QUANTUM PHYSICS III (8.06) Spring 2005

Term Paper

1 Project Summary

Everyone in 8.06 will be expected to research, write and "publish" a short paper on a topic related to the content of 8.05 or 8.06. The paper can explain a physical effect or further explicate ideas or problems covered in the courses. It can be based on the student's own calculations and/or library research. The paper should be written in the style and format of a brief journal article and should aim at an audience of 8.06 students.

Writing, editing, revising and "publishing" skills are an integral part of the project. Each of you will ask another student to edit your draft and will then prepare a final draft on the basis of the suggestions of your "peer editor". We will supply templates for the Revtex version of LaTeX (used by the Physical Review) so that you can prepare your paper in a finished, publishable, form. We will also arrange a LaTeX tutorial, likely in place of sections one day in April.

You will submit your first draft marked up with editorial comments by your peer editor. This first draft will then be critiqued by a "writing assistant" (see below) and returned to you. Two weeks after the first draft is due, you will submit your final draft. Your papers will be graded on the intellectual quality of your work, the effectiveness of your presentation and the success of your prose style. A part of your grade will also be determined by how carefully and constructively you edited the draft of the paper for which you were the peer editor. The grade you earn for your paper will count 20% towards your final grade in 8.06.

Because 8.06 is a CI-M Subject, in order to pass 8.06 you must obtain a grade of C or better on your term paper. If you do not succeed in this, you will get a grade of Incomplete until you revise your term paper sufficiently to earn at least a C, and only at that time you will be assigned a final grade, with your term paper grade counting 20%.

When a practicing physicist writes a research paper, he or she often asks a few colleagues to comment on a first draft. The final draft is then reviewed anonymously by one or several peers before it is accepted by a journal like the Physical Review. The goal of this informal and formal peer review process is to push authors to write papers which successfully communicate ideas among a community of peers. Your goal is to write a paper which presents a phenomenon or problem in quantum physics in a way which communicates your

ideas clearly and effectively to your fellow 8.06 students, namely to *your* peers. Do *not* seek to teach Profs. Liu and Rajagopal, although they are always happy to learn. *Do* seek to teach your peers. If your peers cannot understand what you write, you have not succeeded. Note that writing for your peers is a much higher standard than writing for the faculty. Presenting a topic sufficiently clearly and logically that one of your peers new to this topic can learn about it requires clarity of thought and depth of understanding. These are the prerequisites for an effective written (or, for that matter, verbal) presentation.

We have obtained resources to support four "writing assistants" who can help you with writing, editing and preparing the paper. Each of you will be contacted by email by one of the writing assistants on March 29. (See the schedule below.) You should arrange to meet soon thereafter, and should seek their assistance from then on as you need it. They will critique the proposal and outline for your paper, and will also critique the first draft which you submit after it has been peer edited. In between, you may also ask them to help you with parts of your paper as you write them. Think of your writing assistant as a coach. They are there to help you, and are good at it. If you wish to get their help earlier than March 29, please submit your paper proposal and the name of your peer editor earlier, and one of the writing assistants will be assigned to help you.

By the time you turn in your final paper, it will have been edited by one of your peers and you will also have had time to implement the suggestions of one of the writing assistants. Past 8.06 students have found that their papers improve enormously through this process. Based on experience from previous years, by the time you turn in your finished paper, very many of you will have produced an account of a piece of physics written to a very high standard. It would be a shame if these papers were not "published". We shall have as our goal the "publication" of a journal consisting of all your papers. There are two important caveats: (i) only papers which are submitted electronically, using the LaTeX template provided, will be published; (ii) only papers which earn a grade of B or higher will be published. Subject to these caveats, we hope to produce a compilation of all of your papers. We will circulate this "journal" to all of you, so that you can in the end read the work of all your peers, and not just of the one person whose work you edited.

2 Schedule and Due Dates for the Paper

You should use the first part of the term to consider possible topics and to choose a peer editor. Your peer editor must be an 8.06 student, and must be someone whose own 8.06 paper

topic is unrelated to yours. A list of suggested topics is given below, but you are free to choose topics not on this list upon first obtaining Prof. Rajagopal's approval. By the time Spring Break is upon us, you should have a good idea of what you are going to write about and should be well into the process of reading about your topic and doing the calculations, if any are involved. You should spend Spring Break completing your understanding of the physics that you plan to write about, completing any calculations that you plan, and outlining your paper. You will then be ready to write your proposal:

Your **proposal** is due on **Tuesday March 29**, in lecture. This must consist of: a title, a one paragraph description of what you plan to write about, an outline of your proposed paper, a list of several references you plan to use, the name of your peer editor, and your name and email address.

You will then be contacted by one of the writing assistants. They may either accept your proposal, or request that you revise it in response to their suggestions. You should arrange to meet with them as soon as possible (even if they accept your proposal). Anyone who has not met with their writing assistant at least once before submitting their first draft will be penalized.

Your **peer edited first draft** is due on **Tuesday April 12** in lecture. This means that you must give your first draft to your peer editor several days earlier, to give that person sufficient time to critique it substantively by April 12. Each of you should then meet with your writing assistant by Friday April 15 in order to obtain their comments on your first draft. In fact, if A edits for B and B edits for A, I will make sure that A and B have the same writing assistant and would therefore suggest that you both meet him or her together, to obtain comments on both your papers simultaneously. You will get your first drafts back when you meet with your writing assistant.

A hard copy of your final, polished paper is due in lecture on **Tuesday April 26**. Think of this as submitting your paper to The 8.06 Physical Review. If you get back a positive report (i.e. grade of B or better) from the editor (Prof. Rajagopal) you will then be expected to submit your paper for publication electronically. You will all get a copy of the 2005 Physical Review.

3 Nature of the Paper

The aim of this project is to give a clear and pedagogical presentation of a "problem" or "phenomenon" in quantum mechanics.

- A "problem" could be similar to but more elaborate than the type of problems that appear on problem sets. For example, *coherent states* were introduced briefly in the context of the harmonic oscillator in 8.05. A student might delve deeper into the coherent state formalism, describe the properties of coherent states, explain the types of problems where they are useful, and give some examples of their applications. Such a paper would resemble a short chapter in some hypothetical text book for 8.05. The principal references for a paper like this could be existing quantum mechanics texts and the references to the original literature to be found in them.

- A paper focused on a "phenomenon" would introduce the phenonomenon and explain its origins in terms of the concepts and language of 8.06. For example, when we treated systems of identical particles at the end of 8.05 we alluded very briefly to the "allotropic forms of hydrogen" known as *ortho* and *para* hydrogen. A student might find out what they are, how their properties are understood in terms of Fermi-Dirac statistics, and describe the interesting role they played in the early history of quantum mechanics. Once again the principal references would likely be texts, perhaps modern physics texts in this case, histories of quantum physics, and the original literature.

Papers on "problems" might be based at least in part on your own calculations. Papers on "phenomena" might involve some library research. In either case reference must be given for any material taken from other sources. Do not plagiarize. Anyone who contemplates borrowing material directly from mainstream texts should consider how difficult it is to find a text that presents quantum physics at the level appropriate to 8.06.

We encourage students to write papers which expand upon a problem or phenomenon which was already introduced in either 8.05 or 8.06 lectures. If you do this, you should begin at the level of whatever we have already covered and then go farther. Students may also choose topics which have not appeared at all in class, but whose quantum mechanical explanation can be understood based upon what we have learned in 8.05 and 8.06.

Please do not try to choose subjects which are obscure, difficult or controversial. Misguided attempts like this to gain the respect of the faculty inevitably have the opposite effect. There are plenty of deep, interesting and challenging subjects in the mainstream of quantum mechanics.

Papers can range between 8 - 15 pages (in the LaTeX template provided) in length. These limits are firm.

Students are encouraged to use equations and figures to aid their presentation, much as they are used in articles and sophisticated textbooks.

4 Possible Topics

Students are welcome to suggest topics of their own. You should do this by sending Prof. Rajagopal a brief paragraph by email, summarizing the topic. There is no separate deadline by which you must do this, but note that your complete proposal is due on March 29. At the time you submit your proposal, you should already know that Prof. Rajagopal has approved your choice of topic. (Note that your writing assistant may nevertheless require you to revise your proposal.)

Here is a list of possible topics. In some cases, either Prof. Liu or Prof. Rajagopal will have ideas for where to begin reading about these topics. Not in all cases, however.

1. Coherent states.
2. The allotropic forms of hydrogen.
3. Nuclear Magnetic Resonance. For example, you might take off from where we stopped in 8.05 and explain how NMR is applied in a particular experimental context.
4. Magnetic monopoles, gauge invariance, and the Dirac quantization condition for the magnetic charge of a magnetic monopole.
5. Scattering off a magnetic flux tube.
6. Bell's theorem — can classical mechanics imitate quantum mechanics?
7. Neutrino oscillations in vacuum, beyond what we covered in 8.05.
8. Oscillation phenomena involving kaons and/or B mesons, beyond what we covered in 8.05.
9. The solar neutrino problem.
10. Levinson's theorem — how the scattering phase shift is related to the number of bound states in a potential.
11. The shell model of nuclear structure.
12. The properties of the deuteron.
13. The α-decay of ^{238}U.
14. The rotational and vibrational spectrum of diatomic molecules.

15. Dynamical $SO(3) \times SO(3)$ symmetry of the hydrogen atom.

16. Dynamical $SU(n)$ symmetry of the harmonic oscillator in n-dimensions

17. Supersymmetric quantum mechanics, beyond what we did in 8.05.

18. The Zeeman effect in weak, intermediate and strong magnetic fields

19. The Lamb shift in hydrogen — evidence that relativistic quantum mechanics must be replaced by quantum field theory. (This is an example of a topic where you will not be able to give a complete derivation of the effect, but where those of you interested in the history of physics could write a paper which explains the quantum physics more qualitatively while at the same time describing the experiments and the history in full.)

20. The non-relativistic quark model of the proton, neutron and related particles.

21. Isospin — a quantum symmetry of elementary particles.

22. The 21 cm. line of hydrogen and its role in astrophysics.

23. The Casimir effect

24. Feynman's path integral approach to quantum mechanics, and its application to several problems of your choice which we have previously analyzed using other methods (If you choose a formal topic like this, about a method rather than a phenomenon or problem, you must take it far enough to show how the method is applied to a phenomenon or problem.)

25. The van der Waals force between hydrogen atoms in excited states.

26. Quantum computing? (You may not write a paper that purports to be about "Quantum computing". You may only choose a topic within this area if you have a focussed idea, perhaps involving presentation of one of the ideas for implementation of a quantum computer, the quantum mechanics of the implementation, the difficulties, etc. Note also that you may not write a paper whose sole purpose is the presentation of Grover's and/or Shor's algorithms, since you will see those in lecture at the end of the semester.)

27. Quantum teleportation

28. Quantum cryptography

29. Bose-Einstein condensation.

30. Integer Quantum Hall Effect (There are a number of ways you could go beyond what we do in lecture.)

31. Landauer conductivity in two dimensional systems

32. Photonic Crystals

33. Quantum Dots

34. The deHaas van Alphen effect as a tool for measuring the shapes of fermi surfaces in metals.

35. Periodic potentials and band structure.

36. An introduction to the quantum statistical mechanics of photons and the spectrum of black body radiation. (You could also include an account of how Planck was led to discover quantum mechanics in the first place, or of how the spectrum of black body radiation appears in the cosmic three degree background radiation.)

37. The density matrix formalism in quantum mechanics, and quantum statistical mechanics.

38. Optical pumping, masers, lasers.

39. Masers in astrophysics.

40. Interesting applications of the semiclassical approximation.

41. The Ramsauer-Townsend effect.

42. The Josephson effect.

43. The Wigner-Eckart theorem

44. Fractional statistics in two dimensions

45. Squeezed states and applications

46. Wigner functions and applications

47. Tunnelling, beyond the discussion in class. The Euclidean approach; effects of nonzero temperature.

48. The microscopic origin and effects of quantum dissipation, for example on tunnelling

49. Inverse scattering method and its application to solitons

5 Writing Tips

Here are some tips that you may find useful.

5.1 Structure

- Identify a well-defined topic area as early as possible. Changing your focus is fine, but you may find that it requires substantial rewriting to keep things clear.

- Work through and understand the physics before writing. You should do this over Spring Break. This will ensure that you have a well-defined topic before you start writing. You will find that this will make structuring the paper infinitely easier.

- Make sure the main points of your paper are clearly indicated. This is especially important for scientific writing, since the reader can easily get bogged down in details. Your main points should be highlighted by the structure of the paper as well as mentioned in the introduction and/or abstract.

- Write the abstract and, possibly, the introduction last.

- After you have your outline ready, don't be afraid to draft later sections before earlier sections. If you understand the last half of your argument better than the first, start by writing the last half. Doing so will help you think through how to understand and explain the first half.

5.2 Style

- In thinking about both style and structure, remember that you are writing a scientific paper and not a work of literature. The writing in great works of literature typically has multiple meanings, and can be understood in many ways, at different levels. It can be read differently by readers at different times or with different backgrounds. It often makes veiled allusions to other great literature. Over the years, great literature takes on meanings that go beyond those intended consciously by its author. In contrast, the central purpose of a scientific paper is the clear communication of your ideas to

your readers, with no ambiguity, multiple meanings or veiled allusions. Your goal is to ensure that every one of your readers, who may indeed have varying backgrounds, understands your ideas in precisely the way that you intend. This means that clarity and precision are your paramount goals. You should seek to ensure that no reader can misunderstand what you intend to communicate in any sentence that you write, even should they willfully try to misunderstand you. To this end, write in simple, declarative sentences, avoid contorted constructions and always aim for clarity.

- Feel free to use whichever voice you are most comfortable with. "I will show," "we will show" or "it will be shown" are all fine. For unknown reasons, some students seem to think that personal pronouns are banned and the passive voice is required. Nothing could be further from the truth. Good scientific writing should be animated and compelling. Your paper should "tell a physics story". I find the overuse of the passive voice to be deadening. Don't be dull. Clarity and precision come first, but don't fall into the trap of thinking that this can only be accomplished via boring your reader to tears. Not true.

- Try to lead your reader along, motivating their interest, building up the physics ground work you need them to understand, drawing them into the story you are telling, and working up to a compelling conclusion.

- All the advice I've given you about style is just as important when, later in life, you find yourself preparing a lecture or a seminar.

5.3 Some Details

- Be rigorously consistent in your notation, even at the risk of being repetitive.

- Clearly define every quantity that you introduce.

- Avoid ambiguous references, such as "this shows". Instead, use references like "Eq. 4.1 shows." The LaTeX commands \label and \ref are useful here.

6 More on Peer Editing

As described in the project summary, each of you will act as an editor for one of your peers. (Note: if you cannot find someone to act as your editor, ask Prof. Rajagopal. He will pair

people up as he gets such requests. You must list the name of your peer editor as part of your proposal, due on March 29.) When you finish your first draft, give it to your editor for editing. You must give your editor time to complete their work in time for you to submit your peer-edited first draft on Tuesday April 12.

As you are editing the work of one of your peers, you should start by praising what the document does well. If the author has made specific requests (i.e. "please see if my argument in this section makes sense to you") then spend much of your time responding to these specific requests. Do not focus on spelling and the mechanics of writing, unless asked by the author to do so. (Of course, note problems of this sort which you happen to spot, but this is not your main goal and the author should in general not rely on you for this sort of editorial review.) Instead, focus on helping the author to revise content, organization and logic. Do not just criticize. Make suggestions on how to solve the problems you notice in the paper.

As you edit the work of your peer, here are some of the questions which you should be thinking about:

- What is the paper's main argument?
- How interesting is it? Is the importance of the topic explained?
- How specific is the argument? Would it benefit from being made more general or complete? Would it, in contrast, benefit from being made more focussed?
- Is the paper divided into sections and subsections in a way which makes following its logic easy? Does each section flow logically from the preceding one? Do ideas flow smoothly from one paragraph to the next?
- Early in the text, is there a clear road map of the entire document?
- Are all outside sources documented? If, as will be the case for almost all 8.06 papers, the paper contains ideas which are not the results of calculations done by the author and are not ideas we have all seen in lecture, can you see from which source the author learned each such idea?
- Are all technical terms which are new to you defined clearly, and used consistently?
- If the paper presents the solution to a problem, what are the arguments on which the solution rests? Do you understand each argument and the solution as a whole? Is each

part of each argument substantiated? (Either by calculation presented in the paper, or by reference to 8.05 and 8.06 material which you can see substantiates the argument.) Is there anything missing, which would help complete an argument?

- If the paper describes a phenomenon, do you understand the description? Is the nature of the phenomenon clearly described? Are the reasons why the phenomenon is of interest clear? Do you understand the quantum mechanical explanation of the phenomenon presented by the author? What do you wish the author had included that would have given you a better understanding of the phenomenon?

7 The LaTeX Templates

LaTeX (and its ancestor TeX) are widely used in academic and technical publishing. They are "mark-up" languages, like HTML, that tell a processor how to construct mathematical expressions that look like typeset text. One of the objectives of this assignment is to give you an experience preparing a physics paper for "publication". When practicing physicists submit papers to the Physical Review, they do so by emailing a latex file, and perhaps some postscript figures, to the editorial office. If you wish to have your paper published, you will do the same.

Many 8.06 students have had previous exposure to LaTeX; some have not. Both to level the playing field and to make possible the publication of your finished papers, we will put a template on the web, for you to download. LaTeX itself is already available as standard Athena software. The template will be available from the 8.06 web page soon.

The most computer-illiterate among you — nevertheless more literate than Professors Rajagopal and Liu by far — need only download the templates, open them in your favorite editor (such as *emacs*), and notice the way the LaTeX template deals with title pages, footnotes, references, equations, mathematical symbols in text and set off from text, equation labels, tabs, and so forth. You can construct your paper by cutting the text out of the template text and inserting your own.

In order for students to have access to all necessary macros, already installed on Athena, it may first be necessary to type: `add newtex`. [Note: this was necessary three years ago, but Prof. Rajagopal thinks it is now not necessary.]

You should begin by downloading the template, and making sure that you can LaTeX it successfully, to produce output which looks like the hard copy of the template paper which I will post on the course web page.

In order to do this, you will need the commands:

- `latex filename.tex` will run the LaTeX typesetting program to produce typeset output from your input file. If there are errors in your LaTeX file, the file `filename.log` will contain error messages that are usually helpful. When LaTeX runs successfully, its output is `filename.dvi`, where `dvi` means "device independent". (Note that you will need to run LaTeX twice on the file, in order for all the references to bibliographic items and equation numbers to come out right.)

- `xdvi filename.dvi` will display your output in its finished form.

- `dvips filename.dvi` will convert the `dvi` file to a postscript file, send it to the printer, and then delete the postscript file. If, instead, you want to save a postscript file instead of printing it, use `dvips -o filename.ps filename.dvi`. This creates a postscript file named `filename.ps`. One reason to do this is that you can then view your output using ghostview (gv) instead of xdvi. gv is a more sophisticated viewer than xdvi. (A final note here: gv by default does not antialias to save time. It can be turned on and off from within gv or you can use the -antialias flag when calling gv to do it automatically.)

The template provided will contain postscript figures. If you know how to produce illustrations in postscript, the template will illustrate how to incorporate them into your paper. If you don't or don't want to bother, you are welcome to draw figures by hand or with your favorite graphics package, and simply staple them onto the end of your paper. Note, however, that if you wish to submit your final paper for publication, you *must* prepare it using the LaTeX template and *must* include any figures as encapsulated postscript files, as done in the template.

The template uses a macro called BoxedEPS in order to incorporate encapsulated postscript figures. This macro may be available on Athena, but to be safe we will make it available for you to download at the same time that you download the template itself.

We strongly urge people who are new at LaTeX to communicate with classmates. Likewise we strongly encourage LaTeX wizards to help the less experienced with the nuances of the language.