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

1. **Course:** 443, Quantum Mechanics I Winter 2017

Instructor:
Dr. Alexander Lvovsky
SB 319
(403) 220-4124
LVOV@ucalgary.ca
Office Hours: Walk-in or by appointment, morning preferred

Lecture Section: TR 12:30-13:45 | KNB 133

Course Website: http://ucalgary.ca/~lvov/443

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

2. **Prerequisites:** Physics 325 and 497. (Please see Calendar Description for more information)

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

Weekly home quizzes on mandatory reading material, typically consisting of multiple-choice questions	5%
Report on a laboratory experiment on photon polarization state and quantum tomography	5%
Homeworks (bi-weekly; samples available on the course web page)	25%
Midterm test (2½ hours; samples available on the course web page)	30%
Final examination (3 hours; samples available on the course web page)	35%

Percentage to letter grade conversion scale:

> = 90 %	A +	> = 70 %	B +	> = 55 %	C +	> = 40 %	D +
> = 80 %	A	> = 65 %	B	> = 50 %	C	> = 35 %	D
> = 75 %	A -	> = 60 %	B -	> = 45 %	C -	< 35 %	F

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 with these regulations. See also Section E.6 of the University Calendar.

5. **Scheduled out-of-class activities:** A 2½ -hour midterm examination will be scheduled for the week following the spring break in consultation with the students.

REGULARLY SCHEDULED CLASSES HAVE PRECEDENCE OVER ANY OUT-OF-CLASS-TIME-ACTIVITY. If you have a clash with this out-of-class-time-activity, please inform your instructor as soon as possible so that alternative arrangements may be made for you.

6. Course Materials:

The primary resource is *Quantum mechanics for quantum optics students* available at *Bound and Copied*.
Other useful textbooks:
- Principles of Quantum Mechanics, R. Shankar, (Kluwer, 1994)
- Introduction to Quantum Mechanics , D. J. Griffiths (Pearson Prentice Hall, 2005).

7. Examination Policy: Students should also read the Calendar, Section G, on Examinations.

8. Approved Mandatory and Optional Course Supplemental Fees: None

9. Writing across the curriculum statement: In this course, the quality of the student's writing in laboratory reports will be a factor in the evaluation of those reports. See also Section 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 Section 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 Section 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 laptop

computers, Blackberries or other 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:

Course incomes

Students should have good understanding of primary tenets of linear algebra, such as

- Linear spaces
- Basis, dimension
- Inner product
- Orthonormal basis
- Linear operators and matrices
- Spectral theorem

Students should be able to operate with complex numbers; be familiar with the notions of conjugation, complex phase and complex exponent.
Students should know basic probability theory, including the concepts of mean and variance, as well as primary probability distributions.
Students should be familiar with the Fourier transformation and be able to apply it to solve practical problems.

Course outcomes

Students will know the basic postulates and concepts of quantum mechanics, including the Hilbert space, measurement, and uncertainty principle.
Students will understand the notion of quantum entanglement, the paradoxes arising from it, and their resolution.
Students will be familiar with applications of quantum physics in communications technology
Students will be able to solve problems related to one-dimensional motion of a particle in a potential field.
Students will be able to solve problems related to quantum polarization states of the photon.
Students will be familiar with the quantum treatment of the harmonic oscillator.

Syllabus

1 The quantum postulates

1.1 The scope of quantum mechanics
1.2 The Hilbert Space Postulate
1.3 Polarization of the photon
1.4 Quantum measurements
    1.4.1 The Measurement Postulate
    1.4.2 Polarization measurements
1.5 Quantum interference and complementarity
1.6 Quantum cryptography
    1.6.1 The BB84 protocol
    1.6.2 Practical matters in quantum cryptography
1.7 Operators in quantum mechanics
1.8 Projection operators and unnormalized states
1.9 Quantum observables
    1.9.1 Observable Operators
    1.9.2 Mean value and uncertainty of an observable
    1.9.3 The uncertainty principle
1.10 Quantum evolution

1.10.1 Unitary operators
1.10.2 Schrödinger equation

2 Entanglement

2.1 The tensor product space
2.1.1 Tensor product states and entangled states
2.1.2 Tensor products of operators
2.2 Local measurements of entangled states
2.2.1 Remote state preparation
2.2.2 Partial inner product
2.2.3 Local measurements and causality
2.2.4 Mixed states
2.3 An insight into quantum measurements
2.3.1 Von Neumann measurements
2.3.2 Decoherence and einselection
2.3.3 Many-worlds interpretation
2.4 Quantum nonlocality
2.4.1 The Einstein-Podolsky-Rosen paradox
2.4.2 The Bell inequality
2.4.3 Violation of the Bell inequality
2.4.4 Greenberger-Horne-Zeilinger (GHZ) nonlocality
2.5 Quantum computation
2.6 Quantum teleportation and its applications
2.6.1 Quantum teleportation
2.6.2 Quantum repeater

3 One-dimensional motion

3.1 Continuous observables
3.2 De Broglie wave
3.3 Position and momentum representations
3.3.1 Conversion between position and momentum bases
3.3.2 Position-momentum uncertainty
3.3.3 The original Einstein-Podolsky-Rosen paradox
3.4 The free space potential
3.5 Time-independent Schrödinger equation
3.6 Bound states
3.7 Unbound states
3.7.1 The single-step potential
3.7.2 Quantum tunneling
3.8 Harmonic oscillator
3.8.1 Annihilation and creation operators
3.8.2 Fock states
3.8.3 Coherent states

Appendix. Basics of linear algebra
Appendix. Probabilities and distributions
Appendix. Tutorial on optical polarizations
Appendix. Dirac delta function and the Fourier transformation

Department Approval_____Date_____