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December 21, 2022

SED SC 521: STEM Education: Theory and Practice

# Discussion Materials for Quantum Physics II

In many Boston University Physics Department courses, discussion sections serve to complement lectures by providing students with an opportunity to work through practice problems and ask questions in a more dialogue-based environment. This fall, Undergraduate Quantum Physics II (PY 452) had no graduate teaching assistant (TA), so I, the undergraduate LA, stepped in to plan and organize the discussion section and its materials. Throughout the semester, I have been independently leading discussion and preparing my own example/practice problems for the Undergraduate Quantum Physics II course. These materials are chosen in collaboration with the instructor, Anatoli Polkovnikov, and are designed to provide a framework for solving homework and exam problems, as well as to apply and extend the content presented in lecture. To prepare for the discussions, I created PDF documents formatted in LaTeX and Mathematica, Python, and Julia code that summarizes the solutions to the problems. These documents are uploaded to the course's Google Drive folder after discussion and serve as a reference for students to work on their homework and prepare for exams. The topics have the following titles:

- Symmetries of Time-Averaged Particle in a Box (09/07)
- Classical Hanbury–Brown Twiss (09/14)
- Equivalence of 1st and 2nd Quantizations (09/28)
- Perturbing the 1D Quantum Harmonic Oscillator (10/05)
- Perturbing the 2D Quantum Harmonic Oscillator Using Degenerate Perturbation Theory (10/12)

- Variational Method for the Hydrogen Atom (10/19)
- Variational Method and the Radial Equation (10/26)
- 2 x 2 Degenerate Perturbation Theory (10/26, online only)
- 2 x 2 Degeneracy in a 3 x 3 System (10/26, online only)
- WKB Energies for the Triangle Potential (11/02)
- WKB-Approximated Energies and Wave-functions of the 'Quantum Bouncing Ball' (11/09)
- Yukawa Potential Variational Method and r_max (11/16)
- Time-dependent Perturbation of a Two-level System (11/30)
- Time-dependent Linear Electric Field Perturbation of the Quantum Harmonic Oscillator (11/30)
- Excitations of a Particle in a δ-potential with Fermi's Golden Rule (12/70)

For my final project, I have assembled and organized these materials so that they can be easily accessible and useful for future TAs or LAs designing discussions or students seeking additional resources. Overall, the goal of the project is to provide a comprehensive collection of resources that can help students better understand and learn the material covered in the Quantum Physics II course. By organizing and presenting these materials in a clear and concise manner, I hope to make the learning experience more efficient and effective for future students. To evaluate the quality of the discussion materials and the discussion format, I have conducted a brief survey about the effect and utility of the chosen discussion topics. The results of the survey identified the format and topics this semester were effective and may help inform future instructors when choosing the format of and topics for discussion sections.

The survey (https://forms.gle/oLVUotwpEQ6Y36Ak9) consisted of nine questions, some of which were open-ended and some of which were multiple-choice. The survey was conducted on the Google Forms platform during the second-to-last discussion on November 30 with a total of 12 students respondents (18 people were present in discussion). At the time of the survey, "Excitations of a Particle in a δ-potential with Fermi's Golden Rule" had not yet been presented or posted online. The survey was only conducted during the discussion section, and an email with a link to the survey was *not* sent to students who were not present in discussion that day, creating bias in the responses. The questions asked about how helpful the discussion section topics were to students' understanding of the course material, the relation between discussion content and homework problems, which discussion topics students preferred, the format of the discussion section, and the format and utility of discussion materials uploaded after the discussion. Despite a potentially biased pool of respondents, open-ended comments and general feedback can still provide guidance for how these resources may be used in the future.

To the first question on the survey, "How useful to your understanding of course material were the topics covered in discussion sections?," all respondents answered "Very useful" and no respondents selected other options: "Somewhat useful," "Neutral," "Not useful," "Confusing and distracting." Despite the bias in the sample, this means that for at least 12 out of 24 students in the class, the chosen discussion materials and the format in which they were presented improved students' understanding of the course content.

To the second question, "Should discussion problems resemble homework more closely?," responses were mixed. Seven out of 12 respondents said "Yes, it is often difficult to set up homework questions, so having guidance on a similar problem is a good use of time," two respondents said "Yes" for other reasons, and three respondents said "No" for a variety of reasons including, "problems that are not similar to the homework provide for a greater number of distinct examples." These results suggest to future instructors that many students prefer discussion sections to provide guidance on homework, but if instructors choose to do something more unique or distinct, there may be students who appreciate it.

Next, the survey asked students to evaluate specific discussion topics. To the question, "Looking through the discussion topics covered, which practice problems were your favorites?," the most popular option, with eight responses, was "Variational method for the hydrogen atom (10/19)"; other popular options included, "Perturbing the 2D quantum harmonic oscillator using degenerate perturbation theory (10/12)," with seven responses and "WKB energies and wave function for the 'quantum bouncing ball' (11/09)" with six responses (n.b., multiple responses were allowed). The first two most popular options were not similar to any homework problem, showing that at least eight students found value in a distinct discussion topic, despite the responses to the previous question. When asked, "Looking through the discussion topics covered, which practice problems did you NOT find helpful?," there were few responses, many including an "Other" option where students entered some variation of "None.' However, the options, "2 x 2 degenerate perturbation theory (10/26, online only)," "2 x 2 degeneracy in a 3 x 3 system (10/26, online only)," and "Symmetries of time averaged particle in a box (09/07)" received two, two, and one responses, respectively. When asked for comments, one student responded, "Generally found topics that were more focused on computational solutions (mathematica etc...) harder to follow (with WKB especially), but I guess the topics necessitate it so I don't know if this is helpful", another student responded, "I really understand the degeneracy 2 x 2 from 3 x 3 from your discussion notes [sic]," and another responded "I like when the math is relatively simple but it leads to powerful results." I believe that the first response represents a general difficulty with teaching that involves computational methods: it is difficult to implement these lessons in an engaging way because instructors often sit behind a computer, not making eye contact with students. I believe that the last response is the reason why "Variational method for the hydrogen atom" was popular; the math was relatively simple, but we were able to recover the Bohr radius and ground state energy of the hydrogen atom, a significant result in quantum mechanics.

When asked "How could the format of the discussion section be improved?," responses were mixed (n.b., multiple responses were allowed). The most popular responses included both "More interactive call-and-response when working through a problem on the board" and "Discussion leader should present content without call-and-response," each with three responses. Additionally, three respondents chose "Other" and entered some variation of "No change." These mixed results are difficult to interpret but show that the current discussion format can be used as a starting point for future iterations. In the format implemented this semester, the discussion leader presented a problem statement on the board and asked for students to provide them with steps and suggestions for how to proceed as the discussion leader reveals the solution, highlighting subtleties and possible misconceptions.

Finally, when asked "How often did you view/use the files uploaded to the 'Discussion materials' folder of the Google Drive?," eight students responded, "I occasionally looked at the discussion materials to help with homework, exam review, and/or supplement my understanding on specific topics," and four responded, "I reviewed every week's discussion materials." These results indicate that producing the PDF versions of the discussion content was valuable, and the documents were regularly used by students. Hopefully, future iterations of these discussion sections will find some of these available problems useful, and the existing formatted documents will serve as an easy-to-deploy resource and reference for students.

The results of the survey indicate that the discussion materials prepared were valuable and would be a useful component of this course taught in a future semester. To make this content available, I have put all the files on a GitHub (https://github.com/emmyb-bu/PY-452-Fall-2022-Discussion-Materials) with the LaTeX source code so that the materials can be extended or modified easily. A struggle with this implementation will be making sure that whoever teaches the course in future years knows about these resources. Overall, survey results and informal feedback indicates that the resources available helped students and were valuable to their understanding, making the implementation of the project for this semester a success.