



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

1. **Course:** PHYS 615 Advanced Quantum Mechanics    Fall 2017

**Instructor:** Dr. Barry C. Sanders | SB 303 | (403) 210.8462 | [sandersb@ucalgary.ca](mailto:sandersb@ucalgary.ca) | Office Hours: By Appointment

**Lecture Sections:** LEC 1 | MWF 11:00 - 11:50 | ST 125

**Course Website:** [d2l.ucalgary.ca](http://d2l.ucalgary.ca)

**Department Office:** SB 605, 403-220-5385, [phasugrd@ucalgary.ca](mailto: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: 30%

Project: 20%

Midterm Exam: 20% (in class Friday 20 October 2017)

Final Exam: 30% (to be scheduled by the registrar)

Percentage-to-letter-grade conversion scale:

≥ 95 %	A +	≥ 80 %	B +	≥ 65 %	C +	≥ 50 %	D +
≥ 90 %	A	≥ 75 %	B	≥ 60 %	C	≥ 45 %	D
≥ 85 %	A -	≥ 70 %	B -	≥ 55 %	C -	< 45 %	F

Usually one problem will be set in each class and is due 167 hours later or at 9 am the first regular class day if the due date is a holiday or a reading day. Problems need to be emailed as pdf files and the timestamp on the email must be before the deadline. Each problem is of equal value and graded out of ten (10). The midterm and final examinations are each closed-book, no-calculator/no-computer tests. The mid-term examination is held in class for fifty (50) minutes. The three-hour final examination will be held in the final examination period. The cumulative grade for the course will be determined by adding the numerical grades for the three 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:** *No required textbook*

7. **Examination Policy:** The mid-term examination is held in class and the final examination is scheduled by the registrar. Both examinations are closed-book, and neither calculators nor computers are permitted.
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 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 Accommodation:** 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](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](mailto: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 403-220-5333 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 (FOIPPA). 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: 403-220-3911 Email: [suvpaca@ucalgary.ca](mailto:suvpaca@ucalgary.ca).  
SU Faculty Rep: Phone: 220-3913  
Email: [science1@su.ucalgary.ca](mailto:science1@su.ucalgary.ca), [science2@su.ucalgary.ca](mailto:science2@su.ucalgary.ca) and [science3@su.ucalgary.ca](mailto:science3@su.ucalgary.ca)  
Student Ombuds Office: 403 220-6420  
Email: [ombuds@ucalgary.ca](mailto:ombuds@ucalgary.ca); <http://ucalgary.ca/provost/students/ombuds>
  - (g) **Internet and Electronic Device Information:** Turn your cellphone off in class unless instructed otherwise. Communication with other individuals, via devices connectable to the Internet, is not allowed during class time unless specifically permitted by the instructor. If you violate this policy, you could be asked to leave the classroom. Repeated abuse could 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](http://www.ucalgary.ca/usri)). Your responses make a difference - please participate in USRI Surveys.

**12. OTHER COURSE-RELATED INFORMATION:**

**(a) Course Description**

Review of special relativity, electrodynamics, and nonrelativistic quantum mechanics. Klein-Gordon and Dirac equations with minimal coupling. Antimatter and the PCT Theorem. Foldy-Wouthuysen transformation and relativistic corrections to Hydrogen spectroscopy. Introduction to quantum field theory. (Formerly: Basic formalism of the theory and its interpretation, symmetry generators. Scattering theory. Bound states. Charged particles in electric and magnetic fields. Approximation methods.)

Quantum mechanics without relativity would allow many possible physical systems. Any textbook on nonrelativistic quantum mechanics presents a rich variety of contrived examples – such as particles in rigid boxes or on springs – which do not exist in the real world but are consistent with the principles of quantum mechanics. However, quantum mechanics combined with relativity high restricts possible physical systems. Nature somehow manages to be both relativistic and quantum mechanical; but those two requirements restrict it so much that it has only a limited choice of how to be – hopefully a very limited choice.

Steven Weinberg, "Where we are now", *Science* **180** 276-278 (1973)

**(b) Course Learning Incomes**

Students taking PHYS 615 are expected to have prior knowledge of linear algebra, partial differential equations, quantum mechanics, electromagnetism, special relativity and mathematical methods for physicists.

**(c) Course Learning Outcomes**

- o Understand and be proficient with the methods of relativistic quantum theory.
- o Understand the mathematical underpinnings of quantum mechanics, electromagnetism and special relativity and how they merge into the mathematical structure of relativistic quantum mechanics.
- o Understand antimatter as a consequence of the CPT Theorem.
- o Understand and be familiar with methods for solving atomic spectroscopy corrections due to relativistic effects.

**(d) Syllabus**

**ASSESSMENT**

Assignments	Project	Midterm Examination	Final Examination
30%	20%	20%	30%

**Assignments:** Usually one problem will be set in each class and is due 167 hours later or at 9 am the first regular class day if the due date is a holiday or a reading day. Problems need to be emailed as pdf files and the timestamp on the email must be before the deadline. Each problem is of equal value and graded out of ten (10).

**Project:** The project is a ten-page typed technical, properly-referenced scholarly essay on any relevant topic mutually agreed between the student and the instructor. Examples of topics: superstrings; loop quantum gravity; magnetic monopoles; time-varying fine-structure "constant"; preons/rishons; supersymmetry; cosmic strings; tachyons; dark matter; anyons.

## OUTLINE

- I. Review
1. Special relativity
2. Electromagnetism
3. Quantum mechanics
- II. Relativistic quantum mechanics
1. Klein-Gordon equation
2. Dirac equation
3. Minimal coupling
4. Plane-wave solution
- III. Relativistic covariance of the Dirac equation
1. Nonrelativistic limit for minimal coupling
2. Dirac matrices
3. Lorentz transformations
4. The adjoint spinor
5. Improper Lorentz transformations
- IV. Interpretation of spinors
1. Spin and negative energy
2. Holes and antimatter
3. Charge conjugation and time reversal
4. CPT Theorem
- V. Foldy-Wouthuysen Transformation
1. Relativistic formulation
2. Free-particle transformation
3. General transformation
4. Relativistic correction to Hydrogen spectroscopy
- VI. Relativistic quantum field theory
1. Free field theory: coupled harmonic oscillators
2. Many-particle systems and second quantization
3. Fermions, anti-commutation, and Pauli's exclusion principle
4. Divergence and renormalization

## PARTICIPATION AND PUNCTUALITY

Classroom attendance is not required, but arriving at class punctually is required.

## DEADLINES AND PENALTIES

Late assignments are acceptable but will be penalized according to the following formula: a grade  $g$  will be revised:  $g \rightarrow 0.95^n g$  for  $n$  the number of University working days beyond the due date. A fraction of a day counts as one full day. An assignment will be graded  $g=0$  if it is submitted subsequent to the release of the solutions. Plagiarism will not be tolerated: for a task worth  $g$ , the assigned grade will be  $-g/3$  in the 1<sup>st</sup> instance and  $-2g/3$  in the 2<sup>nd</sup> instance. A course grade of F will be assigned in the 3<sup>rd</sup> instance of plagiarism. Assignment solutions, the project, and answers to the final examination must be legible or incur a grade penalty. Solutions embedded in Mathematica or MATLAB or other codes are not acceptable: solutions must be written as a report with each term and equation explained. Solutions presented as a string of equations connected by banalities are not acceptable. Don't just solve the problem: explain how you solve it!