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So you have to write a senior thesis...

Perhaps you are feeling uneasy about the amount of work required to produce a senior thesis, and you are not quite sure where to begin. You may begrudge those physics professors who at one fateful faculty meeting a few years ago instituted the senior thesis as a requirement. It may seem like they are just making life difficult for students.

Conspiracy

You should know that those professors who made the senior thesis a requirement also added a significant burden to themselves by agreeing to mentor and edit your thesis project. They know that writing is an essential part of communication, and good writing comes only with practice. No matter how well you understand physics and no matter how imaginative your research, if you cannot communicate your ideas clearly, they benefit no one.

Deadwood

Everyone in physics at one time or another has experienced the frustration of being on the receiving end of a poor presentation, the natural result of insufficient attention paid to clear thought. The effort you put into your senior thesis can dramatically improve your ability to communicate. This effort may even be viewed as necessary to justify your many years of study. To this stage in your life you have mainly received from others --- parents, teachers, and those who paid for your education. You have spent countless hours developing the light of knowledge within you; it will take as much effort to remove the bushel that covers it. It is time to begin to let your light shine as you make the transition towards a career.

What is real?

The work on your senior thesis is perhaps the closest thing to a "real-world" experience that you will have in college. Nobody solves textbook problems or takes exams for a living. Soon, others will judge you primarily by your research initiative and on your ability to communicate; your college grades will be superfluous. For the first time (and far from the last) you will be expected to craft and define a problem which inevitably will be murky in the beginning. You will have to find and explain the context for that problem, including a clear summary of the related works of others. You must justify your choice of problem. The research for a senior thesis will require initiative and imagination. You will have the opportunity to develop a clear description of your work and a coherent and concise argument for its conclusions.

Sooner the Better

The senior thesis requirement is designed to challenge you, but the benefit to you will depend on the effort you put into it. The skills that the project will engender are among the most important that you will take with you after graduation. It is far less work to develop them now than to delay the inevitable. In almost any career path you follow, good writing skills will be crucial. If you do not acquire them during college, you will have to develop them later (motivated by survival instinct), most likely in an ad hoc fashion under embarrassing and unpleasant circumstances.

Thoughtfulness

Good writing is foremost an exercise in clarity of thought. The need to communicate with others will therefore guide your work and in the long run make you much more productive. Good writing is not an afterthought, but it plays a central role in physics. The following outline will help you with your thesis project. It is more than a description of required thesis format; it contains important information that is relevant from the earliest stages of thesis research.

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INCREDIBLY USEFUL ADVICE FOR PHYSICS STUDENTS WRITING A SENIOR THESIS

(Title in caps; Center; Note inverted pyramid.)

by

Justin Peatross

Submitted to the Department of Physics and Astronomy in partial fulfillment of graduation requirements for the degree of Bachelor of Science

Brigham Young University

May 2000

(Warning: Those writing an honors thesis should follow introductory -page instructions from the Honor's Program.)

Advisor: Steve Jones

Signature: _____

Thesis Coordinator: Justin Peatross

Signature: _____

Department Chair: R. Steven Turley

Signature: _____

(Leave a 2" space.)

Abstract

The abstract is a *summary* of the thesis, *not an introduction*. Keep in mind that abstracts are often published separately from the paper they summarize. In your abstract, give a concise synopsis of the work, emphasizing the conclusions; you need not include the supporting arguments for the conclusions. The purpose of the abstract is to help prospective readers decide whether to read your thesis, but your goal is not necessarily to persuade people to read your thesis. In fact, a successful abstract enables people to get an accurate overall view of your work without needing to read it. Usually, an abstract contains a single paragraph, but it can have more (try to keep it to less than a page). In the abstract, remember to state the subject of the paper immediately followed by a summary of the experimental or theoretical results and the methods used to obtain them. Avoid equations, graphics, and citations; if a citation is essential it must be cited fully within the abstract. Keep the abstract factual; don't make it "cute." Use lower-case Roman numerals to number pages beginning with "ii" on this page.

(Leave more than a 2" space.)

Acknowledgments

This page is optional. You may acknowledge whom you will --- your advisor, colleagues, family members. Please keep acknowledgments in good taste. I would like to acknowledge Dr. Kristine Hansen, Associate Dean of General Education for Composition, and Dr. Elizabeth Hedengren, Writing-Across-Curriculum Consultant, for providing motivation to this project and also for valuable information presented in their Advanced Writing Seminar. Many of the ideas presented herein were taken from the seminar with no attempt being made to reference original sources. I also wish to thank Jean-Francois Van Huele, Steven Turley, and Ross Spencer for reviewing this document and for ripping it to shreds as every good advisor should do to a thesis draft.

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CHAPTER I. GETTING STARTED

1.1 Choosing an advisor

You need a thesis advisor. Try to get one early, preferably at the start of your junior year or before. If you are unsure who to choose, try using a random number generator. Alternatively, you might want to visit the department web page (http://physics.byu.edu/) and look over the list of faculty and visit their various web sites. Each fall, the BYU Chapter of the Society of Physics Students holds a department research night where students have the opportunity to learn about the different research groups within the department.

Visit with prospective advisors during their posted office hours or by appointment. Ask questions about what research they are doing and how you might become involved. Request a tour of any laboratory facilities that the professor uses. Talk to other students who are currently doing research with the professor. Keep in mind that establishing a connection with a professor is a two-way process: You must choose an advisor, but he must also choose you. Hint: Nothing pleases professors more than if you attend their research group meetings (often held weekly). A list of meeting times can be obtained from the department secretary.

1.2 Themes for projects

When choosing an advisor (and after the choice is made), discuss potential senior thesis projects with him at every opportunity. This will prod your advisor to think about your specific case, and he will more quickly recognize the right project for you in the research group. Of course, you can give as much input as you like. However, please recognize that professors in general are already committed to certain agendas on which their research support is based. The best tack in the beginning is to assist more experienced students with their research project as you "learn the ropes." You will be amazed at how

projects become more interesting when you are involved with them. The problem that you identify as the basis for *your* senior thesis will soon become extremely interesting.

1.3 Financial support

Each summer the Department of Physics and Astronomy supports about a dozen students at 20 hours per week while they work on their senior thesis research. This means that you can get paid for fulfilling your graduation requirement. To be selected for this, you must submit a one-page proposal (along with an ABC report) to the department in consultation with your advisor. The deadline for this is usually in early March. In addition, the department often supports many students at about 10 hours per week to do research during the Fall and Winter Semesters. Final decisions for funding are usually made during the first few days of each semester. The Office of Research and Creative Activities (ORCA) holds a scholarship competition each fall for students involved in research. The award amount is about $1,000 and you can get this on top of the summer or school-year funding. The application deadline is usually in mid October, and you may pick up application materials in A261 ASB. Also, many professors have research funds that are earmarked to pay undergraduate research assistants. For those doing an Honors Thesis, there are some funds available through the Honors Program.

Finally, you should be aware of the *Research Experiences for Undergraduates* (REU) program sponsored by the National Science Foundation. Many universities across the nation participate in the program (including BYU). These universities host undergraduates (mainly from other institutions) and involve them in research during a few summer months. Visit the National Science Foundation web site of *Student Interests* (http://www.nsf.gov/home/students/). Under the heading *For Undergraduate Students*, click on *list of REU sites* for a complete listing of sites and contact information.

It is perfectly legitimate to use your REU research away from BYU as the basis for your senior thesis. If you do so, try as much as possible to prepare your thesis *while* you

are participating in the REU program. Ask the professor with whom you are working to help you to revise your thesis during the visit. Get started early to allow time for revisions. As part of the REU program, you will be required to write a report on your research experience. While a thesis is much more than a report, you can use your thesis (or portions thereof) in the report. For purposes of completing your senior thesis, you will need a thesis advisor at BYU. Choose one before you go to the REU site. After you return, your BYU advisor can help you to revise your thesis and see that it is satisfactory for submission to the department.

1.4 Literature

1.4.1 Using the library

The library holds enormous resources, many of which are probably unfamiliar to you. Contact John Christensen (2323 HBLL, 378-2928) who is the Library Subject Specialist for Physics and Astronomy. He holds training sessions periodically on how to use the library *for physics research*. Attend a training session. He gets paid to teach you. Get as many of your peers in the department as you can to go with you. This training session is more valuable than five quantum-mechanics lectures!

1.4.2 Academic journals

New physics research is mainly published in journals, rather than in textbooks. It takes time for the more relevant information to find its way into textbooks. As you study the relevant issues in your field of research, it is essential that you study articles in academic journals. Some of the more prestigious physics journals are Physical Review A, B, C, D, and E, and Physical Review Letters, which are published by the American Physical Society (APS). There are dozens of other reputable physics journals, often emphasizing specialized areas, many of which can be found in the large new atrium underground wing of the HBLL.

Some journals (such as the above mentioned APS journals, http://publish.aps.org/) can be accessed on-line and articles downloaded.

Journals are collections of scientific articles that undergo scrutiny through an anonymous peer review system. Physicists mainly publish articles about their research in these types of journals. Therefore, journals should be the primary source of background and contextual information in your thesis, as opposed to web sites, for example, which are probably not peer reviewed. *Conference proceedings* are another important source of information. They are collections of short articles submitted by participants at scientific conferences.

1.4.3 Using search engines

An electronic search engine is by far the most important tool for finding relevant research information. The best one currently available at BYU is *Ei Compendex Web* (http://www.ei.org/ev2/home). Unfortunately, this search engine is not purely a physics data base, but it is a little cluttered with engineering articles. It also does not give information on many European journals and fails to provide the abstracts for the American Physical Society journals (although it gives the titles). Nevertheless, if you supplement your Compendex search with the American Institute of Physics (AIP) data base called *SPIN* (http://www.aip.org/ojs/service.html), you will get nearly complete coverage. It is important to use *Ei Compendex Web* since it will include conferences, whereas SPIN does not.

There are other very good physics search engines such as INSPEC to which BYU does not subscribe (since it costs several tens of thousand per year). You should be aware that BYU pays a significant amount for Compendex and for SPIN, and they have to be accessed from a BYU site to be granted entry. BYU pays this money partly for *your* sake, so please take advantage of the service. There are other search data bases which may be accessed through the menus at the HBLL web site. Choose *Article Indexes*. Select *Physics* in the *Specified Subject* box. Some very powerful search engines are available to librarians

only (including INSPEC) which are too expensive to make generally available. Contact John Christensen (2323 HBLL, 378-2928) to be directed to a librarian who can use Computer Assisted Research Services (CARS) on your behalf. Short searches are complimentary, but there is a modest fee to students for lengthy searches.

1.5 Effective searching

When beginning a search, you may initially want to restrict it to articles published in recent years (say, last 10 years) in order to avoid getting deluged with "hits." You will probably want to begin the search using key subject words. As you locate relevant titles, read the abstracts to decide which articles are important to you. As you find relevant articles, follow up with searches using author names. This may turn up additional related articles. It is a good idea to have a word processor open on your computer as you search. Then, when you find important abstracts and citation information, you can copy them into your word processor to be printed later. You can change the font or style to offset particularly relevant abstracts. As you search, you may end up pasting dozens of abstracts into your list. A good search will probably take a few hours as you go through many abstracts.

Take your new list to the library and look up articles from it, beginning with the ones that seem most relevant. Some of the articles may also be available on-line as mentioned in Sect. 1.4.2 above, but it is a mistake to rely solely on these for the sake of convenience. (Hint: You may be able to borrow your advisor's library copying card for this official research business.) Sometimes you will need to order articles through the Interlibrary Loan Service (free to you, but not free to the library). If you do, the article should be important enough to pick up when it comes in --- they get annoyed when people don't bother to pick up the articles they order. After acquiring a few articles, begin to read them (or skim) to further assess relevance. Especially pay attention to the introduction where authors summarize the relevant publications of others. Doing this, you will find

many new references. This is an efficient and very important way to network your search back in time. You are relying on other experts in the field to point you towards seminal research articles. As you find these important papers, use the Science Citation Index which will point you to papers which have referenced them. This is the way to network forward in time.

Take your time in the library. A poor strategy is to photocopy blindly a long list of potentially useful articles. As you look up articles, decide whether they are relevant before you photocopy. After you make a copy, make notes in the margins and use a highlighter to mark references to other important works. Don't forget to include in your networking search from the very beginning any references that you received from your advisor. Those articles will often be the most important. After many hours of using search engines and finding articles in the library, you may have considered more than 50 different articles and found more than a dozen that are very relevant to your research. You will likely summarize a number of these in your thesis introduction and refer to many of them at relevant points throughout your thesis. You may have occasion to refer to a few books as well, so don't forget to do usual Byline searches.

1.6 Reading and understanding the literature

Do not be discouraged when attempting to read physics research articles. Feeling utterly lost is quite normal, even for experienced physicists. It takes time to penetrate physics articles since the information is often presented very compactly, intended for other experts in the field. It is helpful to read initially only the abstract, the introduction, and the conclusion. You might save the interior of important papers for a discussion with your advisor, perhaps during a group meeting. As you read more scientific papers, you will acquire a feel for the overall structure and flow, the manner of documentation and reasoning. In fact, it is exactly this efficient and well-mannered approach to technical writing that should go into your thesis (with a somewhat different audience in mind).

If you struggle to understand physics articles, you may have trouble with more than just the physics. If so, it might help to make a half-hour appointment with a tutor at the BYU Reading Center (JKHB 1010), which is a free service. Describe in advance the purpose of your visit. Take a physics article with you and ask the tutor to help you penetrate it. Of course the tutor will not be able to help you with the physics, but you may be surprised at how well someone without a physics background can locate key issues and conclusions.

CHAPTER II. WRITING MATTERS

2.1 Basic mechanics

It is not your advisor's job to fix mechanical errors in your thesis such as punctuation, dangling or misplaced modifiers, or shifts in tense and perspective. However, these problems often get in the way of what students are trying to say and can make a manuscript unreadable. Most students have serious difficulties with the mechanics of writing. If you think you don't, ask yourself whether you understand the difference between "effect" and "affect." Should the period in the previous sentence be placed before or after the quotation mark? Fortunately, you can get help from the BYU Writing Center. Visit their web site right now (http://humanities.byu.edu/writingCtr/) and click on *Handouts*. Download a series of their one-page handouts that you think will be most helpful to you. (Hard Copies of the handouts are also available at the Writing Center, 1010 JKHB.) You may especially consider downloading the handouts listed in Table 1.

- Paragraph Unity and Coherence
- Comma Splices and Fused Sentences
- Punctuating Parenthetical Words or Word Groups
- Punctuating Quotations
- The Zen of Pronoun Usage
- Active vs. Passive Voice
- Shifts and Perspective Defined
- Combining Sentences
- Dangling and Misplaced Modifiers
- Parallelism

Table 1. A sampling of handouts available from the Reading Writing Center.

Before submitting drafts of portions of your thesis for review by your peers and by your advisor, please have the common courtesy of doing the simple things: *Always* run your spell checker. *Always* re-read your document *at least* a day after you have written it and fix all of the obvious things. Use correct page layout and formatting, including double spacing so that editors can insert comments. Near the beginning of the writing process, you

may want to take advantage of one-on-one feedback from a tutor in the Writing Center, which is a free service. Make a half-hour appointment to discuss any aspect of the writing process. Be aware that the tutors will not edit your thesis.

2.2 American Institute of Physics Style Manual

The American Institute of Physics (AIP) promotes physics research and education in the US and world wide. Their member societies include such organizations as the American Physical Society (APS) and the Society of Physics Students (SPS). To promote uniformity and clarity of writing throughout the physics community, AIP publishes a Style Manual [1] that standardizes the rules for good physics writing. Most physics journals adhere to the AIP style manual, and you should become familiar with it as you write your thesis. Visit the American Institute of Physics web site (http://www.aip.org/), choose *Publishing Services, Author Services,* and then *AIP Style Manual*. Download and study the three pages on *Writing the paper*. This is worth more than ten quantum mechanics lectures! (I am not implying that quantum mechanics is unimportant.) Of course, there are many other sections in the AIP style manual that would be good for study. (Note: Astronomy journals follow slightly different style rules, but for department purposes astronomy students are permitted to follow AIP style rules.)

2.3 References

You will be tempted to delay including references in your thesis until the end of the writing process. This is a big mistake. Prepare your list of references as you go, from the very beginning of the writing process. Otherwise, you may fail to give appropriate credit when you summarize ideas and results, which is a form of plagiarism. Do not reference work that you have not read (at least in part including the introduction and conclusion). Developing your list of references as you write is much less work in the end.

Students often think that the references are not important and are careless when transcribing author and journal names. You must *double check* each detail of every reference listed. Scientists get very annoyed when their names are misspelled. Journal editors, referees, and type setters get very annoyed when misinformation and incorrect protocol are used in references. Advisors get annoyed when they have to correct the reference lists in theses because students are casual about it. The references matter.

A list of various references appears at the end of this document as examples. The list includes a reference to a journal article [2], a reference to a page in a book [3], a reference to multiple pages in a book [4], a reference to an individual author contribution to an edited volume [5], a reference to a conference proceeding [6], a reference to a work that is not yet published [7], a reference to a dissertation [8], and a reference to a private communication [9]. The AIP style manual includes examples of other types of references. It also has a complete listing of abbreviations for journal titles (see Style Manual Appendix G).

Reference numbers should appear in square brackets throughout the text in numerical order as shown in the previous paragraph. The same reference number may appear more than once in the text, but undue repetition should be avoided. You may place your reference list at the end of the entire thesis or at the end of each chapter when there are many chapters (some duplication of references may result).

2.4 Equations

Punctuate equations appropriate to the sentence that contains them [1]. (You get a brownie point if a sentence structure requires a question mark immediately following an equation, but this rarely occurs.) Let entire equations function as a noun (or the restatement of a noun) in a sentence, although it is permissible to allow an equal sign to function as a verb (less desirable). All significant equations should be offset to a line of their own and given a reference number. Small and less important equations can be embedded within the

text unless they require line numbers for later reference. If a thesis contains many chapters and many equations, the equations in chapter 1 should be indexed as (1.1), (1.2), etc., and the equations in chapter 2 indexed as (2.1), (2.2), etc. The example below, extracted from the middle of an article, shows a variety of equation usage.

It is enlightening to consider the form of Eq. (2) in the frequency domain, where the fields are expressed as superposition's of pure frequency components:

$$\vec{E}(\vec{r},t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \vec{E}(\vec{r},\omega) e^{-i\omega t}\, d\omega\,,\ \vec{H}(\vec{r},t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \vec{H}(\vec{r},\omega) e^{-i\omega t}\, d\omega\,. \tag{3}$$

The expected arrival time of the pulse $\langle t \rangle_{\vec{r}}$ can be computed directly from the spectra of the fields, $\vec{E}(\vec{r},\omega)$ and $\vec{H}(\vec{r},\omega)$, which contain the necessary phase information. The results presented in this article are obtained from the following form of Eq. (2):

$$\langle t \rangle_{\vec{r}} = T\left[\vec{E}(\vec{r},\omega)\right], \text{ where } T\left[\vec{E}(\vec{r},\omega)\right] \equiv -i \frac{\hat{u} \cdot \int_{-\infty}^{\infty} \frac{\partial \vec{E}(\vec{r},\omega)}{\partial \omega} \times \vec{H}^{*}(\vec{r},\omega) d\omega}{\hat{u} \cdot \int_{-\infty}^{\infty} \vec{S}(\vec{r},\omega) d\omega}. \tag{4}$$

The denominators in Eqs. (2) and (4) are equivalent in accordance with Parseval's theorem, where the Poynting vector in the frequency domain is defined by $\vec{S}(\vec{r},\omega) \equiv \vec{E}(\vec{r},\omega) \times \vec{H}^{*}(\vec{r},\omega)$.

The individual frequency components obey the Helmholtz equation

$$\nabla^2 \vec{E}(\vec{r},\omega) + \omega^2 \varepsilon(\omega) \mu_o \vec{E}(\vec{r},\omega) = 0\,. \tag{5}$$

The solution to this equation in a uniform medium is given by

$$\vec{E}(\vec{r},\omega) = \vec{E}(\vec{r}_o,\omega) \exp\left\{ i\vec{k} \cdot \Delta\vec{r} \right\}, \tag{6}$$

where the position is $\vec{r} = \vec{r}_o + \Delta\vec{r}$, and where the wavenumber satisfies $k^2 = \omega^2 \varepsilon(\omega) \mu_o$.

2.5 Figures

Take the time to generate professional-looking artwork for your thesis. Schematics of experimental setups should be simple, well organized, and labeled as illustrated in Fig. 1. Figure captions should be concise and descriptive. Write figure captions using a smaller font (10 point). For graphs, be sure to include appropriate units and to provide a legend

referring to the different curves as in Fig. 2. Each figure should be described carefully within the text of your thesis.

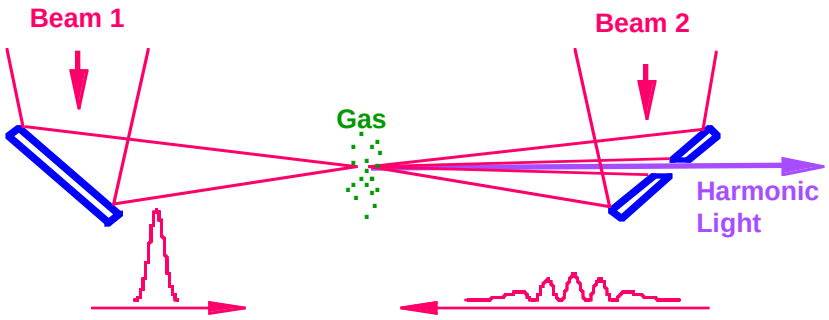

Fig. 1. A mirror with a hole is used to extract high-order harmonics generated in counter-propagating laser beams.

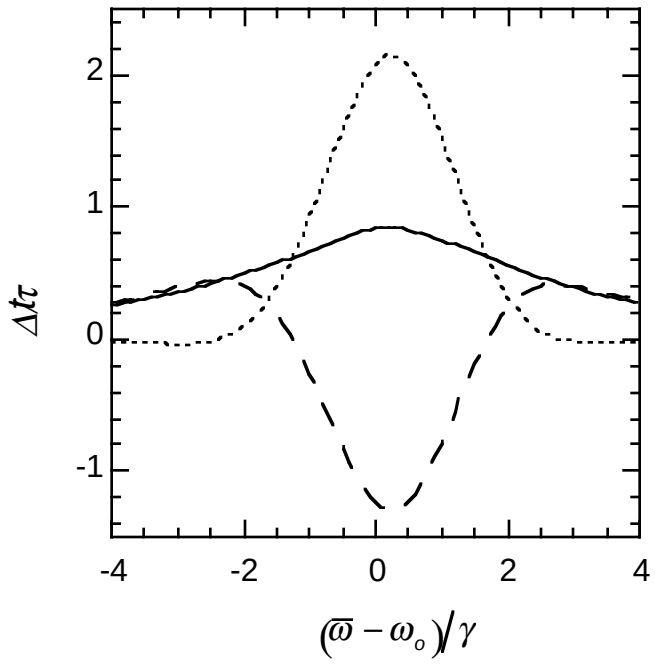

Fig. 2. Group delay (dashed), reshaping delay (dotted), and total delay (solid) as a function of ϖ for the broadband pulse. The reshaping delay is computed at the end of propagation.

CHAPTER III. CLEAR THINKING

3.1 Creating an outline

Once you identify your research project, you should immediately begin the writing process. The initial writing process may begin in your lab notebook. (A good physicist keeps a lab notebook or journal.) Make an outline (as best you can envision) of your thesis. An example of such an outline is shown in Table 2. In this example, the primary student research project is represented in section 2.3. The student will work on a spectrometer which is just one part of a larger research project involving other group members. Nevertheless, the thesis will encompass the overall purpose and results of the entire project (even though this will overlap with theses written by other students). Other students, for example, may have developed the equipment described in sections. 2.1 or 2.2, and so these items would naturally be emphasized in detail by them (in their theses).

Development of a Spectrometer to Study the Influence of Counter-Propagating Light on High-Order Harmonic Generation

Chapter I. INTRODUCTION	**Chapter II. EXPERIMENTAL SETUP**	**Chapter III. RESULTS**
1.1 Overview	2.1 Laser System and Pulse Characteristics	3.1 Measurement of High Harmonics
1.2 Background 1.2.1 Laser Harmonic Generation 1.2.2 High Harmonic Generation 1.2.3 Phase Matching and Conversion Efficiency	2.2 Experimental Setup	3.2 Influence of Counter-Propagating Light
1.3 Using Counter-Propagating Light to Manipulate Phase Matching	2.3 High harmonics Spectrometer 2.3.1 Design Overview 2.3.2 Diffraction Grating 2.3.3 Imaging Issues 2.3.4 Positioning Control	3.3 Interpretation of Results
	2.4 Detection	3.4 Conclusions and Future Outlook

Table 2. Sample outline for a senior thesis.

The overview section (1.1) should motivate the reason for the research without relying on specific background that will be introduced in the later sections. You should include general motivational statements (that you might give, for example, to a science news reporter) as in the following example: "Laser high-order harmonic generation is a unique source of directional and bright extreme ultraviolet radiation (EUV). This short wavelength light source may have future applications in ultrafine resolution photolithography. Because the high harmonics are coherent and generated with short pulse lasers, they can be used to probe ultrafast phenomena when high-energy photons are needed..." The overview should also provide the reader with a clear demarcation of the scope of your contribution to the overall project.

Near the end of Chapter 1, as you narrow to the specific problem to be addressed, be sure to provide a more detailed outline of the overall project than was given in the opening section. Again, be specific about your role in the project. Briefly introduce and summarize what will be discussed in the remainder of the thesis. As is evident, the content of the first chapter depends strongly on what is written in subsequent chapters. Therefore, the first chapter is typically the last chapter to be completed. Nevertheless, it should also be one of the first chapters that you begin to write.

It may happen that, while a student makes a meaningful contribution to the overall project, the final results are not obtained before the senior thesis is submitted. This is not ideal, but this happens to students quite often. In this situation, the final chapter might be entitled "Discussion." If attempts were made at obtaining data, the concluding chapter might describe the reasons (especially reasons involving physics) why the attempts were unsuccessful. The final chapter should provide suggestions on how to remedy the situation (which can be helpful to future students who continue the project). If the data-taking stage is not reached, the concluding chapter might describe preliminary checks of equipment and expected roles for the new equipment in the overall project.

The format suggested in Table 2 is very flexible and would likely be somewhat different, for example, in the case of a thesis based on theoretical work. You should decide what works best for you in consultation with your advisor. You may want to examine several senior theses written by previous students which are available in the physics department reading room (N288). There are examples of good and not-so-good theses there. Exemplary theses were written by Shannon Lunt, Deborah Paulsen, and Michael Ware.

3.2 Importance of feedback

Obtain feedback at every step of the writing process. Go over your outline with your advisor. It is much less painful to rearrange or to delete sections *before you write them*, when they are represented merely in outline form. Make brief notes indicating what will go into each section (e.g. a summary of research by Group X and Y, a schematic of an experimental setup, a blowup view of a critical part, etc.). Discuss your initial ideas and brainstorm together with your advisor.

You should start writing portions of your thesis early, even though some sections will need to wait until after the research is concluded. When possible, begin making figures --- even hand-drawn sketches in your lab notebook. Remember to develop the overall outline before writing specific sections. This helps to avoid writing material that might later have to be discarded. As you write portions of your thesis, show them to your advisor and to other members in your research group for valuable feedback. Your advisor will be much happier reviewing short pieces of your writing periodically, as opposed to reviewing it all at once near the due date. As you receive feedback along the way, you can apply it to sections not yet written. The periodic feedback helps you to revise and reshape your outline continually and guides you in developing a clear scientific writing style.

The writing process forces you to organize your thoughts and to keep a clear vision of your research. This helps you to avoid long periods of stagnation by bringing to the

foreground the next logical step in the research. The important thing is to keep moving forward. No matter what, you will make many mistakes, so try to make them as fast as you can. This is the difference between experience and inexperience.

3.3 Audience

You should consider as your audience the other students in your research group. In particular, after you graduate, your thesis might be used as a resource for students who will move into your former role. Avoid making your thesis too basic; you may assume a certain level of sophistication on the part of the reader. However, the thesis should be easily understandable to a physics professor whose research expertise is in a different field.

3.4 Coherence

Just as the overall outline of the thesis should have a clear and logical organization, the sequence of information presented in each section and paragraph should also follow a logical flow. Continually ask yourself which paragraphs should appear before others. You should be aware of a key sentence in each paragraph which usually appears near the beginning and defines what the paragraph is conveying. If a paragraph is very lengthy, don't hesitate to break it into two (at a logical place). Read your own writing for logical progression and for smoothness. Develop the skill of crafting smooth transitions.

3.5 Conciseness

Cut out the lard. Avoid long strings of prepositional phrases in sentences of theses written by students in their senior year for the physics department at BYU as a graduation requirement for the degree of Bachelor of Science. (Did you get the joke?) Use simple declarative sentences often, but not exclusively. Make every word count.

Vary sentence length. Intermingle short with long sentences in an aperiodic fashion. You might inadvertently kill a reader with boredom if your sentences all have the same length.

In your writing, be as quantitative as the subject matter permits, and avoid inexact word usage. Continually ask yourself how your writing might be misinterpreted. Make sure that arguments are logically complete.

3.6 Active voice

Remember that active verb construction generally captures the reader's attention more than does passive construction. This does not mean that passive voice should never be used. Just keep in mind that an over reliance on passive verb construction results in a rather bland document.

3.7 Document format

This document has been written following the format requested for your thesis. Use a 12 point serif font such as Times for the main text. If you desire variation, you can use a sans serif font such as Helvetica for chapter and section headings (see heading 3.7 above as an example). Set the left margin to 1.5" to allow room to bind your thesis. The other margins should be set to 1". Allow the right-hand side of the text to run ragged; text is easier to read if it is not stretched and compressed in order to create a straight right margin. Double space your lines. This makes the text easier to read and allows for the insertion of mathematical expressions into the text without disrupting the line spacing.

Use page breaks judiciously so that section headings do not become isolated from their subsequent text on the bottom of a page. Strategic positioning of figures within the text can help to avoid large white spaces created when a figure's size forces it onto the next page. If possible, you should avoid inserting figures before they are discussed in the text. Your document should be printed single-sided. However, if preferred you may position

figures on the backs of pages if this facilitates keeping them close to the text describing them (located on the adjacent page).

This document has been prepared using Microsoft Word and MathType for the equations. Check with you advisor to find out which word processor will work best for you. Many professors and students choose to use LaTeX or variants such as REVTeX which is a form used by APS journals (e.g., Physical Review Letters). LaTeX can be downloaded free of charge. For more information, go to the website of the TeX Users Group (www.tug.org). Supplementary REVTeX macros can be obtained from the website of the American Institute of Physics (www.aip.org).

3.8 Appropriate length

How long does a senior thesis need to be? The answer is that it should be as long as necessary to communicate your ideas succinctly. There is no set length. The written document is not an end in itself, but a vehicle to convey your ideas as efficiently as possible to the reader. However, if the main body of your thesis (excluding title pages and appendixes) is only 10 pages, you probably have not included sufficient context and motivation for your work. If the main body of your thesis exceeds 30 pages, you are probably not concise enough. Professors and others don't really want to read a lot of pages. A long thesis may also mean that you have done more work than expected. Remember, you are not asked to complete a masters project, rather a comparatively modest project in your senior year. In the example in Table 2, the introduction chapter *might* have 8 pages, the experimental setup chapter *might* have 11 pages (emphasizing the work actually performed by the hypothetical student in the example), and the results chapter *might* have 6 pages (assuming results are obtained through a group effort).

3.9 Deadlines

You must register for 2 credit hours of Physics 498R (499R if you are in the honors program, 492R if you are in applied physics) in any semester before graduation (usually when you are actively involved in the research). At the end of the semester, if the thesis is still in progress, you will receive a T grade. Then, when your thesis is completed, your advisor will change it to a letter grade. In order to allow for an adequate evaluation period, your thesis should be submitted for review at least six weeks before graduation. (Honor's theses are required ten weeks before graduation, submitted first to the Honor's program and then indirectly to the department.) After the thesis has been approved and signed by your advisor, take it to the Senior Thesis Coordinator, currently Justin Peatross. If acceptable, the Senior Thesis Coordinator will recommend your thesis to the Department Chair for a signature. The Coordinator will then forward the manuscript for binding and archiving in the Physics Department library. Be sure to make an extra copy for yourself (and one for your advisor). Typically, these additional private copies are not bound unless you pay for it.

References

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[5] J. Peatross, J. Zhou, I. Christov, A. Rundquist, M. M. Murnane, and H. C. Kapteyn, "High-order harmonic generation with a 25 femtosecond laser pulse," in *proceedings of 4th Conference on Super Intense Laser-Atom Physics* (SILAP IV, Moscow, Russia, August 1995), edited by H.G. Muller and M. V. Fedorov, (Kluwer Academic Publishers, Dordrecht/Boston/London, 1996), *High Technology* Vol. 13, pp. 455-466.

[6] J. Peatross, W. E. Dibble, S. A. Glasgow, and M. Ware, "Energy Propagation of Broadband Light Pulses in Dispersive Systems," presented at the 15th Annual Interdisciplinary Laser Science Conference (OSA/ILS XV), (Santa Clara, CA, Sept. 1999).

[7] M. Ware, W. E. Dibble, S. A. Glasgow, and J. Peatross, "Energy flow in angularly dispersive optical systems," (to be published).

[8] J. Peatross, "The far-field angular distribution of high-order harmonics produced in light scattering from a thin low-density gas target," Ph.D. dissertation (University of Rochester, Rochester, N.Y., 1993).

[9] J. Peatross (private communication).

[10] N. D. Mermin, "What's wrong with those talks?" Physics Today **45**, 9 (1992).

Appendix A: Things that belong in an appendix

The purpose of an appendix is to provide supplementary information which would distract if included in the main body of the thesis. Items appearing as an appendix might include lengthy derivations. If students feel compelled to include a brief tutorial on relevant background information (not new research), it should appear as an appendix. An appendix might consist of portions of unique computer code that was developed as part of the project.

Appendix B: Presenting a talk

When presenting your thesis work in a talk, you will want to convey an overview of your thesis as a whole. However, you must pick and choose what to emphasize since time will be limited. There is no formal oral defense requirement for the senior thesis (although there is for an Honor's Thesis). However, the department encourages students to make at least one formal presentation in a department meeting (e.g., at the Atomic Molecular and Optics meetings or the Discussions in Theoretical Physics meetings). All students doing a senior thesis, and especially those receiving department funding, are expected to participate in the annual Spring Research Conference held each March in the College of Physical and Mathematical Sciences at BYU. Depending on available travel resources, students may also have the opportunity to present a talk at a professional meeting, either regional (e.g. at the annual APS Four Corners meeting) or national (e.g. the annual meeting of the Optical Society of America).

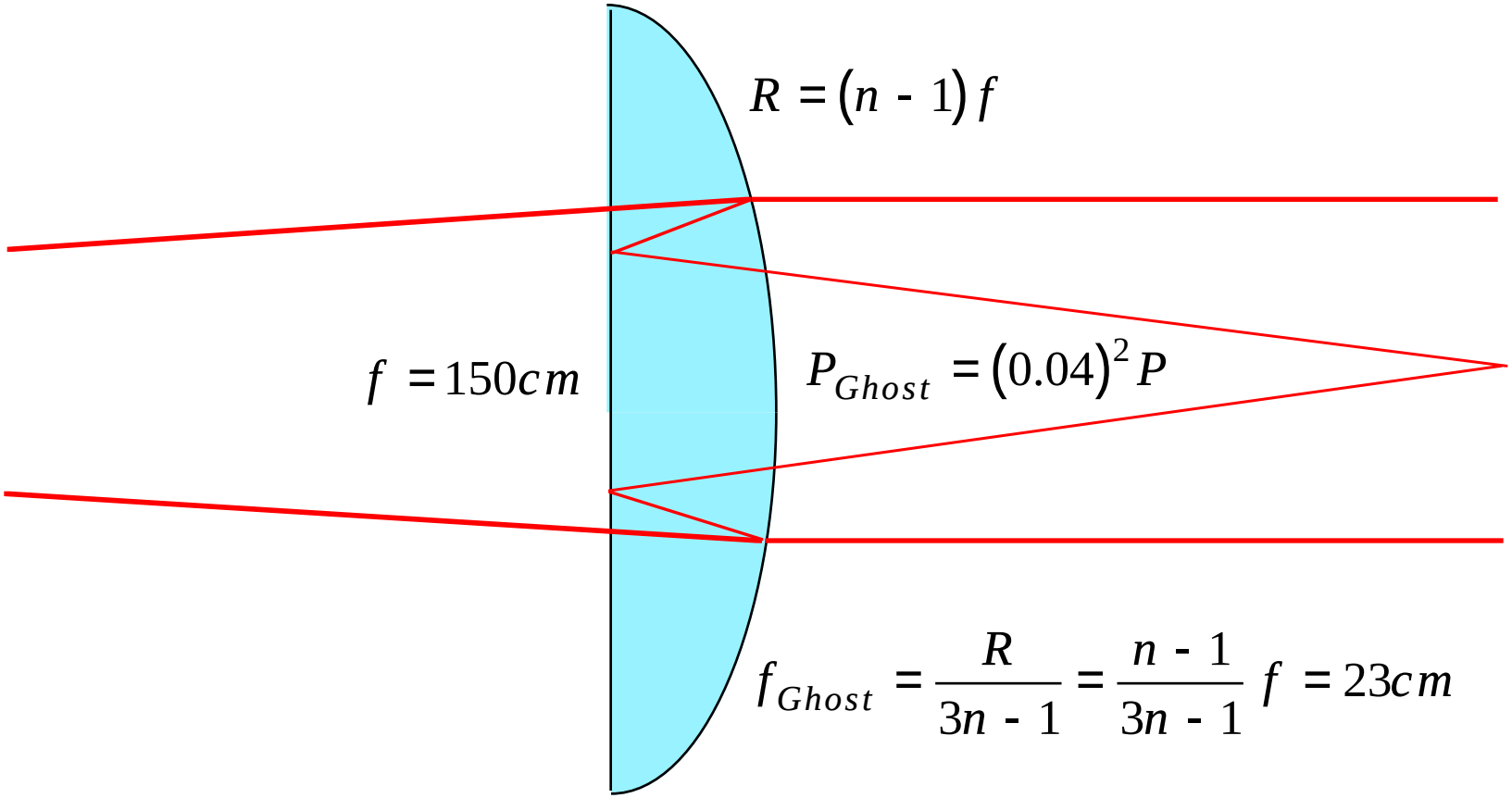
For short talks, you should have no more than two thirds as many slides as you have minutes allocated for your talk. For longer talks, you should have somewhat fewer slides. Create a title page which acknowledges everyone who has contributed to the work. Prepare an outline slide that will let the audience know what you are going to be presenting. (If time is extremely short (e.g. 7 minute talk), you may dispense with the outline slide.) *At least* a third of your talk should be introductory in nature, providing background that will help the audience appreciate the work. The main goal in giving a talk is to convey to the audience a

sense that your work is important; the goal is not to give the audience a lot of details which they will never remember nor even get straight in the first place. Less is more. A conclusion slide can be used to remind the audience of your main points and to summarize the significance of your work. Keep it brief. The conclusion slide may be omitted if it seems too redundant, depending on how you presented the material[10].

Many of the figures that you prepare for your thesis will be useful for your slide presentation. Keep slides simple and uncluttered. Include less information on a view graph than you plan to talk about. Be sure that important labels are present (such as the units on graph axes). Use large fonts so that your slides are easy to read, even for people in the back. It is a good idea to place a single large "header" sentence at the top of each view graph (no more than two lines using a 24 point font). Think of the main idea that you want an audience member to get from a slide, and use that for the header sentence. Use color if resources permit. An example of a view graph is given on the next page. Be sure to use ample margins so that the entire view graph fits on the overhead projector. Having to shift the transparency is a distraction.

Practice your talk to yourself and to others in your research group, especially your advisor. Timing your practice runs is essential. If you do not practice, you will most likely give too many irrelevant details and muddle through or even miss your main points, a sure recipe for a boring talk.

The ghost beam focuses inside of the collimated beam



$$\begin{pmatrix} 1 & 0 \\ (n-1)/R & n \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 2/R & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1/n \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ (3n-1)/R & 1 \end{pmatrix}$$

ABCD matrices for ghost beam relative to incident beam