PHYS 686: Numerical Quantum Optics (Spring 2007)

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Office hours: WF 1-2, and by appointment (best to email first)  
Course home page: http://atomoptics.uoregon.edu/~dsteck/teaching/07/spring/phys686

Schedule: MWF 12:00-12:50, 318 Villamette  
Course reference number: 36058  
Credits: 4  
Prerequisites: PHYS 685

Links:

- news  
- course notes  
- assigned projects  
- software resources

Course overview

This course will provide a broad overview of computational methods in physics, with a focus on problems in quantum optics, and in particular quantum measurement. We will also continue coverage of topics from last term, such as quantum vacuum effects.

The major shift this term from the previous terms will be the focus on computer simulations. Students will work in teams (assigned by the instructor) on two assigned projects and a term project. We will cover some topics in numerical methods, such as methods for solving ODEs and parabolic PDEs. However, the projects will require a somewhat broader knowledge than what we will cover in class. You can learn these extra topics from the examples provided for the projects, from the resources posted here, from the instructor, and from other group members.

The primary language for this course will be Fortran 90/95, although I would encourage you to become familiar with the Octave numerical language for testing calculations before coding them in Fortran.

Computer Access

You will be given access to my general use lab computers (three G5 iMacs, atomoptics.uoregon.edu, gossamer.uoregon.edu, copacetic.uoregon.edu, with shared user home directories), which you can use remotely or in person. The best times for using these are "off-peak" hours, though you will obviously need to find someone to let you in the lab (236 WIL). These are the "primary" computers for the course in the sense that you should store the final versions of your codes there. You should also post your project writeups on web pages on these machines.

The above machines are relatively lightweight; although we will not tackle extremely computationally intensive problems in this course, you should also request an account on the UO Computing Center Cluster.

The unix environment is the de facto standard for high-performance numerical computation, and the programming examples will be for unix. Your codes must also compile and function under unix, although you can of course run the codes wherever you like. For remote access to the lab and cluster computers (say, from your personal computer), you will need a terminal application that supports secure shell (ssh), as well as an X Window server. These are all included on unix/linux and Mac OS X systems, but need to be installed on Windows systems. Contact the instructor for assistance with remote access.

Grades

Grades for the course will be based on two assigned group projects and a group term project. The relative weights will be as follows:

- Assigned projects: 50%  
- Term project (40% written, 10% in-class presentation): 50%

Assigned projects: Two projects will be assigned, with about 3 weeks available to complete each project. Teams of three or four students (assigned by the instructor) will work cooperatively to complete the projects. Groups will primarily be responsible for managing themselves, particularly regarding work-load distribution. Writeups for the projects must be prepared in LaTeX, and submitted to the instructor on paper. Writeups must also be posted on a web site prepared by each team on atomoptics.uoregon.edu.

Term project: The term projects will be on a topic of common interest by team members, but the topic must be approved by the instructor. The instructor can suggest problems for term projects, if necessary. By Monday, 7 May, groups must turn in a one-page summary of the term project, by this point you should have cleared the topic with the instructor. Teams will present their project results in class. The writeups are due the following week, by noon on Thursday, 19 June. As for the assigned projects, writeups for the term projects must be prepared in LaTeX, submitted to the instructor on paper, and posted online.

Pass/fail grading option: does not make sense due to the cooperative nature of the course work. The level of effort required to pass is essentially the same as the effort required for a good grade.

Syllabus

Possible topics to cover in class include those listed below. Primary emphasis will be on the quantum theory of open systems and quantum measurement.

- Quantum Theory of Open Systems  
  - Stochastic Calculus  
  - Wiener Process  
  - Itô Calculus  
  - Stratonovich Calculus  
  - Cauchy Process
Lindblad Form of the Master Equation
System-Reservoir Dissipation of the Master Equation
Heisenberg-Langevin Formalism (and the Onoistein-Uhlenbeck process)
Master Equation for Spontaneous Emission
Quantum Measurement
  Stochastic Master Equation: Quantum Jumps
  Stochastic Master Equation: Homodyne Detection
  Stochastic Schrödinger Equation
  Detector Inefficiency and Multiple Observers
  Positive Operator-Valued Measures

Quantum-Mechanical Atom-Field Interactions
  Quantum Vacuum Effects
    Lamb Shift
    Cesium-Polder Forces
    Enhancement and Suppression of Spontaneous Emission
    Vacuum Drag Forces
    Unruh Effect
  Dissipation and Measurement in Cavity QED
    Cavity QED: Input-Output Formalism
    Quantization of a Traveling Wave
    Resonant Formalism
    Connection to the Classical Field

II: Quantum Theory of the Laser
  Master Equation and Folker–Planck Equation
  Threshold Behavior
  Laser Oscillation and Gain Saturation
  Transient Behavior: Vacuum Seeding and Relaxation Oscillations
  Frequency Pulling
  Schawlow-Townes Limit
  Injection Locking
  Photon Statistics

IV: Bose-Einstein Condensation in Dilute Gases
  Gross-Pitaevskii Equation
  Bogoliubov Linearization
  Hartree–Fock–Bogoliubov Approximation
  Production of BECs
  Coherence Properties
  Dispersion and Superfluid Behavior

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**Calendar**

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<tr>
<th>Monday</th>
<th>Wednesday</th>
<th>Friday</th>
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<tbody>
<tr>
<td>2 April</td>
<td>4 April Project 1 assigned</td>
<td>6 April</td>
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<td>9 April</td>
<td>11 April</td>
<td>13 April</td>
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<td>16 April</td>
<td>18 April</td>
<td>20 April</td>
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<tr>
<td>23 April</td>
<td>25 April Project 1 due; Project 2 assigned</td>
<td>27 April</td>
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<td>30 April</td>
<td>2 May</td>
<td>4 May</td>
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<td>7 May Term project summaries due</td>
<td>9 May Class to be (tentatively) rescheduled: CLEO/QELS</td>
<td>11 May Class to be (tentatively) rescheduled: CLEO/QELS</td>
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<tr>
<td>14 May</td>
<td>16 May Project 2 due</td>
<td>18 May Class to be rescheduled: NW Section meeting</td>
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<td>21 May</td>
<td>23 May</td>
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<td>28 May No Class: Memorial Day</td>
<td>30 May</td>
<td>1 June</td>
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<td>4 June</td>
<td>6 June</td>
<td>8 June Term project presentations</td>
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