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

1. **Course:** PHYS 615 Advanced Quantum Mechanics Fall 2016

   Instructor: Dr. David Feder | SB 535 | (403) 220.3638 | dfeder@ucalgary.ca | Office Hours: M 11:00-13:00

   Lecture Sections: LEC 1 | MWF 10:00-10:50 | SA 125

   Course Website: d2l.ucalgary.ca

   Department Office: SB 605, 403-220-5385, phasugrd@ucalgary.ca

2. **Prerequisite:** Physics 543 or equivalent.

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:

   Assignments: 40%
   Previews: 10%
   Term Paper: 25%
   Final Presentation: 25%

   Percentage to letter grade conversion scale:

≥ 94 %	A +	≥ 82 %	B +	≥ 70 %	C +	≥ 58 %	D +
≥ 90 %	A	≥ 78 %	B	≥ 66 %	C	≥ 54 %	D
≥ 86 %	A -	≥ 74 %	B -	≥ 62 %	C -	< 54 %	F

   There will be approximately six assignments over the course of the term, constituting 40% of the final grade. In addition, each week students will be expected to write a preview of at most one page each. These will summarize the main conceptual points to be covered in the next week. The emphasis is on understanding rather than on the formalism, so mathematics should be avoided unless absolutely required. Marks on previews will be deducted for unnecessary use of mathematics! The reviews are to be submitted at the beginning of the first lecture of each week, and no late reviews will be accepted. These don't have to be long, often a paragraph or two is sufficient. Original artistic contributions are also encouraged, including but not limited to poetry, lyrics, song recordings, movies, interpretive dance, comics, paintings, etc. A term paper is worth 25% of the final grade. The topic should be identified early in the term in consultation with the instructor. A final presentation on the term paper topic makes up the remaining 25% of the grade. The cumulative grade for the course will be determined by adding the numerical grades for the four components and then converted to a letter grade according to conversion table above.

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 University Calendar in 3.6. Each student is responsible for becoming familiar with these regulations. See also E.6 of the Calendar.

5. **Scheduled out-of-class activities:** Not applicable.

6. **Course Materials:** *Quantum Mechanics: Fundamentals, 2nd Ed.*, Kurt Gottfried and Tung-Mow Yan

7. **Examination Policy**: None.

8. **Approved Mandatory and Optional Course Supplemental Fees**: None

9. **Writing across the curriculum statement:** In this course, the quality of the student's written project and clarity in the presentation of assignments will be factors in the evaluation of these tasks. See also E.2 of the University Calendar.

10. **Human studies statement:** Students in the course will not be expected to participate as subjects or researchers. See also E.5 of the University Calendar.

11. OTHER IMPORTANT INFORMATION FOR STUDENTS:

(a) **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 K. Student Misconduct to inform yourself of definitions, processes and penalties.

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

(c) **Student Accommodations:** 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 http://www.ucalgary.ca/policies/files/policies/procedure-for-accommodations-for-students-with-disabilities_0.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 and Astronomy, Dr. David Feder, by email (dfeder@ucalgary.ca) or by phone (403.220.3638).

(d) **Safewalk:** Campus Security will escort individuals day or night (http://www.ucalgary.ca/security/safewalk/). Call 220-5333 for assistance. Use any campus phone; emergency phone or the yellow phones located at most parking lot pay booths.

(e) **Freedom of Information and Privacy:** This course is conducted in accordance with the Freedom of Information and Protection of Privacy Act (FOIPP). As one consequence, 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 also http://www.ucalgary.ca/secretariat/privacy.

(f) **Student Union Information:** VP Academic Phone: 220-3911 Email: suvpaca@ucagary.ca.
SU Faculty Rep: Phone: 220-3913 Email: science1@su.ucalgary.ca, science2@su.ucalgary.ca and science3@su.ucalgary.ca
Student Ombuds Office: 403 220-6420
Email: ombuds@ucalgary.ca; http://ucalgary.ca/provost/students/ombuds

(g) **Internet and Electronic Device Information:** You can assume that in all classes that you attend, your cell phone should be turned off unless instructed otherwise. Also communication with other individuals, via

devices connectable to the Internet, is not allowed in class time unless specifically permitted by the instructor. If you violate this policy you may be asked to leave the classroom. Repeated abuse may result in a charge of misconduct.

(h) U.S.R.I.: At the University of Calgary, feedback provided by students through the Universal Student Ratings of Instruction (USRI) survey provides valuable information to help with evaluating instruction, enhancing learning and teaching, and selecting courses (www.ucalgary.ca/usri). Your responses make a difference - please participate in USRI Surveys.

12. OTHER COURSE RELATED INFORMATION:

(a) Course Description

Formalism of Quantum Mechanics. Entangled systems and their applications. Quantum non-locality, Einstein-Podolsky-Rosen paradox, Bell Theorem. Interpretations of quantum mechanics. Second quantization. Quantum theory of the electromagnetic field. Addition of angular momenta, Clebsch-Gordan coefficients, Wigner-Eckhart theorem.

(b) Course Learning Outcomes

This is the first graduate course in non-relativistic quantum mechanics. As such, it covers many of the same topics that you might have seen as an undergraduate, but in a mathematically more sophisticated way and in much greater depth. We will be primarily employing the Dirac notation, which tends to be more efficient. Students in the course will explore the conceptual foundations of quantum mechanics, learn analytical techniques, and solve a range of practical problems in quantum mechanics. Students will have numerous opportunities to communicate their understanding of both the conceptual and mathematical aspects of quantum mechanics. Students will also pursue an individual series of inquiries on an advanced topic not covered in the syllabus, and to express their understanding of this material both orally and in writing.

(c) Syllabus

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

II. Angular Momentum
   i. Angular Momentum Review (Sakurai)
   ii. Angular Momentum: Integer and Half-Integer (GY 3.1)
   iii. Orbital Angular Momentum: Spherical Harmonics (GY 3.2)
   iv. Spin (GY 3.3)
   v. Free-Particle States: Representation by Spherical Harmonics (GY 3.4)
   vi. Addition of Angular Momenta: Clebsch-Gordan Coefficients, Wigner 3-j symbols (GY 3.5)

vii. The Rotation Group: SO(3) and SU(2): Irreducible Representations, Euler Angles, Cayley-Klein Parameters (GY 7.4)
viii. Rotational Invariance: Helicity, Rigid-Body Rotation (GY 7.5)
ix. Tensor Operations: Wigner-Eckhart Theorem, Racah and 6-j Coefficients (GY 7.6)
x. Generalized Rotations: Berry Phase, Berry Curvature, Berry Connection, Chern Number (GY 7.7)

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

IV. Hydrogenic Atoms
i. Qualitative Behaviour (GY 5.1)
ii. Kepler Problem: Lenz Vector, Spectrum (GY 5.2)
iii. Fine and Hyperfine Structure: Spin-Orbit Interactions, Lamb Shift (GY 5.3)
iv. Zeeman and Stark Shifts (GY 5.4)

V. Quantum Electrodynamics
i. Quantization of the Free Field: Photons, Helicity, Parity (GY 10.1)
ii. Complementarity (GY 10.2)
iii. Vacuum Fluctuations: van der Waals Potential, Casimir Effect, Lamb Shift (GY 10.3)
iv. Radiative Transitions (GY 10.4)
v. Quantum Optics: Beam Splitters, Complementarity, Hanbury-Brown Twiss Effect (GY 10.5)
vi. Atom-Photon Interactions: Jaynes-Cummings Model (time permitting)

VI. Quantum Foundations
i. The Einstein, Podolsky, Rosen Paradox (GY 12.1)
ii. Hidden Variables (GY 12.2)
iii. Bell's Theorem: The Clauser-Horne and Clauser-Horne-Shimony-Holt Inequalities (GY 12.3)
iv. Locality (GY 12.4)
v. Measurement: Entanglement Entropy, Delayed Choice Experiments (GY 12.5)

(d) Lab Schedule: Not Applicable

Department Approval_____Date_____