PHYS 308 Quantum Physics

Course information:

Course title: Quantum Physics

Course catalog and # section: PHYS 308

Semester: Fall 2023

Instructor name: Jesús Pérez Ríos

Office location: 139-B on the A floor of the physics building

Instructor's email: jesus.perezrios@stonybrook.edu

Office hours: Tuesday and Thursday, 10.00-11.30 am

Course description:
Quantum mechanics explains the dynamics of atomic, molecular, microscopic, and mesoscopic systems, thus, being one of the most critical and relevant theories in physics. In addition, quantum mechanics appears in large-scale scenarios like cosmology or astrophysics. Apart from its relevance in fundamental physics, it founds applications in modern technologies like quantum information and quantum computing. However, quantum mechanics is counterintuitive and leads to unexpected behaviors, which makes it, one of the most intriguing and beautiful topics to study.

In this course, we will explore the fundamentals of quantum mechanics, bringing a new set of concepts: the probability current, the uncertainty principle, Hilbert spaces and operators, the spin, the quantization of the action, among others. Indeed, these concepts are key to understanding modern physics in any of its flavors, like nuclear physics, high energy physics, condensed matter physics, quantum chemistry, spectroscopy, chemical physics, and atomic, molecular and optical (AMO) physics.

A detailed index of the course is given below:

Chapter 1. **A first approach to wave-mechanics**
This chapter will introduce the atomic model that motivated the application of quantum mechanics to atoms and molecules: Bohr's atomic model. This model will help us to understand the important link between the quantum realm and classical mechanics. Then, we will briefly introduce wave-mechanics, i.e., the study of wave phenomena and how they are helpful in introducing quantum mechanics.

Chapter 2. **The formal structure of quantum mechanics**
This chapter will study the basics of the mathematics behind quantum mechanics. In particular, we will introduce the concept of Hilbert space, operators, eigenfunctions, and eigenvalues, along with commutation relations and their properties.

Chapter 3. **The postulates of quantum mechanics**
This chapter will present the six postulates of quantum mechanics and how they give rise to the whole quantum world.

Chapter 4. **1-dimensional quantum mechanics**
This chapter will present a study on quantum mechanical scenarios in 1-D. For instance, we will cover a particle in a box, bound states, scattering states, and barriers, introducing the concept of reflection and transmission coefficients for particles.

Chapter 5. **The quantum harmonic oscillator**
This chapter will be dedicated to studying the harmonic oscillator from a quantum mechanical perspective due to its importance in different fields of physics. In class, we will use two different formalisms to solve the quantum harmonic oscillator: the algebraic one, based on the introduction of creation and annihilation operators, and the other solving directly the Schrödinger equation.

Chapter 6. **Quantum mechanics in 3-D**
In this chapter, we will solve Schrödinger's equation for 3-D systems: 3D harmonic oscillator and a particle in a 3D box. Next, we will derive the Schrödinger equation for systems with spherical symmetry, i.e., central potentials, leading to the concept of angular momentum.

Chapter 7. **Quantum angular momentum theory**
This chapter will cover the basics of the quantum theory of angular momentum. Specifically, we will introduce the angular momentum operator and calculate its spectra leading to spherical harmonics—one of physics's most relevant special functions.

Chapter 8. **The hydrogen atom**
At this point in the course, we count on all the tools and concepts necessary to face any realistic quantum mechanical problem. This chapter will deal with the hydrogen atom, the cornerstone of modern atomic and molecular physics. The hydrogen atom serves as an arena to study the basics of the electronic structure of atoms and molecules and to understand the shell structure of atoms.

Chapter 9. **The spin**
This chapter introduces the concept of spin, a quantal magnitude that does not have a classical analog. To show that, we will introduce the spin via the famous Stern-Gerlach experiment. In addition, we will study its commutation relations and matrix

representations, as well as time-dependent problems involving spin in external fields and its applications to modern technology like MRI.

Chapter 10. **Symmetries in quantum mechanics**
This chapter will present the difference between bosons and fermions and the indistinguishability of particles characteristic of quantum mechanics. In particular, we will discuss the N-body problem from a quantal perspective.

Recommended textbooks (optional):

Using different textbooks to cover various aspects of the same topic is preferable. In this way, students can observe different perspectives and pedagogical styles to develop their intuition further.

- S. Gasiorowicz, “Quantum Physics” (John Wiley, 1996)
- D. Griffins, “An introduction to Quantum Mechanics” (Cambridge University Press, 1995)
- D. A. Fleisch, “A Student´s Guide to the Schrödinger Equation” (Cambridge University Press, 2018).
- L. D. Landau and E. M. Lifshitz “Quantum mechanics” (Butterworth-Heinemann, 2003)

Teaching philosophy:

Science, generally speaking, is about finding answers to questions about nature. However, these answers only make sense if one communicates them, thus, leading to knowledge. Indeed, this knowledge is the fundamental pillar where any scientist builds the foundations of new theories and discovers new challenges. Therefore, communicating results and motivating questions is one of the most relevant duties of a scientist.

Knowledge is not having a bunch of data in your memory but the capability of developing a physical intuition to face any problem independently of its nature. In the same vein, true knowledge demands curiosity to explore the world around us. As a result, I will focus in class on the facts behind quantum mechanics, making you think about every phenomenon we discuss in the lectures. This course is about questioning what we know about our world, and more importantly, it is about thinking. Finally, it is worth emphasizing that science is about having fun: science is a way of enjoying nature's wonders.

Learning Objectives and Assessments

The first goal of this course is to teach the student the fundamentals of quantum mechanics and how to apply quantum mechanics in different scenarios. In particular, the student will learn how to solve the Schrödinger equation in 1-D and 3-D systems with a different number of particles by solving partial differential equations and operator techniques. Similarly, the student will learn about the mathematical foundations of

quantum mechanics based on Hilbert spaces and operators. Finally, the student will be introduced to the quantum theory of angular momentum and spin. With all these concepts, the student could face any problem in quantum mechanics and have the background necessary to take more advanced courses in nuclear physics, AMO physics, solid state physics, particle physics, or quantum information.

These goals will be achieved through homework problems to exercise some concepts and methods explained in the lectures. In this way, students can test their understanding of the topics and methods discussed in the lectures and come up with questions. Additionally, there will be two midterm exams: the first around half of the course and the second on the last day of class.

How to succeed in this course:
- Attend all the lectures
- Complete the homework
- Ask questions
- Perform well in the midterm exams

Learning Outcomes

This course is about a first encounter with the quantum realm and the intimate life of atoms, photons, nuclei and solids. As a result, after taking this course, students will know how to face any quantum mechanical scenario of interest to nuclear physics, atomic and molecular physics, quantum chemistry, spectroscopy, particle physics, cosmology, astrophysics, statistical mechanics, quantum optics, quantum information, and condensed matter. Therefore, the student will learn about the relationship between different physics and chemistry disciplines. In addition, the student will be exposed to novel mathematical concepts such as Hilbert spaces and partial differential equations with applications in chemistry, biology, sociology and economy, to cite a few.

Grading, Attendance and Late Work Policies

Assessment and grading:

There will be 5-7 homework assignments that must be completed during the course. The homework will count for 20% of the final grade. The first midterm exam will count for 30% of the final grade, whereas the second will count for 50%. The homework should be submitted in due time; otherwise, the student will get the lower possible score. Only in unique cases, such as a medical urgency (it will be required a letter from a doctor explaining the problem and the kind of urgency) or a significant problem (a primary justification will be required), will the student be granted an extension. The grades will be given numerically between 0 and 10, 0 being very bad and 10 excellent. Then the final grade will be computed as 0.2 x homework + 0.3 x first midterm +0.5 x second midterm, and here is the final grading correspondence:

Final numerical grade	Final grade
9.5-10	A
8.5-9.5	A-
8-8.5	B+
7.5-8	B
7-7.5	B-
6.5-7	C+
6-6.5	C
5.5-6	C-
5-5.5	D+
4.5-5	D
< 4.5	F

University and course policies

Academic Integrity Statement:
Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Any suspected instance of academic dishonesty will be reported to the Academic Judiciary. For more comprehensive information on academic integrity, including categories of academic dishonesty, please refer to the academic judiciary website at http://www.stonybrook.edu/uaa/academicjudiciary/

Electronic communication
Email to your University email account is an important way of communicating with you for this course. For most students the email address is firstname.lastname@stonybrook.edu, and the account can be accessed here: http://www.stonybrook.edu/mycloud. It is your responsibility to read your email received at this account.

Religious observances
See the policy statement regarding religious holidays at https://www.stonybrook.edu/commcms/provost/faculty/handbook/employment/religious_holidays_policy. Students are expected to notify the course professors by email of their intention to take time out for religious observance. This should be done as soon as possible but definitely before the end of the 'add/drop' period. At that time they can discuss with the instructor(s) how they will be able to make up the work covered.

Disabilities
If you have a physical, psychiatric/emotional, medical or learning disability that may impact on your ability to carry out assigned course work, you should contact the staff in the Disability Support Services office [DSS], 632-6748/9. DSS will review your concerns and determine, with you, what accommodations are necessary and appropriate. All

information and documentation of disability is confidential. Students who require assistance during emergency evacuation are encouraged to discuss their needs with their professors and Disability Support Services. For procedures and information go to the website http://www.sunysb.edu/ehs/fire/disabilities.shtml

Critical incident management
Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the University Police and the Office of University Community Standards any serious disruptive behavior that interrupts teaching, compromises the safety of the learning environment, and/or inhibits students' ability to learn. See more here: https://www.stonybrook.edu/commcms/studentaffairs/sccs/policies/disruption

Student resources

Amazon @ Stony Brook: Order your books before classes begin. Phone: 631-632-9828; email: Bookstore_Liaison@stonybrook.edu; website: http://www.stonybrook.edu/bookstore/

Bursar: For help with billing and payment. Phone: 631-632-9316; email: bursar@stonybrook.edu; website: http://www.stonybrook.edu/bursar/

Career Center: The Career Center's mission is to support the academic mission of Stony Brook University by educating students about the career decision-making process, helping them plan and attain their career goals, and assisting with their smooth transition to the workplace or further education. Phone: 631-632-6810; email: sbucareercenter@stonybrook.edu; website: http://www.stonybrook.edu/career-center/

Counseling and Psychological Services: CAPS staff are available by phone, day or night here.

Ombuds Office: The Stony Brook University Ombuds Office provides an alternative channel for confidential, impartial, independent and informal dispute resolution services for the entire University community. We provide a safe place to voice your concerns and explore options for productive conflict management and resolution. The Ombuds Office is a source of confidential advice and information about University policies and procedures and helps individuals and groups address university-related conflicts and concerns. http://www.stonybrook.edu/ombuds/

Registrar: Having a registration issue? Let them know. Phone: 631-632-6175; email: registrar_office@stonybrook.edu; http://www.stonybrook.edu/registrar/

SBU Libraries: access to and help in using databases, ebooks, and other sources for your research.
• Research Guides and Tutorials: http://guides.library.stonybrook.edu/
• Getting Help: https://library.stonybrook.edu/research/ask-a-librarian/

Student Accessibility Support Center: Students in need of special accommodations should contact SASC. Phone: 631-632-6748; email: sasc@stonybrook.edu; https://www.stonybrook.edu/sasc/

Writing Center: Students are able to schedule face-to-face and online appointments.
https://www.stonybrook.edu/writingcenter/