UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
DEPARTMENT OF PHYSICS & ASTRONOMY
COURSE OUTLINE

1. **Course:** PHYS 615, Non-Relativistic Quantum Mechanics -- Fall 2018

Instructor Name	Email	Phone	Office	Hours
L01: (MWF 10:00 - 10:50 in SA 245)				
David Feder	dfeder@ucalgary.ca	(403) 220-3638	Science B 535	Mondays 13:00 - 15:00 in ST 026

Note: This course is held simultaneously with PHYS 543.

Course Site:

D2L: PHYS 615 L01-(Fall 2018)-Advanced Quantum Mechanics

Department of Physics & Astronomy:
Office: Science B 605
Phone: 403 220-5385
Email: phasoffice@ucalgary.ca

Note:
Students must use their U of C account for all course correspondence.

2. **Requisites:**

See section 3.5.C in the Faculty of Science section of the online Calendar.

3. **Grading:**

The University policy on grading and related matters is described in F.1 and F.2 of the online University Calendar. In determining the overall grade in the course the following weights will be used:

Component(s)	Weighting %	Date
Assignments (5)	40%	
Previews (10)	10%	
Midterm examinations	20% (10% each)	October 24 and October 26
Final Examination	30%	

Each piece of work (reports, assignments, quizzes, midterm exam(s) or final examination) submitted by the student will be assigned a grade. The student's grade for each component listed above will be combined with the indicated weights to produce an overall percentage for the course, which will be used to determine the course letter grade.

The conversion between a percentage grade and letter grade is as follows.

	A+	A	A-	B+	B	B-	C+	C	C-	D+	D
Minimum % Required	94 %	90 %	86 %	82%	78%	74 %	70 %	66%	62%	58 %	54 %

This course has a registrar scheduled final exam.

This course is likely to be unusual for you, in that no traditional lectures will take place. Rather, in-class time will be spent answering short quizzes (individually) and working on assignments (in groups or individually), with me acting as facilitator.

Assignments:

There will be approximately one assignment every two weeks, due Friday evenings (on D2L); the schedule is posted on D2L. All assigned work is to be submitted electronically to the appropriate Dropbox on D2L, as I will do all marking on-line. If you are writing up the assignment long-hand, then please scan the assignment (all the campus copiers will do this free of charge). That said, while you naturally will work on the assignments by hand, I strongly encourage you to write them up for submission using the LaTeX typesetting software. This software can be installed on computers running linux, Mac, or Windows. LaTeX is a powerful package for writing mathematics, and is the industry standard in physics. If you intend to stay in the physics business then you really need to know it. Also, it is the easiest way to write up your senior thesis. If you are working in groups, you can minimize the effort typesetting your assignment by distributing the responsibility for writing up different parts. The result will generally be much easier for me to parse when I am marking the assignments.

As many of you will be working on assignments together, you are welcome to submit the assignments as a group. To facilitate this, it would be helpful if you could communicate to me the members of your group by email. Then when I grade the assignments on D2L, the grade will be automatically propagated to all members of the group. You are of course welcome to change your group membership throughout the term, but must communicate this to me and all parties must agree.

Please note that some of the assignment questions will require solving for the solution numerically. You may apply your knowledge of Python or Matlab, and computational physics gathered over the years. But you are also encouraged to become familiar with a symbolic computation package, such as Maple or Mathematica.

Previews:

Approximately every week (I anticipate ten previews total), you will be asked to write a preview of at most one page each, preferably using LaTeX. Previews will summarize one or two important conceptual points to be covered in the following weeks. These don't have to be long, often a paragraph or two is sufficient. In fact, I won't read beyond a single double-spaced page, and I will deduct marks for unnecessarily long previews. The previews are to be submitted at the beginning of the first lecture of the week they are due (i.e. at 10:00 on Monday mornings), and no late previews will be accepted. The emphasis is on understanding rather than on the formalism. Part of the motivation for these previews is to give you practice expressing yourself clearly in writing, and I will mark for clarity as well as grammar. Bonus marks for humour! The other motivation is to make sure that you are keeping up with your reading, as you are essentially teaching yourself the theory of quantum mechanics by reading the textbook outside of class time. Traditionally, I would deduct marks for the use of mathematics in previews, so that you can focus on the concepts. That said, part of the motivation for these previews is so that you can learn LaTeX, if you don't already know it. So I encourage the limited use of mathematics as a way to complement the writing, but please remember that the written expression of your understanding is key.

Original artistic contributions are also encouraged, including but not limited to poetry, lyrics, song recordings, raps, movies, interpretive dance, comics, paintings, weavings, etc. If you decide to submit a preview in one of these ways, then I will be grading you on your ability to convey the central concepts in an artistic way. You can be oblique, but if I don't understand it at all then your grade will suffer. You can submit all of your previews in these alternative ways, but you won't learn LaTeX this way. But if you already know LaTeX then no worries! Last term I received almost no previews in this format which made me sad.

Please note that all previews are individual submissions.

Midterms:

Because classes are only 50 minutes long, there will be two midterms during the week of October 22. The first of these will focus on concepts, and the second on calculations. Each is worth 10% of the term grade.

4. **Missed Components of Term Work:**

   The regulations of the Faculty of Science pertaining to this matter are found in the Faculty of Science area of the Calendar in Section 3.6. It is the student's responsibility to familiarize himself/herself/themself with these regulations. See also Section E.3 of the University Calendar.

5. **Scheduled out-of-class activities:**

   There are no scheduled out of class activities for this course.

6. **Course Materials:**

   Required Textbook(s):

   Kurt Gottfried and Tung-Mow Yan, *Quantum Mechanics: Fundamentals (2nd ed)*: Springer .

   In this course, I will be following the required textbook by Gottfried and Yan relatively closely. Please note that this is a major upgrade / modernization of the classic 1st edition (by Gottfried only), so the 1st edition is not an appropriate substitute. That said, there are many other great grad-level quantum mechanics textbooks that cover the same material in largely the same way. Many of these are considered indispensable classic references, and you won't harm yourself by becoming familiar with them. These include the texts by Sakurai (Modern Quantum Mechanics, which deals with non-relativistic quantum mechanics as opposed to Advanced Quantum Mechanics which is devoted to the relativistic case), Cohen-Tannoudji et al., Shankar, etc. Many such books are now old enough that they have passed into the pubic domain, so that electronic versions can be found free of charge and perfectly legally on the internet archive, https://archive.org/. In fact, the first three of the above-listed books can be found there.

7. **Examination Policy:**

   No aids are allowed on tests or examinations.

   Students should also read the Calendar, Section G, on Examinations.

8. **Approved Mandatory and Optional Course Supplemental Fees:**

   There are no mandatory or optional course supplemental fees for this course.

9. **Writing across the Curriculum Statement:**

   For all components of the course, in any written work, the quality of the student's writing (language, spelling, grammar, presentation etc.) can be a factor in the evaluation of the work. See also Section E.2 of the University Calendar.

10. **Human studies statement:**

    Students will not participate as subjects or researchers in human studies.

    See also Section E.5 of the University Calendar.

11. **Reappraisal of Grades:**

    A student wishing a reappraisal, should first attempt to review the graded work with the Course coordinator/instructor or department offering the course. Students with sufficient academic grounds may request a reappraisal. Non-academic grounds are not relevant for grade reappraisals. Students should be aware that the grade being reappraised may be raised, lowered or remain the same. See Section I.3 of the University Calendar.

    1. **Term Work:** The student should present their rationale as effectively and as fully as possible to the Course coordinator/instructor within **15 days** of either being notified about the mark, orof the item's return to the class. If the student is not satisfied with the outcome, the student shall immediately submit the Reappraisal of Graded Term work form to the department in which the course is offered. The department will arrange for a re-assessment of the work if, and only if, the student has sufficient academic grounds. See sections I.1 and I.2 of the University Calendar

    2. **Final Exam:** The student shall submit the request to Enrolment Services. See Section I.3 of the University Calendar.

12. **OTHER IMPORTANT INFORMATION FOR STUDENTS:**

    a. **Mental Health** The University of Calgary recognizes the pivotal role that student mental health plays in physical health, social connectedness and academic success, and aspires to create a caring and supportive campus community where individuals can freely talk about mental health and receive supports when needed. We encourage you to explore the mental health resources available throughout the university community, such as counselling, self-help resources, peer support or skills-building available through the SU Wellness Centre (Room 370, MacEwan Student Centre, Mental Health Services Website) and the Campus Mental Health Strategy website (Mental Health).

    b. **SU Wellness Center:** The Students Union Wellness Centre provides health and wellness support for students including information and counselling on physical health, mental health and nutrition. For more information, see www.ucalgary.ca/wellnesscentre or call 403-210-9355.

c. **Sexual Violence:** The University of Calgary is committed to fostering a safe, productive learning environment. The Sexual Violence Policy (https://www.ucalgary.ca/policies/files/policies/sexual-violence-policy.pdf) is a fundamental element in creating and sustaining a safer campus environment for all community members. We understand that sexual violence can undermine students' academic success and we encourage students who have experienced some form of sexual misconduct to talk to someone about their experience, so they can get the support they need. The Sexual Violence Support Advocate, Carla Bertsch, can provide confidential support and information regarding sexual violence to all members of the university community. Carla can be reached by email (svsa@ucalgary.ca) or phone at 403-220-2208 .

d. **Misconduct:** Academic misconduct (cheating, plagiarism, or any other form) is a very serious offence that will be dealt with rigorously in all cases. A single offence may lead to disciplinary probation or suspension or expulsion. The Faculty of Science follows a zero tolerance policy regarding dishonesty. Please read the sections of the University Calendar under Section K. Student Misconduct to inform yourself of definitions, processes and penalties. Examples of academic misconduct may include: submitting or presenting work as if it were the student's own work when it is not; submitting or presenting work in one course which has also been submitted in another course without the instructor's permission; collaborating in whole or in part without prior agreement of the instructor; borrowing experimental values from others without the instructor's approval; falsification/ fabrication of experimental values in a report. **These are only examples**.

e. **Assembly Points:** In case of emergency during class time, be sure to FAMILIARIZE YOURSELF with the information on assembly points.

f. **Academic Accommodation Policy:** Students needing an accommodation because of a disability or medical condition should contact Student Accessibility Services in accordance with the procedure for accommodations for students with disabilities available at procedure-for-accommodations-for-students-with-disabilities.pdf.

   Students needing an accommodation in relation to their coursework or to fulfill requirements for a graduate degree, based on a protected ground other than disability, should communicate this need, preferably in writing, to the Associate Head of the Department of Physics & Astronomy, Dr. David Feder by email phas.ahugrd@ucalgary.ca or phone 403-220-8127. Religious accommodation requests relating to class, test or exam scheduling or absences must be submitted no later than **14 days** prior to the date in question. See Section E.4 of the University Calendar.

g. **Safewalk:** Campus Security will escort individuals day or night (See the Campus Safewalk website). Call 403-220-5333 for assistance. Use any campus phone, emergency phone or the yellow phones located at most parking lot pay booths.

h. **Freedom of Information and Privacy:** This course is conducted in accordance with the Freedom of Information and Protection of Privacy Act (FOIPP). Students should identify themselves on all written work by placing their name on the front page and their ID number on each subsequent page. For more information, see Legal Services website.

i. **Student Union Information:** VP Academic, Phone: 403-220-3911 Email: suvpaca@ucalgary.ca. SU Faculty Rep., Phone: 403-220-3913 Email: sciencerep@su.ucalgary.ca. Student Ombudsman, Email: suvpaca@ucalgary.ca.

j. **Internet and Electronic Device Information:** Unless instructed otherwise, cell phones should be turned off during class. All communication with other individuals via laptop, tablet, smart phone or other device is prohibited during class unless specifically permitted by the instructor. Students that violate this policy may be asked to leave the classroom. Repeated violations may result in a charge of misconduct.

k. **Surveys:** At the University of Calgary, feedback through the Universal Student Ratings of Instruction (USRI) survey and the Faculty of Science Teaching Feedback form provides valuable information to help with evaluating instruction, enhancing learning and teaching, and selecting courses. Your responses make a difference - please participate in these surveys.

As discussed above, the course will closely follow the textbook by Gottfried and Yan. We will cover a significant portion of this textbook, supplemented by material in Sakurai's book. Please note that the pace of learning in this course is going to be pretty intense, as there is a lot of material to cover. In the syllabus below, the associated sections of Gottfried and Yan [GY] or Sakurai [S] are written in square brackets. We will also briefly use the classical mechanics textbook by Goldstein (3rd ed).

Syllabus

I. Mathematical Formalism

- [GY 2.1] Hilbert Space: Spaces, Operators, Transformations
- [GY 2.2] States and Probabilities: States, Measurements, Density Matrices, Wigner Distribution, Entanglement
- [Goldstein] Classical Mechanics Review
- [GY 2.3] Canonical Quantization: Wavefunctions, Uncertainty
- [GY 2.4] Equations of Motion: Schrodinger, Heisenberg, and Interaction Pictures
- [GY 2.5] Symmetries and Conservation Laws: Groups, Rotations, Reflections, Gauge Transformations
- [GY 2.6] Propagators and Green Functions: Time-dependent Perturbation Theory, Born Series
- [GY 2.7] The Path Integral: Baker-Campbell-Hausdorff Formula
- [S 2.5] Derivation of Schrödinger's Equation
- [GY 4.2] Example: Harmonic Oscillator: Dirac Representation, Number and Coherent States
- [GY 4.3] Example: Motion in a Magnetic Field: Landau Levels, Integer Quantum Hall Effect, Aharonov-Bohm Effect

II. Angular Momentum

- [S 3.1] Angular Momentum Review
- [GY 3.1] Angular Momentum: Integer and Half-Integer
- [GY 3.2] Orbital Angular Momentum: Spherical Harmonics
- [GY 3.3] Spin
- [GY 3.4] Free-Particle States: Representation by Spherical Harmonics
- [GY 3.5] Addition of Angular Momenta: Clebsch-Gordan Coefficients, Wigner 3-j symbols (time permitting)
- [GY 7.4] The Rotation Group: SO(3) and SU(2): Irreducible Representations, Euler Angles, Cayley-Klein Parameters
- [GY 7.5] Rotational Invariance: Helicity, Rigid-Body Rotation
- [GY 7.6] Tensor Operations: Wigner-Eckhart Theorem, Racah and 6-j Coefficients (time permitting)
- [GY 7.7] Generalized Rotations: Berry Phase, Berry Curvature, Berry Connection, Chern Number (time permitting)

III. Scattering

- [GY 3.6] The Two-Body Problem: Bound States
- [GY 4.4] Scattering in One Dimension: Resonance
- [GY 8.1] Scattering in Three Dimensions: Partial Waves, Optical Theorem
- [GY 8.2] Elastic Amplitudes
- [GY 8.3] Approximations: Born Approximation, Fraunhofer and Fresnel Diffraction
- [GY 8.6] Low-Energy Scattering: Effective Range, Scattering Length
- [GY 8.7] Identical Particles
- [GY 9.2] Inelastic Collisions: The S Matrix, Transition Rates, Cross Sections, Fermi's Golden Rule (time permitting)

IV. Hydrogenic Atoms

- [GY 5.1] Qualitative Behaviour
- [GY 5.2] Kepler Problem: Lenz Vector, Spectrum
- [GY 5.3] Fine and Hyperfine Structure: Spin-Orbit Interactions, Lamb Shift
- [GY 5.4] Zeeman and Stark Shifts

V. Quantum Electrodynamics

- [GY 10.1] Quantization of the Free Field: Photons, Helicity, Parity
- [GY 10.2] Complementarity
- [GY 10.3] Vacuum Fluctuations: van der Waals Potential, Casimir Effect, Lamb Shift
- [GY 10.4] Radiative Transitions
- [GY 10.5] Quantum Optics: Beam Splitters, Complementarity, Hanbury-Brown Twiss Effect (time permitting)

VI. Quantum Foundations

- [GY 12.1] The Einstein, Podolsky, Rosen (EPR) Paradox
- [GY 12.2] Hidden Variables
- [GY 12.3] Bell's Theorem: The Clauser-Horne (CH) and Clauser-Horne-Shimony-Holt (CHSH) Inequalities
- [GY 12.4] Locality
- [GY 12.5] Measurement: Entanglement Entropy, Delayed Choice Experiments

Course Incomes:

Students entering this course should have a good familiarity with:

- Solving problems in physics analytically (i.e. using calculus, Fourier methods, etc);
- Solving problems in physics numerically (i.e. with python, Matlab, or Maple / Mathematica);
- Solving differential equations (both ordinary and partial homogeneous differential equations);
- Diagonalizing and manipulating matrices;
- The concepts, philosophy, and mathematical representation of quantum mechanics;
- Analytical and numerical approaches to solving problems in undergraduate quantum mechanics, including Schrödinger's equation, orbital and spin angular momentum, approximation methods;
- Complex analysis;
- Word processing software for writing documents.

Department Approval: Electronically Approved **Date:** 2018-09-05 14:57

Course Outcomes

- Students will explore the relationship between quantum states, wave functions, and propagators (Green's functions);
- The student will apply the propagator formalism to a range of applications, including the motion of charged particles in external fields, elastic and inelastic scattering;
- Students will come to appreciate the origins of quantum mechanics as a natural extension of Hamilton's and Lagrange's equations in classical mechanics;
- Students will explore the quantization of free fields and the foundations of quantum optics;
- Students will be exposed to concepts in quantum information theory, including entanglement and non-locality.