

The Senior Paper – Guidelines and Format

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Abstract

In this paper we describe the requirements for the Senior Paper in Physics at Haverford College, along with the procedures to be used for evaluation. The recommended format is similar to that used for scientific papers submitted to journals based in the United States. We describe the desired organization of the paper section by section, including detailed information concerning the format of equations, figures, captions, and tables. We conclude with some useful general advice.

I. Introduction

Each Haverford physics major presents a one-half hour talk and writes a Senior Paper based on independent work, which may be either research or an extension of an upper level course.

While the talk is meant to be accessible to the other senior majors, the Senior Paper should be a more complete and deeper presentation of results. Material omitted from the seminar because of its complexity or length can be included in the Paper.

II. Requirements and Evaluation

Scientific writing is generally expected to be succinct. The paper should contain 12-15 pages of text (double-spaced, 12 point type, with 1.25" margins)¹, not including a separate title page with abstract, figures with captions, and a list of references. By editing carefully and using references to the literature where appropriate, you can meet this page limit while still communicating effectively. If you are reporting on a research project in a 400 level course, your advisor may require appendices documenting the technical aspects of your work or containing useful background information. These appendices may be submitted separately to your Advisor, and are not evaluated as part of the Senior Paper.

The paper will be examined by two readers, at least one of whom is a faculty member in the Physics/Astronomy department at Haverford. The readers will be concerned both with the quality of your writing and with the content of the paper. Generally a Haverford faculty member provides an initial reading, even when the work is the result of a collaboration with a scientist at another institution. The first reader then returns the paper to the student within one week with a list of comments and requests for revision. (The readers

¹In order to save paper this printed version uses a single-spaced format. The electronic version which you can download to use as a template has double-spaced paragraphs. (Its location is specified near the beginning of section III.)

general make comments directly on the text and figures, so submit only *copies* of any important original figures.) When possible the reader also discusses the reading in detail with the student.

The student then revises the manuscript carefully and thoroughly within 7-10 days. If you consider any of the requests inappropriate, you should consult with the reader. *The revised paper should be re-submitted with the initial version attached. A copy should be given simultaneously to the second reader.* If the paper is based on work done off-campus, it will be sent to the mentor at this point. (The student is expected to make arrangements with this individual well in advance to ensure that this reading, which may generate further revisions, can be done in a timely fashion.)

At this point the paper will be evaluated (and graded) by both readers. The evaluation will be based both on the depth of understanding and on the quality of the writing. Further corrections and additions may still be required, but generally the evaluation process is not repeated. We also expect you to meet the timetables that are set to allow this complicated process to proceed efficiently.

Your final requirements for turning in your Senior Paper are as follows:

- 1 final hardcopy (bound or unbound) for first reader/research advisor needed by noon, May 10. (This includes all changes suggested by the first and second readers after they read the second version, which is due on May 2.
- 2 unbound hardcopies for departmental files needed by May 16 at noon (One of these will go into a hardbound volume of all this year's theses, to be kept in the library. One will be filed in the department's file cabinet drawer containing past senior theses.) Please give these to Scott.

One full electronic copy (including all subsidiary files) needed by May 16. Please place in the "'01 Theses" folder in Walter Smith folder on the faculty server. If there is anything non-obvious about how to open the files, etc., please include a short help file. If there are multiple files, put them into a folder first.

In addition, you will probably want some copies for yourself, your parents, graduate school admissions committees, potential employers, etc. You have put a great deal of effort into this Senior Paper, and it is worth while to produce a few extra copies, so that you can give them out as desired over the next several years.

The department will arrange for and pay for the comb binding of up to six personal copies. These turn out quite well, include reasonably nice covers, and are suitable as gifts, so we encourage you to take advantage of this offer. You must bring the fully collated personal copies to Walter Smith by May 16 at noon if you wish for the department to bind them.

We strongly recommend that you produce all the copies at the same time. This will really reduce your overall time spent on reproduction. Although the deadline for departmental copies (other than that for the advisor) is May 16 at noon, it will make life easier for all of us if you can turn them in well before then.

You may use the printer in 108b for the three officially required copies, including text-only pages. The 108a printer should only be used for pages which require color. You may also use these printers to generate personal copies of the pages in your Senior Paper which will not xerox well (i.e. pages which include grayscale figures or color). However, you must use a xerox machine to produce personal copies of all pages which do xerox well (e.g. those which don't contain any figures). You are expected to pay for the copying of these pages (for personal copies) yourself. We realize that this policy requires some extra work from you in collating the copies. However, based on extensive past experience, we feel it necessary to restrict the use of the printers in 108a and 108b as described here; otherwise overuse will lead to their demise rather quickly.

A summary of the above paragraph:

*Use the 108a printer to generate all copies of pages which include color, including personal copies. Do not use this printer for any pages which don't require color.

*Use the 108b printer to generate all copies of pages which include grayscale figures, including personal copies.

*Use the 108b printer to generate the three officially required copies of pages which do not include grayscale figures.

*Do not use the 108b printer for personal copies of pages which do not include grayscale figures. Instead, use a xerox machine, and pay for these copies yourself.

III. Format

The format of your Senior Paper should be similar to that of a standard scientific article. For examples of papers, you may consult the American Journal of Physics available in Stokes 107. (Many of the papers in this journal are accessible to a senior physics major.)

If you use Microsoft Word, this document is available for use as a template. (You can download it from the departmental web site. Follow the Course Materials link to the Physics 399 page.) We recommend that you attach styles to paragraphs rather than formatting them individually. Your paper should contain the following sections, and *all* pages, including the tables and figures at the end, except the first one should be numbered.

A. Title and Byline

The choice of a title is important in communicating the main subject of a paper. The byline gives the authors names, institution, and address.

B. Abstract

The abstract summarizes the *results* obtained, not merely what was done, as cogently and precisely as possible. The abstract is written as a single paragraph, and could be up to about 200 words for a long paper. It is conventionally placed on the title page of the paper and may if necessary continue onto the following page. Indent both margins and use right and left justification for the abstract.

C. Introduction and Background

This section gives the scope and objectives of the paper, explains its relationship to previous experimental and theoretical work, and motivates what follows. You should try to *get the reader interested* in what you have to say at the very beginning of this section. Then you should proceed to a more detailed review of previous work relevant to the project, *suitably referenced*. The Introduction and Background could be either one or two sections, depending on the amount of material to be covered here.

Short equations like $c=$ can be left in the text if not particularly important. Equations you wish to emphasize and which will be needed later should be set off on a separate line. All such equations should be numbered sequentially and followed by suitable punctuation, like this:

$$g(y) = \int_0^y F(x)dx . \quad (1)$$

Note that *italics* are generally used for lower case (but not upper case) symbols.

D. Experimental or Computational Methods

In this section the apparatus, measurement methods, circuits, numerical methods, etc. are described in considerable detail. Methods that are standard are generally not described. You should supplement this discussion with suitable schematic drawings, circuit diagrams, etc.

You should clearly indicate the strengths and limitations of your measurement or computational methods (for example, the precision that was obtained and possible systematic errors). They might be compared to alternative methods in some cases.

Purely theoretical papers usually do not have a separate methods section, unless an approximate approach is being used and requires description or a particular numerical procedure is employed for the work.

E. Results

Here you should explain your findings in detail, making full use of tables and graphs (prepared using Cricket Graph or Kaleidagraph software, for example) where appropriate. All figures must be referenced and described in the text of the paper. Be selective in deciding what figures to include. Don't allow your paper to become repetitive by including too many figures of a given type. The figures themselves are gathered in order at the end of the paper and must have captions (see below). Tables are also placed at the end of the paper and follow their own formatting rules (see below).

F. Discussion and Conclusions

Begin this section with a brief recapitulation, and then proceed to evaluate your results, compare to theory or experiment as appropriate, and suggest future directions if this seems appropriate. You must communicate clearly what you have accomplished that was not known before, in case you are reporting the results of original research.

G. Acknowledgments

This is the place to acknowledge assistance you obtained from others, including for example your advisor, other students, or professors who assisted you substantially. It is also proper to acknowledge helpful communications you had with scientists at other institutions, or the receipt of unpublished information or preprints. It is not customary to list your advisor as a co-author of your Senior Paper, though coauthorship is customary if you later submit a paper based on your work to a journal.

It is worth mentioning here that in a situation of multiple authorship, prudence and integrity require that all authors should have read the paper carefully and in its entirety.

Each should regard his or her presence in the byline to be a pledge to the scientific community of their complete confidence in the validity of the work².

H. References

It is important to demonstrate your familiarity with the literature, to acknowledge those who have gone before you, and to make use of their work to expedite the presentation of yours.

- Single author references are indicated by giving the last name followed by the date of publication as in the following sentence. For a review of theoretical issues relating to the surface structure of insulating materials see LaFemina (1996).
- When a paper has two authors the reference in the text lists both last names followed by the date, as follows. Boughn and Uson (1995) give an important constraint on the content of dark matter in dwarf stars in the halo of our own galaxy.
- When a paper has more than two authors one uses the *et al.* abbreviation, as follows. A significant instrumental advance for scanning tunneling microscopy has been reported by Smith, et al. (1996).
- Books are referred to using the same format as articles as follows. Baker and Gollub (1996) give an excellent introduction to chaotic dynamics.
- Material that has not yet appeared in print, as in the case of McCoy and Roelofs (1997) at this writing, is handled slightly differently. (See the References section.)

²If you continue in scientific research you may encounter occasional lapses from this commitment, particularly in large groups. You would be well advised to be wary of such situations; your future co-workers may not be as honest as you are. For example, note the problems of Nobel-Laureate David Baltimore (see the July 5, 1991 issue of *Science*). [Note that footnotes are placed at the bottom of the page on which they occur.]

All sources cited in your paper are listed alphabetically in the References section which follows the main text of your paper. (The format used in the reference section for various sorts of sources--articles, books, chapters in books, etc.--are indicated in the references section of this paper.)

Sometimes you need to provide information that you received from another individual, and which is not available in published form. This is termed a *personal communication*, and you handle the referencing as follows. The deadline for first submission of the senior paper is typically in mid' April (L. D. Roelofs, Haverford College, personal communication, 1997). Such citations are given parenthetically in the text and are not repeated in the References section.

I. Appendices (optional)

It is sometimes helpful to provide the reader with supporting material in one or more appendices, which follow the references. It is especially appropriate to relegate elements to appendices if they are somewhat lengthy, and would distract the reader from the main flow of your presentation. If you include more than one appendix, label them with sequential letters, Appendix A, Appendix B, etc., and refer to them in that form in your main text. This paper includes an Appendix offering some "Do's and Don't's" for effective writing.

J. Tables

Some information is most effectively presented in tabular form. Tables have titles and captions at the top, and headers on each column. When the data represents physical quantities, the units must be specified in notation consistent with the text. Table 1 in this paper is an example taken from LaFemina (1996). Note that if there are references associated with items in the table, they are given as a separate column in the table in the same format as used for other references in the paper. Any necessary footnotes are

included at the bottom of the table itself. All tables must be referenced in the text. The tables themselves are attached at the end of the paper following the references and *preceding* the figures.

K. Figures

For preparation of figures, consult examples from the American Journal of Physics (in Room 107). The two figures at the end of this document--both taken from McCoy and Roelofs (1997)--illustrate some of the important issues in figure usage and preparation. Fig. 1 was prepared using Super Paint and then cut and pasted into the WORD document. Fig. 2 was prepared with CricketGraph. The inset was added using SuperPaint and then the result was imported into Word. (The last step is unnecessary.) Fig. 1 is included to illustrate the usefulness of drawings or diagrams in displaying complex spatial or instrumental situations. Rendering all the information in that figure in the form of text would be difficult in the extreme. Fig. 2 shows how information is presented graphically in a scientific paper. The axes should have labels that include units if the quantity plotted is dimensional. For example: "Time (s)" or "Frequency (Hz)". You could also use variables defined in your paper, "t (s)" or " (Hz)" instead of the words, and some journals prefer this approach. In that case, be sure to define each important symbol in the caption of the first figure where it appears, even if this duplicates the text. Finally, note that legends containing text are *not* used in the figure. Symbols and lines should be defined in the caption instead.

Hand-drawn diagrams of apparatus and flow charts are acceptable if done neatly with dark lines and lettering.

L. Figure Captions

All figures must have captions. Symbols used in the figures should be identified in the caption even if they are defined in the text. *The main point of the figure should be indicated in the caption, so that the reader can skim your paper by reading the abstract and conclusions and looking at the figures.* Papers are submitted to journals with the figure captions gathered on their own page(s) immediately preceding the collected figures themselves. However, it has also become conventional for the convenience of readers of the pre-publication version of the paper to *paste a copy of the appropriate caption on the lower edge of each figure page.* This latter method should be used for your Senior Paper. Captions have been included with the figures at the end of this paper. Some additional examples are:

Fig. 1. Schematic diagram of the circuit used to control the current through the sensor. Typical currents are about 5 mA.

Fig. 2. Power spectrum $P(\)$ of the time-dependent signal, on a logarithmic scale. A single sharp peak is evident; this indicates a periodic state.

III. Final Advice

1. Be clear, concise, and complete.
2. Plan your work so that the paper will be complete a few days before it is due.

Then Revise carefully and extensively at least twice, and preferably more, before even considering that your paper might be ready to submit. (This document has been revised many times but probably still contains errors and certainly could be improved significantly!) As you revise, check each level of organization:

- Does each sentence communicate effectively and clearly?
- Does each paragraph accomplish your purpose?

- Does each section flow logically and contain all the needed information?
 - Do the figure captions complement the text, and allow the harried reader to get the gist of the paper quickly before pursuing all the details.
 - Recheck the abstract, introduction, and conclusion again; these are the most important parts of your paper.
3. Run a spelling checker, proofread carefully for grammatical and other errors.
The Writing Center staff can be helpful with the mechanical aspects of good writing. An Appendix offers some do's and don't's of effective writing.
 4. Think of yourself as both a creative artist and a craftsman. A carefully prepared paper contains interesting physics expressed in clear and graceful prose. In addition, it should be visually appealing to invite the reader's interest and to inspire trust.
 5. Print out your manuscript in double-spaced format with margins of at least 1.25", to leave room for comments and suggestions for revision.

References

- Baker, G. L. and J. P. Gollub, 1996, *Chaotic dynamics : an introduction* 2nd ed. (Cambridge University Press, Cambridge) [Book]
- Boughn, S. B. and J. M. Uson, 1995, Phys. Rev. Letters **74**, 216. [Journal article]
- LaFemina, J. P., 1996, in *Handbook of Surface Science--Vol. 1 Physical Structure*, W. N. Unertl (Ed.) (Elsevier, Amsterdam), pp. 137-184. [Article in Book]
- McCoy, J. and L. D. Roelofs, 1997, Surface Sci. (to appear). [Journal article that has been accepted by a journal, but has not yet appeared in print. One uses '(to be published)' for an article that has been or will be submitted, but has not yet

been accepted for publication by a journal and '(unpublished)' for a work that you do not expect to appear in print in the near-term future.]

Smith, W. F., M. C. Abraham, J. M. Sloan and M. Switkes, 1996, *Rev. Sci.*

Instrum. **67**, 3599. [Journal article with multiple authors]

Wheeler, J. A., 1999, *Am. J. Phys.* **67**, 945.

Appendix – Some stylistic suggestions

Even if your paper is well-organized and clearly written, errors of style and usage can detract from its affect and impact. Such stylistic issues transcend the categories of expository writing—'clunky' expression is as deplorable in scientific writing as in any scholarly or learned genre. Note that the Writing Center staff is trained to provide assistance this area. For the advice of a famous physicist and skilled writer of physics textbooks and papers we also refer you to the short article "Wheeler's Rules of Writing" Wheeler (1999). We summarize a few of the common elements of good writing here, illustrating in some cases with examples from actual senior papers.

- Avoid excessive use of passive voice. (However, by convention, Abstracts may be fully in the passive voice, if desired.)
- Use active verbs instead to sustain pace and excitement. Avoid excessive use of linking verbs.
- Avoid concatenated prepositional phrases as in the following example. *The lack of emphasis on the impulse-momentum theorem on homework assignments may have lead to this result.* Here is an improved version that eliminates the chained phrases and the rather weak verb and adds an interesting word. *The impulse-momentum theorem was not emphasized in course assignments, a likely explanation for this disconcerting result.*
- Avoid singular-plural inconsistencies between either subject and verb, or verb and object.
- Use vivid nouns with well-chosen adjectives so that you can avoid excessive use of modifier clauses beginning with *that...* and *which...* .
- Avoid long, drawn-out sentences. Example: *At sufficient vibration frequencies near 25 Hz and vibration acceleration amplitudes of 8g, they observed a new phenomenon where [sic] the system achieved a*

coexistence of the gas and liquid phases, without being triggered toward either attractor after a sufficient time for the system to stabilize.

- Write generally in the present tense except for matters that are in the past relative to the work you are describing. Avoid all other changes in verb tense.
- Show that you have an impressive vocabulary by avoiding repeated use of particular words.
- Use the best word in every situation, or at least avoid malapropisms and even slightly incorrect usages. When in doubt consult Fowler's *Dictionary of Modern English Usage*.

Tables

Table 1. First layer spacing for the relaxed MgO(001) surface. (The references listed in this table were not included in the References section of the paper, since they are included only to demonstrate proper format. Normally, of course, all references listed in tables are included in the References section.)

d_{12} (Å)	Method	Reference
-0.04	TBTE ^(a)	LaFemina and Duke (1991)
0	<i>ab initio</i> HF ^(b)	Causà et al. (1986)
0.02	Shell Model	Lewis and Catlow (1985)
-0.03 ± 0.03	LEED ^(c)	Prutton et al. (1979)

^(a)Tight-binding total energy computation.

^(b)*Ab initio* Hartree-Fock computation.

^(c)Low-Energy Electron Diffraction analysis (experiment)

Figure Captions

Fig. 1. A four-layer pyramid modeling an asperity on the W(001) surface. The stability of this structure was examined by studying the energetic barriers against degradation of the asperity along certain paths, labelled A, B, and C. In path A, the tip atom is pulled down onto the substrate. Path B describes the concerted displacement of a second tier atom and the tip atom. Path C involves four displacements. Note that the final configurations for these three rearrangements are symmetrically equivalent.

Fig. 2. Cohesive energy of the system as a function of lateral displacement of tip atom. The open circles describe the energy barrier associated with path A. The discontinuities of the curve result from passage of the moving atom between local bonding regimes (see text). The overall barrier for this move is 6.50 eV. The filled points show the reduction of the energy barriers occasioned by cooperative distortion of a nearby atom. In the case of the first and largest barrier the distortion is a displacement of atom 5 by about 0.20 Å roughly toward atom 4. The inset shows the tip of the pyramid, identifying the atoms referred to in the text and depicting the distortions occasioned as the tip atom moves from one local bonding regime to another.

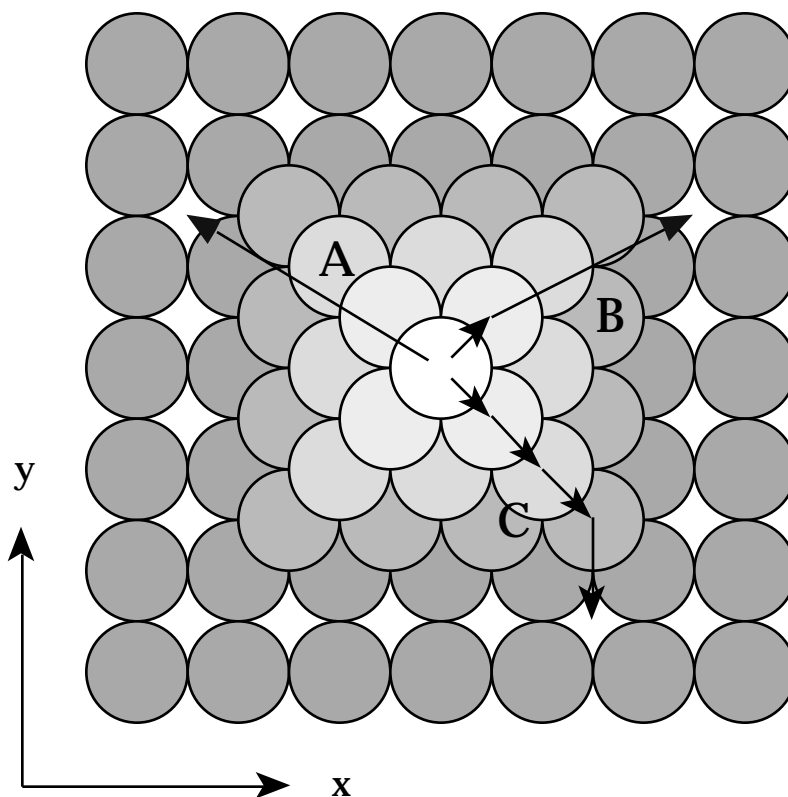


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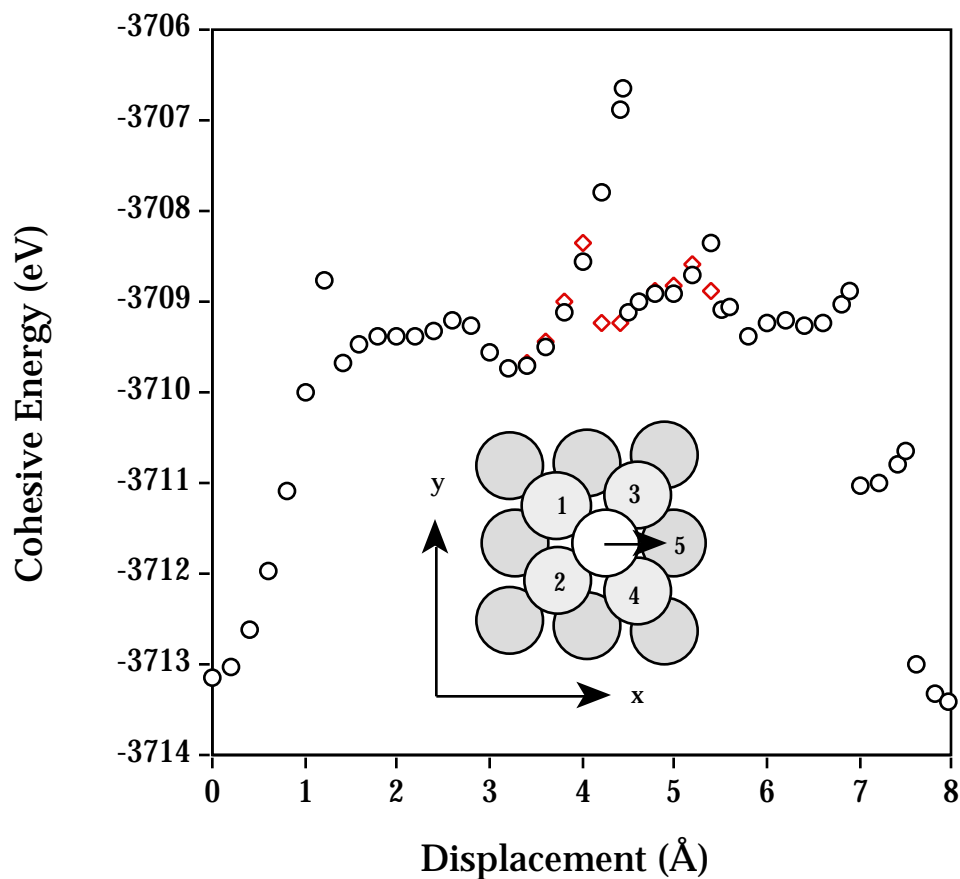


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