Applied Physics 150b: Quantum Measurement and Control

(Dated: Winter, 2017)

Instructor:
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Lectures:
Tu,Th 2:30-4:00PM, Rm. 104 Watson

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Course Website:
`http://copilot.caltech.edu/classes/aph150_QMC`

Course work:
1 HW/week ($\sim$ 8 HWs). HW will be given out at the end of Thursday lecture, and due the following Thursday. HWs should be handed in to the "INBOX" box outside Watson 264. You can pick up graded HWs from the "OUTBOX". There will be no exams, and HW will make up 100% of your grade. Please talk to me if you feel you want to take the course pass/fail.

Policies:
Homework: Limited collaboration allowed; make sure to work out the details of solutions on your own. Use of any texts, any notes, computers, etc. is fine. For MATLAB and Mathematica output please provide brief (but comprehensible) commentary.

Textbooks and References:
We will follow pretty closely the text of Howard M. Wiseman and Gerard J. Milburn, "Quantum Measurement and Control", augmented by studies of recent experiment and theory in this field. Lecture notes will be made available electronically at the end of each week of lecture, and posted to the class website.

Required Textbooks:
"Quantum Measurement and Control," by Howard M. Wiseman and Gerard J. Milburn (WM2010). Caltech has the ebook, which you can access here: `http://dx.doi.org/10.1017/CBO9780511813948`
"Quantum Measurement Theory and its Applications," by Kurt Jacobs. Caltech also has this ebook, which can be accessed at this link: `http://dx.doi.org/10.1017/CBO9781139179027`

Recommended for supplemental reading:
"A Computation Toolbox for Quantum and Atomic Optics," originally by Sze M. Tan [QuTip]
"Optical Resonance and Two-Level Atoms," by L. Allen and J.H. Eberly
"Statistical Methods in Quantum Optics 1," by Howard J. Carmichael
"Quantum Noise," by C. W. Gardiner and P. Zoller
"Quantum Optics," by D. Walls and G. Milburn

Course Outline: The class is intended as an in depth review of quantum measurement theory, and an introduction to the feedback and control of quantum systems. The course will also attempt to introduce the physics and applications of these ideas to quantum information processing and quantum metrology. Depending upon the interest of students, this can either be a one term or a two term class. Below is a syllabus for a one term class which ends with a brief introduction to quantum feedback control. A second term would continue with a more thorough study of quantum feedback and control and its utility in quantum information processing.

1. **Quantum Measurement Theory (Ch. 1 of WM2010)** [2 weeks; lectures 1,2,3,4]
   review of classical measurement theory, projective measurement, systems and meters (i.e., non-projective measurement),

measurement operators and effects (POVMs, etc.), representations of operators as outcomes, measument in the Heisenberg picture, classification of measurements, measuring a single photon in cavity-QED.

2. **Quantum Parameter Estimation (Ch. 2 of WM2010)** [3 weeks; lectures 5,6,7,8,9,10]
   Helstrom-Holevo lower bound, distinguishability and Fisher information, Cramér-Rao lower bound and CR optimal estimators, quantum statistical difference, Braunstein-Caves optimality (BC-optimal), examples of BC-optimal parameter estimation (spatial displacement, harmonic oscillator phase), standard quantum limit for interferometery, optimal states for interferometery, adaptive parameter estimation and interferometry, quantum state discrimination.

3. **Open Quantum Systems (Ch. 3 of WM2010)** [2 weeks; lectures 11,12,13,14]
   Born-Markov master equation, radiative-damping of a two-level atom in a cavity, spin-boson model, quantum Brownian motion, fermionic reservoirs, the Linblad form of the master equation, preferred ensembles, decoherence in a cavity, decoherence in a quantum electromechanical system, Heisenberg-picture dynamics ("quantum stochastic differential-equation technique" or "quantum Langevin approach")

4. **Quantum Trajectories (Ch. 4 of WM2010)** [3 weeks; lectures 15,16,17,18]
   quantum jumps, quantum trajectories for simulations, stochastic master equation, photodetection, homodyne detection, heterodyne detection, quantum trajectories on the Bloch sphere, monitoring in the Heisenberg picture, imperfect detection, examples: continuous measurement of a quantum dot.

5. **Intro to Quantum Feedback Control (Ch. 5 of WM2010)** [1 week; lectures 19,20]
   feedback with linear optics, in-loop squeezing, QND-based feedback using non-linear optics...