**PHY 444 SYLLABUS**

Physics 444 – **Photon Quantum Mechanics Laboratory (half of the Advanced Laboratory)**

Time: MW 3:00-4:50 PM

Location: S180

Text: First three chapters of: *Quantum Mechanics: Theory and Experiment*, Mark Beck (Oxford University Press)

Co-Requisite: PHY442 – Quantum Mechanics I

Pre-Requisite: MTH335 – Differential Equations

**Instructor**

Thomas E. Wilson, Ph.D.

Office: S153

Lab: S154

Phone: 696-2752

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**Office Hours**

MWF 3:00-4:00 pm, or by appointment.

**Overview**

Developments in the technology for producing and detecting correlated photon pairs via parametric down conversion have enabled the implementation of undergraduate-level laboratories for demonstrating fundamental quantum mechanical principles, such as superposition and entanglement. During the past decade, with the support of National Science Foundation, a number of universities have developed undergraduate laboratories with correlated photons and have recently started offering undergraduate quantum mechanics courses with associated laboratories based on these types of experiments. The American Institute of Physics is strongly encouraging the wide adoption of this course nationwide as a means to modernize the physics curriculum, and as a result, I have developed this new component of the curriculum. Many of the details are provided by Enrique J. Galvez in *Resource Letter SPE-1: Single-Photon Experiments in the Undergraduate Laboratory*, Am. J. Phys. **82** (11), November 2014, and in Beck’s text. Also see http://nsdl.oercommons.org/courses/modern-quantum-mechanics-experiments-for-undergraduates/view)

As noted by Dr. Enrique A. Galvez at Colgate:

“Laboratories with correlated photons are important because they underscore fundamental concepts of quantum mechanics. They allow students to learn quantum mechanics via experimentation and thus start their quantum physics education from a position where they can gain valuable physical intuition. Experiments on interference of light at the single-photon limit serve as exercises in quantum mechanical concepts and algebra. Thus they constitute direct applications of a topic that is otherwise purely theoretical and abstract. An interesting feature of these types of experiments is that they give the instructor the flexibility to tailor the explanation of the results to his or her quantum mechanical formalism. We use an increasingly popular source of correlated photons: spontaneous parametric down conversion. It consists of sending a pump laser beam to a nonlinear crystal to produce photon pairs that are correlated in time, energy, momentum and polarization. The pairs can be used as a source of non-classical light. In some cases one photon of a pair heralds the other one going through an interferometer, and in other cases both photons go through the interferometer for demonstrating richer quantum mechanical effects. Many experiments with correlated photons cannot be reproduced by an attenuated source of light. With special modifications the source can produce photon pairs entangled in polarization, and thus enabling tests of Bell’s inequalities.”

Planned Experiments (taken from Laboratories 1-3 at the end of Beck)

1. Spontaneous Parametric Downconversion (A 3-Wave Mixing in Nonlinear Optics technique used to create entangled photons
2. [Proof of the Existence of Photons (the Grangier Experiment)](http://people.whitman.edu/~beckmk/QM/grangier/grangier.html)

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!"

1P. Grangier, G. Roger, and A. Aspect, "Experimental evidence for a photon anticorrelation effect on a beam splitter: A new light on single-photon interferences," Europhys. Lett. **1**, 173-179 (1986).

1. [Single Photon Interference](http://people.whitman.edu/~beckmk/QM/inter/inter.html)

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.

**Attendance**

Attendance of all scheduled laboratories is expected, but allowance will be made for extenuating circumstances. Students are responsible for material presented in the associated lectures, whether they are in attendance or not.

**Academic Integrity**

Complete information on the academic integrity policy can be obtained from the Dean of Students. For general university policies: http://muwww-new.marshall.edu/academic-affairs/policies/

**Grade Determination**:

All Laboratory Reports (assumes attendance) will each count 1/3 of the total %100.

Overall Course Average: A = 90% or above, B=80% or above, C=70% or above, D=60% or above, F=less than 60

**Syllabus for Advanced Laboratory - First 5 weeks**

 **(PHY 544/444 – Section 101 – CRN 3699/3712) - Fall 2018**

**Science Building, Room 180 – (MW: 3-4:50 pm)**

**First 5 weeks of the course taught by Dr. McBride, remainder of the course taught by Dr. Wilson**

***Course Description:*** This is a 2-credit hour laboratory style class. You will perform hands-on laboratory experiments that are designed to be completed at the pace of 1 experiment per week in groups of two (one graduate student paired with one undergraduate). Each lab will require addressing questions in the provided instructions for each lab and will also require you to write up a brief lab report for each experiment. “Developments in producing and detecting correlated photon pairs has enabled implementation of undergraduate laboratories demonstrating fundamental quantum mechanical principles (Dr. Wilson). This laboratory also incorporates fundamental solid state and materials science experiments (Dr. McBride).” ~ 2018 - 2019 undergraduate course catalog.

***Textbook:*** None required for first 5 weeks. Detailed instructions will be provided for each lab. The following text books are good starting point references to dive deeper into the material:

 (1) Introduction to Solid State Physics. Charles Kittel, 1996. John Wiley and Sons, Inc.

(2) The Physics and Chemistry of Materials. Joel I. Gersten and Fredrick W. Smith, 2001. John Wiley and Son, Inc.

***Pre/Co-requisite Courses:*** PR: PHY 425 and PHY 442

CR: PHY 442 and PHY 425

***Course Instructor Info:*** Dr. Sean P. McBride**,** Science Building 152, (304)-696-2758/8852, mcbrides@marshall.edu

Office Hours: (**M** 10am -12 pm, S152), & (**F** 1-5pm S152/S179) and/or by appointment

Teaching Homepage: <http://www.science.marshall.edu/mcbrides/teaching/>

Research Homepage: <http://science.marshall.edu/mcbrides/>

***Objectives:*** During the first 5 weeks of this course you will set up and run some classic fun undergraduate laboratory experiments that may have eluded you in your other laboratories. These experiments are focused on looking at the Seebeck effect, the Hall effect, Dia-, Para-, and Ferro-magnetism, superconductivity, and Young’s Modulus. The lab packet for each lab provides a brief history of the experiments and their founder along with some information guiding you through the observations you will encounter. At the surface, some of these experiments will be rather simple, but the underlying mechanisms at work leading to the observations you will see can be quite complex.

***For Graduate Students Only:*** You will be required to either (1) develop a new lab from start to finish, including providing a budget for implementation, help order components, write an instruction guide, and complete the new lab in the current semester or (2) revise an existing lab to make it better for the next generation of students (i.e. dive deeper into the underlying physics and develop different content than what is presented currently in the instruction manual to stimulate the next generation of students who complete the lab (you will need to make your own lab questions and provide your own answers). This can be viewed as option (1) is for the experimentalists and option (2) is for the theorists; however, either option is acceptable. Through either of these experiences you will hopefully gain a deeper understanding of the material for the lab you are designing or revising.

***Learning Outcomes:*** In the process of carrying out the laboratory experiments as described above, **the overarching** **goal**, is for you to work together in a team, become confident in setting up experiments effectively with help from the provided instructions, communicate what you have done and observed, and to be able to visualize & better understand some concepts that might have been taught in your undergraduate classes (but never directly witnessed or recorded data for). In order to accomplish this goal successfully, you will be given **practice** via conducting weekly labs with a partner and writing laboratory reports. Your individual success in achieving this goal will be **assessed** by your individual performance on weekly lab reports due every Monday.

***Attendance:*** I view all university level students as adults, who can or must do adult things, such as drive a car, vote, pay taxes, and who can also be sentenced to jail as an adult. Thus, as adults, I expect you to be responsible and be in lab at all scheduled meeting times; however, you will not be docked points if you have an emergency. Notify me immediately when you realize a conflict exists so we can come up with an alternative plan. All labs need to be completed for a grade.

***Grading:*** Each lab will be 20% of your total grade 100% Total

***Determination of Final Grade:*** 90% or above: A

80% or above: B

70% or above: C

60% or above: D

59.9% or lower: F

***University Policies:*** By having the privilege of being enrolled in higher education and thus this course, you agree to all the University Policies and codes listed below. It is the student’s responsibility to read the full text of each policy and code by going to <http://www.marshall.edu/academic-affairs/> and clicking on “Marshall University Policies”, or, you can access the policies directly by going to <http://www.marshall.edu/academic-affairs/policies/>. The individual policies and codes are: Academic Dishonesty, Academic Dismissal, Academic Forgiveness, Academic Probation and Suspension, Affirmative Action, Dead Week, D/F Repeat Rule, Excused Absences, Inclement Weather, Sexual Harassment, Students with Disabilities, and University Computing Services’ Acceptable Use, and the Code of Student Rights and Responsibilities ‐ also referred to as the Student Code of Conduct (<http://www.marshall.edu/student-conduct/files/2300_Student_Conduct.pdf>).

***Statement Regarding Students Requiring Special Accommodations &*** [***Students with Disabilities***](http://www.k-state.edu/accesscenter)***:*** “Marshall University is committed to equal opportunity education for all students, including those with physical, learning, and psychological disabilities. University policy states that it is the responsibility of students with disabilities to contact the Office of Disability Services (ODS) in Prichard Hall 117 (304.696.2467) to provide documentation of their disability. Following this, the ODS Coordinator will send a letter to each of the student’s instructors outlining the academic accommodation he/she will need to ensure equality in classroom experiences, outside assignment, testing, and grading. The instructor and student will meet to discuss how the accommodation(s) requested will be provided. For more information, access the website for the Office of Disabled Student Services: <http://www.marshall.edu/disabled>.” Before any type of accommodations can be given, I must receive official documentation; **therefore, take care of this the first week of classes.** For University policies and the procedures for obtaining services, please go to MU Academic Affairs (URL: <http://www.marshall.edu/academic-affairs/policies/> ).

***Statement for***[***Copyright***](http://www.k-state.edu/copyright/)***Notification:*** Copyright (2018) - Dr. Sean P. McBride, as to this syllabus and all course material. During this course, students are prohibited from selling notes to or being paid for taking notes by any person or commercial firm without the express written permission of the professor teaching this course. “All materials used in this class (in any form, electronic, printed, or verbal), including, but not limited to, exams, quizzes, handouts, lectures, homework assignments, and all material on the university’s learning management system (currently Blackboard) and its peripherals, are copyright protected works under US Code Title 17.  (1) Unauthorized copying, distribution, recording, selling, or posting of any portion of class materials, in any form, in any way, is a violation of federal law; this specifically includes posting any portion of the class materials to the World Wide Web through the Internet, and/or via any other means of electronic communication. (2) Unauthorized sharing of class materials in any form, specifically including, but not limited to, uploading class materials to websites for the purpose of seeking/providing solutions or sharing those materials with current or future students is a violation of the Academic Dishonesty Policy set forth in Marshall University's Student Code of Conduct. 'Unauthorized' means without explicit permission from the instructor. Violation of (1) or (2) will result in all necessary disciplinary actions taken against the student.” ~ Marshall University Copyright Statement, updated fall 2016.

***Campus Services:*** There are many [Campus Services & Resources](http://www.science.marshall.edu/mcbrides/images/Campus%20Services%20From%20EN.pdf) that you or someone you know throughout your college career may find useful or desperately need at some point. The above link provides contact information for Counseling and Health Services, Services for Students in Financial Need, Tutoring Services, and a wide variety of other services and resources (there are many services within each of these categories - check them out now so you know what is available to students). Chances are a version of this syllabus will always be posted on my Teaching Homepage if you ever need this information, even after the class is over.

**Young’s Modulus will be conducted in the hallway outside room 180. Part of the superconductivity lab will be done in 152.**

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|  | **Seebeck Effect** | **Young’s Modulus** | **Superconductivity** | **Magnetics** | **Hall Effect** |
| **Week 1** | Group 1 | Group 2 | Group 3 |  |  |
| **Week 2** |  | Group 1 | Group 2 | Group 3 |  |
| **Week 3** |  |  | Group 1 | Group 2 | Group 3 |
| **Week 4** | Group 3 |  |  | Group 1 | Group 2 |
| **Week 5** | Group 2 | Group 3 |  |  | Group 1 |

**Group 1 - Dillon Buskirk & Jayden Leonard**

**Group 2 - David Facemyer & Emily Sutherland**

**Group 3 - Ryan Vincent & Noah Wigton**

***Lab Reports:*** Lab reports are due Mondays. Your completed laboratory report should include all questions from the instruction packet answered and all requested plots and data processing/analysis completed. The reports should include your findings, observations, and a discussion of the physics involved related to what you observed in the lab. Reports should include an abstract, results and discussion section, and a conclusion section. In the one paragraph abstract, concisely state the objective of the experiment, how you meet that objective, what your results were, and did the results support the objective (most of the time these are numerical values). In the results section be specific, discuss the underlying physics, discuss errors, discuss how the results support or do not support the objective. Discuss what you learned. Comment on how the data presented in the graphs proves or does not prove the objective of the experiment. As you do experiments try to visualize where errors could arise and how these errors contributed to your results. Evaluating your data and results in an effort to understand whether the results are meaningful is a valuable part of experimental science, and often a very difficult part. Discuss these errors in the results and discussion section, this should be part of every lab. The conclusion for every experiment should make a statement about what you have achieved by doing the experiment, what results you have obtained, how the experiment and data supports the involved physics laws, concepts, and principles. A concise well written lab report without figures and raw data should be about 2.0 pages. If your group is running short on time during the lab, you can finish the lab during other times during the week.