Modern Undergraduate Quantum Mechanics Experiments

Beck Lab

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Textbook

My book is titled *Quantum Mechanics: Theory and Experiment*, and is written for a junior/senior level quantum mechanics class. It is unique in that it describes not only quantum theory, but also presents laboratories that explore truly modern aspects of quantum mechanics. The book begins the presentation of quantum mechanics using photon polarization as a prototypical two-dimensional quantum system. It also has chapters describing quantum measurement, entanglement, quantum field theory and quantum information. You can order the book from the publisher, or from Amazon.

Description

Technology has advanced to the point where truly modern experiments which explore the fundamentals of quantum mechanics are accessible to undergraduates. Whitman College has developed a series of such experiments. We have also developed course materials and computer simulations which complement the experiments. This work was funded by the National Science Foundation* and by Whitman College.

Overview

- **Slides of a talk given at Amherst College in Oct. 2004.** This talk gives an overview of some of our earlier work: Proving light is made of photons, single photon interference, and the quantum eraser.

- **Slides of a talk given at AAPT Meeting, July 2006.** This talk overviews other experiments, with an emphasis on Hardy’s test of local realism.

- **Slides of a talk given at AAPT Meeting, July 2006.** This talk describes some of the equipment we use, and some of our “tricks of the trade”.

Experiments

**Proof of the Existence of Photons (the Grangier Experiment)**

This experiment duplicates the experiment of Grangier, Roger and Aspect [1], in which they demonstrate that if a single photon is incident on a beamsplitter, it can only be
detected at one of the outputs (not both.) To quote these authors, "a single photon can only be detected once!"


**Single Photon Interference**

This experiment demonstrates that individual photons interfere with themselves when they traverse an interferometer. We simultaneously measure both the interference and the second-order coherence $g^{(2)}(0)$. Since we find $g^{(2)}(0)<1$, this simultaneously demonstrates both particle and wavelike behavior of light.

**Bell Inequalities**

We have replicated the experiment of Dehlinger and Mitchell [2,3], testing a Bell inequality using polarization entangled photons. We have measured $S=2.467 \pm 0.015$, which violates the Bell inequality $S \leq 2$ by over 30 standard deviations.


**Quantum Eraser with Polarization Entangled Photons**

We have constructed an experiment where the visibility of an observed fringe pattern is affected by the types of measurements performed on two spatially separated beams.

**Hardy’s Test of Local Realism**

We have performed a test of local realism using entangled photons produced by spontaneous parametric downconversion. This experiment is based on an idea originally proposed by Hardy for a test of local realism without inequalities [4,5]. We find an over 70 standard deviation violation of the predictions of local realism.


**Virtual Laboratories**

**Simulated Experiments**
We have built computer simulations of some of our experiments. The programs are built from similar programs used to control actual experiments, so they have the same look and feel as the experimental programs. In particular, experimental noise is incorporated into the simulations in a realistic way.

Other Stuff

**Important information about detectors! Good news!**

**Coincidence Counting Units**

We have designed two different coincidence counting units (CCUs) that measure all the coincidences you need to do all these experiments. The original CCU is based on discrete logic components, while the latest CCU is based on a programmable logic IC (an FPGA). Both CCUs are significantly cheaper than the $10K of NIM electronics used in time-to-amplitude converter based coincidence measurements. Our CCUs even have higher count rates than the expensive stuff!! Click the above link to learn more about the units, and to get the info you’ll need to build one yourself. Done in collaboration with Dave Branning and his students at Trinity College.

**Parts List**

Here’s the [parts list](#) a lot of people have been asking for. It’s reasonably comprehensive and up to date as of May 2013. It describes the equipment needed do all the experiments described on these pages.

**LabView vi’s**

Copies of the LabView vi’s we use to do most of our experiments.

**Pictures of the Experiments**

**Links**

Some other groups we’ve collaborated with:

- [Colgate University](#) (Prof. Enrique Galvez)
- Trinity College (Prof. David Branning)
- Harvey Mudd College (Prof. Richard Haskell)
- Reed College (Prof. John Essick)
Notes

Updates The latest info we have on tips, equipment, etc.

We intend to add more material as it gets developed; please check back for updates.

Many of the files in this archive are stored in portable document format (.pdf). This format is viewable and printable by using Adobe Acrobat Reader. Acrobat Reader is free, and runs on Macintosh, Windows and UNIX.

If you have any problems downloading or printing the documents, please let me know at: beckmk at whitman.edu (replace "at" with @)

People Involved

Faculty:

· Mark Beck, Principle Investigator

· Rob Davies, presently at Utah State University (Grangier expt., single photon interference)

Students:

· Jeremy Thorn, presently at the University of Oregon (Grangier expt.)

· Matt Neal, presently at Oregon State University (Grangier expt.)

· Vinsunt Donato, presently at Oregon State University (Grangier expt., single photon interference)

· Geoffrey Bergreen (Grangier expt., single photon interference)

· Ashifi Gogo, presently at Dartmouth College (Bell, quantum eraser)

· Will Snyder (Bell, quantum eraser)

· J. Alex Carlson, presently at Google (Hardy test)

· Matt Olmstead, presently at the University of Utah (Hardy test)

· Jesse Lord, presently at the University of Colorado (Coincidence Counting Electronics)

*Any opinions, findings, and conclusions or recommendations expressed in this material are those of
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