUIREMENTS OF THE COURSE AND HOMEWORK RULES</u>**

1. The basic knowledge of calculus based General Physics, Differential Equations and Math-Methods are required. Undergraduate Quantum Mechanics is a good support for understanding of Phys-607.
2. Homework is assigned after some sections are covered.
3. Homework paper should be 8.5 x 11 inches with no torn or tattered edges.
4. Show all your work; the answer alone is not worth anything. Homework problems must include <u>enough English</u> to be understandable.
5. Homework answers should have units and a reasonable number of significant digits.

6. **Circle the finale answers that you want to be graded.**

➢ COURSE DESCRIPTION AND CONTENTS

The course of Atomic and Nuclear Physics is devoted to the main experimental and theoretical results in atomic and subatomic physics, which were achieved in the 20-th century. The PHYS-607 gives a basic knowledge about the a) atomic configuration and atomic spectroscopy including fine structure in atomic spectra; b) basic concepts of nuclear physics including properties of alpha particles; c) atoms in magnetic and electric fields; d) many-electron atom; e) X-Ray spectroscopy; f) lasers and modern methods of optical spectroscopy. The applications of quantum mechanics to the atoms and nuclei are discussed.

PART 1:

1. Introduction: Classical Physics and Quantum Mechanics.

2. The Mass and Size of the Atom (Ch. 2).
Determination of the Mass. Methods for Determining Avogadro's Number.
Determination of the Size of the Atom. Can Individual Atoms Be Seen?

3. Isotopes (Ch. 3).
The Periodic System of the Elements. Mass Spectroscopy. Modern Applications of the Mass Spectrometer.

4. The Nucleus of the Atom (Ch. 4).
Passage of Electrons Through Matter. Passage of Alpha Particles Through Matter; Rutherford Scattering.

5. The Photon (Ch. 5).
Wave Character of Light. Thermal Radiation.The Photoelectric Effect. The Compton Effect.

6. The Electron (Ch. 6).
Production of Free Electrons. Size of the Electron. The Charge of the Electron. The Specific Charge q/m of the Electron. Wave Character of Electrons and Other Particles. Interferometry with Atoms.

7. Bohr's Model of the Hydrogen Atom (Ch. 8).
Basic Principles of Spectroscopy. The Optical Spectrum of the Hydrogen Atom.
Some Quantitative Conclusions. Motion of the Nucleus. Spectra of Hydrogen-like Atoms. Muonic Atoms. Excitation of Quantum Jumps by Collisions. Sommerfeld's Extension and the Experimental Justification of a Second Quantum Number. Orbital Degeneracy and the Relativistic Mass Change. Rydberg Atoms. Exotic Atoms: Positronium, Muonium, and Antihydrogen.

8. Lifting of the Orbital Degeneracy in the Spectra of Alkali Atoms (Ch.11).
Shell Structure. Screening. The Term Diagram. Inner Shells.

9. Orbital and Spin Magnetism. Fine Structure (Ch. 12).
Magnetic Moment of the Orbital Motion. Precession and Orientation in a Magnetic Field. Einstein-de Haas Method. Detection of Directional Quantization by Stern and Gerlach. Fine Structure. Calculation of Spin-Orbit Splitting. Level Scheme of the Alkali Atoms. Fine Structure in the Hydrogen Atom. The Lamb Shift.

Test 1 (Class # 13), Chapters 2 - 6, 8, 11, 12 ------- Tuesday, October 2.

PART 2:

10. Atoms in a Magnetic Field (Ch. 13).
Experiments and Their Semiclassical Description: Directional Quantization in a Magnetic Field. Electron Spin Resonance. The Zeeman Effect. The Vector Model. The Pashen-Back Effect.

11. Atoms in a Magnetic Field: Quantum Mechanical Treatment (Overview of Ch. 14).
Quantum Theory of the Zeeman Effect. Quantum Theoretical Treatment of the Electron and Proton Spins.

12. Atoms in an Electric Field (Ch. 15).
Observation of the Stark Effect. Theory of the Stark Effect. Spin and Photon Echoes.

13. General Laws of Optical Transitions (Ch. 16).
Symmetries and Selection Rules. Optical Matrix Elements. Symmetry Behaviour of Wave functions . Selection Rules.

14. Many-Electron Atoms (Ch. 17). ....
The Spectrum of the Helium Atom. Electron Repulsion and the Pauli Principle. Angular Momentum Coupling. Russell-Saunders Coupling and *JJ* Coupling. Magnetic Moments of Many-Electron Atoms. Multiple Excitations.

15. X-Ray Spectra, Internal Shells (Ch. 18).
X-Radiation from Outer Shells. X-Ray Bremsstrahlung Spectra. Emission Line Spectra: Characteristic Radiation. Fine Structure of the X-Ray Spectra. Absorption Spectra. The Auger Effect. Photoelectron Spectroscopy (XPS), ESCA.

16. Structure of the Periodic System. Ground States of the Elements (Ch.19).
Periodic System and Shell Structure. From the Electron Configuration to the Atomic Term Scheme. Atomic Ground States. Excited States of Atoms and Possible Electronic Configurations.

17. Nuclear Spin, Hyperfine Structure (Ch. 20).
Influence of the Atomic Nucleus on Atomic Spectra. Spins and Magnetic Moments of Atomic Nuclei. The Hyperfine Interaction. Hyperfine Structure in the Ground State of the Hydrogen Atom, the Sodium Atom, and the Hydrogen-like Ion. Hyperfine Structure in an External Magnetic Field, Electron Spin Resonance. Direct Measurements of Nuclear Spins and Magnetic Moments, Nuclear Magnetic Resonance. Applications of Nuclear Magnetic Resonance. The Nuclear Electric Quadrupole Moment.

Test 2 (Class # 25), Chapters 13 – 20 ---------- Tuesday, November 13.

18. The Laser (Ch. 21).
Basic Concepts for the Laser. Rate Equations and Lasing Conditions. Amplitude and Phase of Laser Light.

19. Modern Methods of Optical Spectroscopy (Overview of Ch. 22).
Classical Methods. Quantum Beats. Doppler-free Spectroscopy. Level-Crossing Spectroscopy. Laser Cooling of Atoms. Single-Photon Detection.

20. REVIEW: Last class # 28 on Thursday, November 29, 2007.

- **FINAL EXAMINATION ----------- Wednesday, December 5, Noon.**

- - The dates of chapter tests are tentative and may be changed, but NOT THE FINAL EXAMINATION DATE/TIME.