UC San Diego, Department of Astronomy & Astrophysics

ASTR 106, Quantum Mechanics of Radiation, Atoms and Molecules, Spring 2025

Instructor	**Lecture Info:**	**Instructor Office Hours:**
Prof. Steven Boggs (he/him) seboggs@ucsd.edu	MWF 9:00a - 9:50a 2321 HSS	W 11:00p – 11:50a 412 SERF
GSI	**Discussion Info:**	**GSI Office Hours:**
Emily Broadbent ebroadbent@ucsd.edu	M 2:00p - 2:50p 217A Center Hall	TBD

Welcome to Quantum Mechanics of Radiation, Atoms and Molecules. Building upon our solid grasp of the fundamentals of quantum mechanics, we are ready to jump into applications for atomic, molecular, and nuclear processes. We have exhausted the simplest quantum systems that we can solve exactly. Fortunately, we will study multiple approximation techniques for deriving quantitative solutions to more complex quantum systems (multi-electron atoms, molecules, nuclei). Throughout the course we will highlight the astrophysical implications of the quantum mechanical processes we study.

Course Website: http://canvas.ucsd.edu/
The website includes course materials and information, a link to Gradescope for homework submission, useful links and references, and important course notices.

Learning Goals: My goals for the course are:
- Learn approximation techniques for calculating energy states of complex quantum systems.
- Explore deeper into atomic physics through fine structure and multi-electron atoms.
- Understand the quantum structure of molecular and nuclear bonds.
- Study photon emission, absorption and scattering in terms of quantum dynamics.
- Recognize the role these quantum phenomena play in driving astrophysical systems.

Learning Outcomes: After completion of the course, students will be able to:
- Describe quantum approximation techniques and in what situations each is applicable.
- Explain the derivation of fine structure in hydrogen and similar effects in multi-electron atoms.
- Solve the structure for simple multi-electron atoms, diatomic molecules, and nuclei.
- Calculate the rates and selection rules for atomic and molecular radiative transitions.
- Set up and solve the scattering cross section for a potential barrier.
- Explain the role of the strong and weak forces in nuclear processes relevant to astrophysics.

Prerequisites: ASTR 105. A good working knowledge of multivariable calculus is essential.

Course Mode: In-person lectures, problem solving in discussion, ~weekly homework, written exams.

Expectations: Students are expected to read the relevant textbook sections ahead of class, attend lecture and discussion section, review lecture notes after class, complete ~weekly assignments, and actively engage with questions and discussions in lecture, discussion section, and office hours to achieve the Learning Outcomes.

Required Texts: ***Introduction to Quantum Mechanics*** (Third Edition), David J. Griffiths and Darrell F. Schroeter, Cambridge University Press, 2018. ISBN: 9781107189638. Though not specifically geared for astrophysics students, this book has become a modern standard for learning the fundamentals of quantum mechanics.
Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles (Second Edition), Robert Eisberg and Robert Resnick, John Wiley & Sons, 1985. ISBN: 0-471-87373-X. This book is out-of-print, but we will be utilizing excerpts of the text for deeper dives into molecular and nuclear QM. We will skip sections of both texts not relevant for our course. Sections you can skip are listed in the weekly reading assignments, please note those when diving into your reading. We will supplement the texts with material provided in lecture notes and homework assignments.

Gradescope: All homework will be assigned and collected through Gradescope which is linked on the Canvas site. Students should complete HW #0 the first week of class, which is just an exercise for verifying access to the system.

Homework: Working homework problems is central to learning the course material. You will have 8 ~weekly problem sets of approximately 5-7 problems of varying difficulty. Homework assignments will be posted on Canvas at least one week prior to the due date of the assignment. You must scan and submit your homework solutions using Gradescope. Homework solutions will be posted the morning after the homework is due. Two homework problems will be graded quantitatively (0-10) and the rest will be graded qualitatively (0-2). The choice of the two problems to grade quantitatively will be made after the homework is collected. No late homework will be accepted, but your lowest homework score will be automatically dropped.

In each problem you do over the quarter it is important to not only show your work, but also to explain the steps you are taking. We will be performing many integrations and series expansion in this course. You are welcome and encouraged to use outside resources (tables of integrals, Mathematica, Maple, SymPy, etc.) to help expedite your solutions. However, all your work needs to be shown including simplifying complex integrals to the point of facilitating use of these outside resources, and documenting the resource utilized in your solution. Failure to adequately document your detailed solution to a problem will result in partial credit. You are encouraged to work together on assignments, but each student must submit their own work.

Lectures: You are responsible for material presented in lecture that is not in the book. The complete lecture notes are provided at the start of the quarter. Lecture attendance is required and will count towards your final grade; however, students can miss up to three (3) lecture sessions without affecting their final grade if they send an excusal request within 48 hours of missing lecture.

Grading: Your grade will be based on weekly homework sets, lecture attendance, one (1) in-class midterm exam, and a final exam:

homework	40%
midterm exam	20%
final exam	30%
class attendance	5%
discussion section attendance and participation	5%

Homework and exams are scored on the following scale: A[85-100%], B[70-85%), C[55-70%), D[40-55%), F[<40%]. The course letter grade is determined on the same scale. Your overall homework score is the average of the seven highest problem sets. Homework is not curved. Each exam will be curved separately. As a rough guideline, typically 30% of the exams will be in the A range, 30% will be in the B range, 30-40% will be in the C range. Grades of D or F will be assigned on an individual basis for outlier performance.

Exams: The exams will include material from assigned readings and lecture notes. Students will be allowed to use their own notes. Calculators are required. There will be a number of problems on each exam similar to the kinds of problems you do in homework assignments. To pass the course you must take both exams. In the event of serious personal illness or a death in the immediate family, requiring your absence from an exam, please contact me before the exam.

References: Both of the required texts are on reserve in the Library, as well as ***Tables of Integrals and Other Mathematical Data***, Herbert Dwight, The Macmillan Company, 1961. Also out of print, but I find it to be more easily accessible than most books of integrals.

Useful Links: Here are a few online links to tables of integrals and series expansions.
Indefinite Integrals
Definite Integrals
Series Expansions

Use of Course Materials: The materials provided by the instructor in this course including, but not limited to, lecture notes, homework assignments, solution sets, exams, exam solutions, and study materials (collectively "course materials") are for the use of the students currently enrolled in the course only. Distribution or public display of the course materials by students for non-enrolled students is not permitted, and may constitute academic misconduct under Sections 102.01, 102.05, and 102.23 of the UCSD Student Conduct Code. The course materials are also subject to copyright protection, with copyright held by the instructor. As such, the course materials may not be duplicated, distributed, publicly displayed, or modified in a manner contrary to law.

Schedule: Subject to change. Changes to this schedule will be updated on Canvas.

Week (start)	*Lecture Topics*	*GS, ER sections (class notes)*	*HW Due*
1 (3/31)	*Perturbations of Stationary States:* perturbation theory, fine structure of hydrogen	***Griffiths & Schroeter*** 7.1, 7.3 [skip 7.2] (pp. 126-137)	
2 (4/7)	*Perturbations of Stationary States:* fine structure of hydrogen (cont.), fine structure splitting in sodium, Zeeman effect, hyperfine splitting in hydrogen	7.4-7.5 (pp. 138-151)	#1, 4/8
3 (4/14)	*The Variational Method:* variational principle, harmonic oscillator examples, helium ground and first excited states	8.1-8.2 (pp. 152-165)	#2, 4/15
4 (4/21)	*The Variational Method:* negative hydrogen ion (H^-), molecular hydrogen ion (H_2^+), hydrogen molecule (H_2)	8.3-8.4 (pp. 166-179)	#3, 4/22
5 (4/28)	*Quantum Dynamics:* time-dependent perturbations, sinusoidal perturbations, electromagnetic waves **In Class Midterm Thursday 5/1 (class notes pp. 126-179)**	11.1-11.2 (pp. 180-187)	#4, 4/29
6 (5/5)	*Quantum Dynamics:* electromagnetic waves (cont.), Einstein's coefficients, line broadening, selection rules, forbidden transitions, Fermi's golden rule	11.3-11.4 [skip 11.5] (pp. 188-203)	
7 (5/12)	*Quantum Dynamics:* Born approximation for particle scattering *Molecular Structure and Spectroscopy:* Born-Oppenheimer approximation, molecular energy scales, rotational spectra	***Eisberg & Resnick*** 12-1:12-5 (pp. 204-216)	#5, 5/13
8 (5/19)	*Molecular Structure and Spectroscopy:* rotation-vibration spectra, forbidden transitions revisited, fluorescence and phosphorescence *Nuclear Structure:* strong force, nuclear binding energy	12-6, 15-1:15-4 [skip 12-7:12-9] (pp. 217-231)	#6, 5/20
9 (5/26)	**No Class 5/26** *Nuclear Structure:* Fermi gas model, nuclear square well, shell model, radioactivity, alpha decays, neutrons	15-6:15-8 [skip 15-5, 15-9:15-11] (pp. 232-245)	#7, 5/27
10 (6/2)	*Nuclear Structure:* beta decays and the weak force, gamma decays **In Class Catch Up and Review Friday 6/6**	16-1:16-3, 16-5, 16-10 [skip 16-4, 16-6:16-9] (pp. 246-252)	#8, 6/5
Finals (6/7)	**Final Exam Wednesday 6/11, 8:00a-10:59a, 2321 HSS (Humanities and Social Sciences Building)**		