**PHYS 334 LEC 0.50**  
**Quantum Physics 2**


**Prereq:** PHYS 234 or CHEM 256/356; One of MATH 228, AMATH 250, 251; MATH 227 or 237 or 247.

**Antireq:** AMATH 373

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**2016W Session**

**Instructor**

Chris O’Donovan  
office: PHY-370  
email: odonovan@uwaterloo.ca  
office hours: Tuesday & Thursday, 13:00-16:00 (and any time my office door is open).

**Teaching Assistant**

Guiyang Han  
g5han@uwaterloo.ca

If you have questions about the marking of your assignments please approach Wei first and, if you are still unsatisfied, please come and see me then.

**Learning Objectives**

Upon completion of this course the student should be able to apply approximation methods to quantum mechanics in two and three dimensions in order to calculate energies, momenta, and angular momenta.

**Course Content**

**Linear Algebra**

- Function Spaces
- Change of Basis
- Similarity Transformations

**Harmonic Oscillator**

- Operator Methods
- 1D Harmonic Oscillator
- 2D Harmonic Oscillator

**Approximation Methods**

- Perturbation Theory
- Degenerate Perturbation Theory
- Variational Method

**Central Potentials**

- Angular Momentum
- Spin
- Clebsch-Gordan Coefficients

Hydrogen-like Atoms

- Ground State of Helium
- Hydrogen Molecular Ion
- Fine Structure of Hydrogen

**Assessment**

Assignments 15%  
Term Test 35%  
Exam 50%  
Bonus Essay +5%

In order to pass the course a mark of 50% or better must be achieved on the test and exam combined mark (i.e. (35(test) + 50(exam))/85), otherwise this mark will be the final mark.

**Course Web Site**

I will use Learn for course communication.

**Textbook**


**Lectures & Tutorials**

Two 80 minute lectures in PHY 150, Tuesdays and Thursdays, 10:00-11:20.

**Assignments**

There will be weekly assignments. These problems are to be submitted in the box across from PHY-204. Only a selection of the submitted problems may be marked.

In general, assignments will be posted on Wednesday, briefly discussed during class, and due at noon on the following Wednesday.

Late assignments, unless arranged beforehand, will not be accepted without a legitimate, documented reason. I expect the assignments to take from three to seven hours per week to complete. If you find that you are taking either much less of much more time to complete the assignments please come and talk with me.

**Bonus Essay**

If you wish you may write an essay on how one or more of the topics covered in this course are applied to other fields of science. This essay should go significantly beyond what we will cover in this course (chapter 1-7 of the textbook). For example, you could examine an aspect in more mathematical depth, or solve a related problem without an analytic solution numerically. The essay should be presented as a scientific paper (please use the PRL templates available from the APS).

**Term Test**

There will be one term test which is tentatively scheduled for the week of February 22.

If the test is missed for a legitimate, documented reason a make-up test will be offered at a mutually convenient time in the following seven days.

**Exam**

There will be a 150 minute exam to be scheduled by the Registrar.

If the exam is missed for a legitimate, documented reason a make-up exam will be offered on either the ’’Last Friday of Fall exams and first full-week Friday of Winter term.’’.

**Important Dates**

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<tr>
<th>Date</th>
<th>Event</th>
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<tr>
<td>Jan 4</td>
<td>Lectures Begin</td>
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<tr>
<td>Jan 23</td>
<td>Drop, Penalty 1 Begins</td>
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<td>Jan 29</td>
<td>Essay title and abstract due</td>
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<tr>
<td>Feb 11</td>
<td>Exam Schedule Posted</td>
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<td>Feb 15-19</td>
<td>Reading Week</td>
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<td>Feb 19</td>
<td>50% tuition refund deadline</td>
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<td>Feb 22</td>
<td>Revised essay abstract &amp; outline due</td>
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<td>Feb 22-26</td>
<td>Test Week</td>
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<td>Mar 14</td>
<td>Essay due</td>
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<td>Mar 19</td>
<td>Drop, Penalty 2 Begins</td>
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<td>Mar 25</td>
<td>Good Friday Holiday</td>
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<td>Apr 4</td>
<td>Lectures End</td>
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<td>Apr 8</td>
<td>Exam Period starts</td>
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<td>Apr 23</td>
<td>Exam Period ends</td>
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<td>May 6</td>
<td>Unclaimed course material will be shredded</td>
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In order to pass the course a mark of 50% or better must be achieved on the test and exam combined mark (i.e. (35(test) + 50(exam))/85), otherwise this mark will be the final mark.
Assignment 1.1. Semi-Infinite Square Well
Consider a particle of mass \( m \) in a square well having an infinite wall at \( x = 0 \) and a wall of height \( U \) at \( x = L \). (a) For the case \( E < U \) obtain solutions to the Schrödinger equation inside the well \( (0 < x < L) \) that satisfy the appropriate boundary condition at \( x = 0 \). (b) For the case \( E < U \) obtain solutions to the Schrödinger equation in the region beyond \( (x > L) \) that satisfy the appropriate boundary conditions as \( x \to \infty \). (c) Enforce the proper matching conditions at \( x = L \) to find an equation for the allowed energies of this system. (d) Solve the resulting equation either graphically or numerically (or both ways). (e) Are there conditions for which no solution is possible?

Assignment 1.2. Similarity Transformations
(a) Find the eigenvalues and eigenvectors of the matrix

\[
A = \begin{pmatrix}
2 & \sqrt{3} \\
\sqrt{3} & 4
\end{pmatrix}
\]

and plot the normalized eigenvectors in the plane. (b) Construct the matrix \( U \) whose columns are the normalized eigenvectors of \( A \) and calculate the product \( U^\dagger AU \) where \( U^\dagger \) is the Hermitian conjugate of \( U \) (ie, the transpose of the complex conjugate). Such a transform is called a “similarity transform”. (c) Calculate \( U^\dagger U \) and \( UU^\dagger \) and discuss what the result tells you about the the eigenvectors of \( A \). (d) Solve the problem \( A\vec{x} = \vec{b} \) where \( \vec{b} = (1, \sqrt{3}) \) by direct multiplication and then solving the resulting system of equations. Take \( \vec{x} = (x_1, x_2) \). (e) Instead now solve \( A\vec{x} = \vec{b} \) by multiplying each side of the equation by \( U^\dagger \) and inserting \( UU^\dagger \) between \( A \) and \( \vec{x} \) and then calculating \( U^\dagger AU \). The vectors \( \vec{x} = U^\dagger \vec{x} \) and \( \vec{b} = U^\dagger \vec{b} \) represent the vectors in the basis defined by the eigenvectors of \( A \). Solve the problem for \( \vec{x} \) in this basis and plot the results in the same diagram used for part (a). Now transform back to the unprimed system, \( \vec{x} = U\vec{x} \), to find the solution to the original problem. (f) Discuss the relative difficulty of the two methods of solving \( A\vec{x} = \vec{b} \) if instead of \( A \) being a \( 2 \times 2 \) matrix it was very large.