This brief guide is provided to aid students in writing the M.S. or Ph.D. prospectus required by the BYU Chemical Engineering Department. In addition, I give writing principles which apply to writing scientific papers, technical reports, and the thesis or dissertation.

1 Objectives and Audience

For any kind of writing you should understand the objectives of the document and tailor your material for the intended audience. The objectives for almost all technical writing are to

- Sell your ideas. This means you should convince the intended audience that your experiments and theories are important, interesting, valid, and useful.
- Disseminate scientific knowledge. This means you should accurately and concisely document your experimental procedures, mathematical model, and numerical results for others to use and verify.

The prospectus is a research proposal. It is written to gain approval to carry out the project. In defining the scope of your project, the approved prospectus becomes a kind of contract between you and your committee so that you know when you are done. It is recognized that you may change directions along the way, but with the prospectus in hand you have a place to start and an idea where to stop.

Because the prospectus is written before most of the research work is done, the emphasis is on the first item above (“Sell your ideas”). You must convince your graduate committee that

- Your project addresses an important problem in an appropriate way.
- You have adequate preparation and a plan to solve the problem in a reasonable amount of time.

The audience is your graduate committee, a small group of professors. They will understand general scientific and engineering concepts like process optimization, phase equilibria, kinetic vs. transport limitations, validation of numerical models, experimental design, and data analysis. Not all committee members are experts in your particular subfield, and so will need to be given the appropriate background material to understand the terminology and theory specific to your project. They need to be told what is “common knowledge” in your subfield and what is new and innovative about your work.
2 Prospectus Content

Below is the general order of topics that I recommend, along with a suggested length for each item for a Ph.D. prospectus. The Ph.D. prospectus should contain 20-28 pages (not including bibliography); an M.S. prospectus should be half this length.

1. **Introduction (1.5 pages)**

   (a) Give a brief background of your field of work, identify a problem, and establish the problem’s importance. This is your opportunity to generate interest in the audience about your project. Avoid using highly technical jargon at this point and don’t make this part longer than 1 page.

   (b) State the scope of your project. Do not just say you will work on X or study subject Y. Instead give scientific hypotheses you will test or research questions you intend to answer, and outline the tools and methods you will use. What is the anticipated impact of your work, if successful, on your field?

   (c) Outline the topics that are covered in the remainder of the document, i.e. give a road map.

2. **Background (around 10 pages, with a subsection for each topic)**

   Do a more extensive background discussion on the problem, showing you have a good grasp of the field in which you are working (around 10 pages, with multiple subsections). You are preparing your audience to understand the nature of the problem and appreciate the value of your proposed solution in item 4 below. Extensive experimental details or equations are not appropriate in a research-proposal type of document.

   This section includes your “literature review,” though don’t name it as such. In particular, describe where others’ prior work overlaps with your proposed work, showing ideas you can gain from them or knowledge gaps that need to be filled. A Ph.D. prospectus should reference at least 30 prior works, and an M.S. about half that—some references are more important and will deserve individual and critical analysis, while other references can be lumped together as part of a discussion of related works that address a particular issue.

3. **Prior Results (around 2 pages)**

   Give prior results generated by you, showing a few quantitative or theoretical results to demonstrate you know how to get started and have been able to overcome a couple early hurdles. You do not need to show everything you have done—the purpose is to establish your credibility in carrying out the proposed research, not to provide the same level of detail that would be found in an academic publication. Frequently the best logical flow of material is to combine this section with item 2 above or item 4 below, so that there is not a separate Prior Results section.
4. **Work Plan (around 8 pages, with a subsection for each task)**

List the tasks that are required to answer your hypotheses or questions, giving detail on the technical challenges you anticipate and how you plan to overcome those challenges. Provide the logic guiding your choice of tasks, so that the reader can see why the proposed activities are the best means of answering your questions. Help the committee to distinguish your unique contribution to the field by explicitly identifying ideas that are new to your work as opposed to ideas that originated with others. Figures and tables illustrating the proposed experimental design(s) are quite helpful. For instance, you can list parameters you will hold constant and parameters that will be changed (with a range of values) in your experiments or models. Give alternative paths (i.e. backup plan) if your original plan of attack is not successful. State how you will maintain laboratory safety.

5. **Time Line (0.5 page)**

Give a time line or Gantt chart summarizing the tasks and steps that will lead to completion of dissertation or thesis, including the specific papers you plan to write and publish.

6. **Bibliography (2 or more pages)**

List cited references, using a consistent format taken from a leading journal in your field.
3 Writing Rules

Below is my advice for improving your scientific writing, in the form of 45 rules. They are based on my observations of trouble spots for beginning (and sometimes more-experienced) technical writers.

General Scientific Writing

1. Good writers habitually reread and rewrite what they have written, to fix mistakes and make improvements. They take ownership of their work and pride in producing a high-quality product. The best writing requires many edits and drafts over the course of days and weeks. Printing out a draft of your document can be helpful in detecting mistakes, because the text and formatting will appear differently to your eye than on a computer screen: try it and see.

2. When someone else edits your document, learn from their corrections. Fix all instances of that mistake in the document and do not repeat the same mistake in the future. The editor may be your advisor or simply a “fresh pair of eyes,” a person who doesn’t necessarily need a technical background. There is a temptation to postpone fixing grammar and spelling mistakes. However, with a polished draft your advisor can spend more time addressing “big picture” things like the logical structure and flow of ideas, rather than getting distracted by the grammar and spelling mistakes.

3. Good writers tune their writing to their audience’s general level of technical experience and prior knowledge and interest in the topic, which will be different from the writer’s current knowledge and interest. Try to anticipate a typical reader’s questions and objections, gaps in knowledge, and what they will find confusing or tedious. Then modify your writing to meet those needs and expectations. Similarly, follow the golden rule in writing: write the kind of paper that you like to read when you are new to a topic. Think about particular papers that have been especially helpful to you as a beginning researcher. What did the authors do that was so helpful? Then write that kind of paper.

4. Scientific writing is essentially telling a story built from logical thought, decisions, and data outcomes. In the initial stages of writing, outline or sketch the series of figures and tables that will contain the data that tell your story. Further, to convince your audience that your work is sound, you must do more than tell them what you did; you must also tell them why you made the scientific choices you made: Why this type of experiment? Why this particular model? Why these assumptions? Take the reader through the logical decision-making process that you followed. Show how these decisions fit into a larger research plan.

5. Good scientific writing, while thorough, is concise and expresses concepts in the minimum space necessary. Each paragraph and sentence should contain
substantial new information, rather than largely repeating concepts already expressed and established. The exception to this would be in a larger document in which some repetition is helpful at widely separated locations to remind the audience of important concepts, such as in a conclusion section.

6. You cannot presume an audience will simply trust your conjectures or opinions. Whenever you present an idea or finding that is not generally understood or accepted in the scientific community, or is likely to be questioned by your audience, you must support it by mathematics, logic, or data or provide a citation that does the same. If the matter is not central to your work, a citation is generally preferred (to keep discussion concise). If you cannot support a questionable statement, then you must qualify or narrow the statement so that it is supportable, or eliminate it entirely.

7. Relatedly, you should express a proper amount of scientific humility, objectivity, and self-skepticism—this will give your work more credibility and make embarrassing mistakes less likely. Outside of pure math, virtually nothing in science can be absolutely proven or is 100% certain. Instead, there are things that are more or less likely to be true or accurate, based on the available evidence and assumptions used. Avoid strong categorical and superlative terms like always, never, all, none, wrong, right, best, worst, and most. Instead express scientific judgements in more measured and narrow terms, and when possible quantify your certainty using appropriate statistical analysis (see rule 37). Compare the following expressions:

- “this result is correct” vs. “this result is accurate at a 95% confidence level”
- “this is the best explanation” vs. “this is a more satisfying explanation”
- “the data prove that” vs. “the data suggest that”
- “we are sure that” vs. “we have greater confidence that”
- “this measurement has never been done before” vs. “this measurement has not to our knowledge been done before”

8. You must provide a bibliographic citation for any unique ideas, text (even if you change a few words around), images, or data you obtain from another source. While it is less common in scientific writing (paraphrasing is more often used), if you use the exact words of another, they must be enclosed in quote marks or otherwise set apart. Not to give due credit to another’s work is called plagiarism, and this academic sin can have extremely harmful consequences.

9. Copyright is a different concept than plagiarism, though they can overlap in some situations. Copyright law requires that you get permission from the copyright holder of an original work before using a significant portion of that work subsequently, even if you provide a citation to the original or it was created by you. Sometimes there is legal uncertainty about how much included material would be considered copyright infringement, but in most instances there are
generally accepted practices. For instance, if you want to use a copy of a figure from a scientific paper in your own public document, you must contact the publisher of the journal for permission to do this, which permission they generally give. Many scientific journals now give an author or co-author automatic permission to republish their original content in a subsequent thesis or dissertation, but you should still check the copyright policy of the publisher.

Organization

10. Paragraphs that lack a proper topic sentence, are too long, and switch between ideas are one of the most common problems of beginning scientific writers. Every time you write a paragraph, ask yourself: “What is the single main idea of this paragraph?” That idea should come out in the first or second sentence, which is known as the topic sentence. Every following sentence should provide information that relates to the topic sentence. If I were to read only the topic sentences for the whole document, I should get every important idea, if not the details. Again, do not switch ideas in the middle of the paragraph or add extraneous information that does not support the main idea; instead start a new paragraph.

11. Make sure the introduction is particularly interesting, effective, and organized. It sets reader expectations for the remainder of the document. A person should never have to read more than one or two pages of your document before finding out the main ideas and scope of your work. Avoid introducing too many new terms or unfamiliar jargon in the introduction; instead use more general language to establish the problem you are setting out to solve. Writing an effective introduction often requires more time and editing than you will spend on other sections of the document.

12. A longer scientific document should also have a conclusion. The conclusion should do more than just repeat or summarize the preceding material; it also should elucidate key insights and lessons from the work, should express how the results might impact more broadly than the original problem, and could express possible extensions to or planned continuation of the work.

13. There should be a new section or subsection at least every two pages. Each needs a heading and introductory paragraph. The introduction summarizes the main ideas and logically connects the present topic to the prior topic. Frequent roadmaps like this keep you as a writer focused and keep the reader from getting lost.

14. Generally you should not create a section (or subsection) unless there are at least two parallel elements (i.e. sections on the same level). This principle also applies to bulleted lists (i.e. never have a list with only one bulleted item).

15. The abstract is a fully independent summary of the document, and so has parallel purposes to the introduction in securing reader interest, though in a shorter
format. The abstract additionally contains an overview of the principle methods, findings, and significance of the work.

16. An appendix or supplementary section is the best place to put extended data sets or mathematical derivations that would otherwise interrupt or distract from the logical flow of the main part of the document or would be of less interest to the general audience.

Scientific Grammar

17. Technical writing requires a careful choice of words and punctuation to convey meaning clearly and concisely. With each sentence or other construction, ask yourself: “Is there any way for a reader to misinterpret the intended meaning of this statement?” Here are some examples of problem areas:

(a) Confusion can arise if you use an anaphor (e.g. it or this or that) to refer to an antecedent (a previous idea, object, or person) and it is not clear to which thing or things you are referring because there are multiple possibilities. Example: change “the above discussion demonstrates that it is not true” to “the above discussion demonstrates that the adiabatic assumption is not true.”

(b) Make your lists complete: avoid use of “etc.” in lists because it requires logical extrapolation and therefore your intended meaning may therefore be unclear.

(c) Avoid use of the slash character (/) as a conjunction: “liquid/gas mixture” could unclearly mean “liquid and gas” or “liquid or gas.” Similarly, the construction “and/or” is not entirely clear.

(d) Compound adjectives abound in technical writing. A compound adjective is a group of words that operate together to modify a noun. Such often require hyphens to eliminate possible misunderstanding. As an example of the importance of hyphens in compound adjectives, note the difference in meaning in the following phrases: “man eating dog” vs. “man-eating dog,” “twenty two minute delays” vs. “twenty two-minute delays,” “out of the box solution” vs. “out-of-the-box solution,” and “more common species” vs. “more-common species.” The exception to the use of hyphenation is if an adjective and noun are so frequently used together that the meaning is clear. For instance, “molecular dynamics simulation” is acceptable without a hyphen because “molecular dynamics” is a common term in theoretical chemistry.

18. When discussing upcoming sections, figures, and equations in the present document, or discussing enduring scientific principles, use verbs in the present tense. When discussing human actions, such as experimental data collection or the work of others, you may use the appropriate past or future tense. Examples: “Section 2 describes prior experimental results collected by Turner et al.” or
“kinetic energy is given by the following formula” or “the data set measured using this instrument is presented in Table 2” or “we anticipate this technology will be used to improve performance.”

19. Particular journals have particular formatting and grammatical conventions—look for a style guide or author instructions on the journal’s website, or imitate a paper published in that journal. If not writing for a journal, you should consistently apply a format of your choice. For example:

(a) For the headings of chapters, sections, and subsections you can choose to follow the convention for capitalization of a title (mostly capitalized) or to capitalize the heading like a sentence (only the first word and any proper nouns).

(b) Be consistent in how you capitalize and abbreviate a cross reference to a numbered chapter, section, equation, or figure: “see Fig. 2” vs. “see fig. 2” vs. “see figure 2.”

(c) Either italicize or don’t italicize all Latin expressions (e.g., i.e., et al., vs., etc.)

(d) Correctly and consistently format the bibliography. It is common for bibliography entries to get misformatted or to be missing key information. Double check each reference in the printed document.

20. When referring to others’ work by name, put the numerical citation immediately following the name or at the end of the sentence. If there are two authors list both last names: “Jones and Wu [3] developed a method that...” If there are more than two authors of a paper, explicitly list the first author only: “Srinivasan et al. [4] state that...” If there are multiple publications from one research group, you may refer to the senior author or leader of the work: “Newman and coworkers [5–7] developed a series of models...”

21. Chemical symbols are always capitalized (e.g. Ar, H₂O₂, Li-ion battery), in contrast with expanded chemical names (e.g. argon, hydrogen peroxide, lithium-ion battery). Chemical names are only capitalized if they are the first word of a sentence or are part of a title or heading, according to convention.

22. The first time an acronym is used, it must be defined by using parentheses, e.g. “focused ion beam (FIB).” If your reader at some later point is likely to have forgotten an unfamiliar acronym (particularly for long documents), then define it again as a courtesy. Do not use inappropriate capitalization in your definition: “Focused Ion Beam (FIB)” is wrong, whereas “Federal Bureau of Investigation (FBI)” is correctly capitalized.

23. Some writers use an apostrophe to make a plural out of an acronym, abbreviation, or symbol. However, avoid this where possible: “two SEMs” is preferable to “two SEM’s” and “three τ values” is preferable to “three τ’s.”
24. Some academics insist that personal pronouns and possessives (e.g. I, we, my, our) not be used in technical writing. This is an old tradition that is losing its hold. As appropriate you may occasionally use personal pronouns in describing your proposed research and results, in order to avoid awkward passive constructions. On the other hand, do not overdo the use of personal pronouns: the science, not the people doing the science, should be the main focus of the writing.

25. The choice of article (the, a, or neither) on a noun depends on whether it has been introduced yet or is familiar to your audience as a specific instance. In other words, you could initially say, “this work requires a new type of conductivity experiment.” After this experiment has then been properly described you refer to it as “the conductivity experiment.” Use no article on a noun when you are discussing a concept abstractly or collectively: “diffusivity is a measure of transport by local molecular motion” vs. “the diffusivity of helium is high because of its small molecular weight.”

26. Whether to use a or an as the indefinite article depends on how something sounds when spoken aloud (“an SPH model” not “a SPH model”; “a unique process” not “an unique process”).

27. Whenever you form a list, each item should be grammatically parallel with the others. For instance, if item 1 starts with a verb, then so should item 2.

28. Sometimes you need to assign an attribute to each item in a list or to compare two lists item-by-item. To make the assignment or comparison more compact, one can use the terms respective or respectively. For example, “Equations 1 and 2 are respectively mass and energy balances,” or “the first three results were positive, negative, and negative, respectively,” or “respective model and experimental data are given in the columns of Table 2.”

29. Use the words “data” and “species” properly. “Data” is the plural of “datum.” Thus, “the data show” is correct and “the data shows” is not correct (though you could say “the data set shows”). “Species” is the singular of “species.” Thus, “this species is the most prevalent” is correct.

Figures and Tables

30. Tables are used for data sets to enable the reader to obtain precise values for their own use, or where there are data for only a small number of experimental conditions. For example, a table of parameter values used in a model is helpful. Otherwise figures are preferred for presenting data because of the brain’s ability to rapidly assimilate information and detect trends when data are presented graphically or visually. Avoid putting the same set of data in both tabular and graphical form.
31. A figure in the form of a line drawing or schematic is necessary to describe an important experimental apparatus or model geometry that is unfamiliar to your audience. A conceptual diagram explaining the process steps, experimental design, or workflow of your project is also helpful.

32. Optical or electron microscope images should have a scale bar overlaid on the image.

33. Generally speaking, in your plots represent experimental data with discrete points or symbols; represent fits to the data or theoretical relationships with lines or curves. If you use a series of graphs to represent related data, use a consistent system of symbols and colors to aid the reader. Use colors and patterns that enable the plot to be interpretable when printed in black and white, not just color (also consider using “Color Universal Design” in your choice of colors). If you use Microsoft Excel to generate plots, know that the default settings do not make for nice graphs in formal documents—you will need to adjust formatting so they look better.

34. Each table and figure should be numbered, and have a caption that contains a title and, in most cases, an additional description that allows the table or figure to “stand on its own” without other supporting text. Even so, each table and figure should also be referenced and discussed in the main body text. Other rules about captions:

(a) Table captions go above the table; figure captions go below the figure. Additionally, tables may have labeled footnotes below the table.

(b) Multi-part figures have a single caption that describes the parts in sequence (a, b, c, and so on).

(c) The figure caption should define explicitly any symbols or lines in the plot, if a symbol key is not present in the plot itself.

(d) If there are special conventions in presenting the data, these should be mentioned. For example, you might use captions that include statements like “lines between experimental points are a guide to the eye,” or “overlapping points have been offset horizontally for clarity,” or “formatting is identical to that used in Fig. 2,” or “error bars represent 95% confidence intervals,” or “not drawn to scale.”

(e) For a book-length document that has a List of Figures and List of Tables in the front matter, a shortened form of the caption that fits on one or two lines should be used there.

35. When possible, use appropriate file formats for producing and saving figures: vector format for line drawings and graphs (.eps, .svg, .wmf) and raster format for photos and images (.jpg, .tif, .png, .gif). When using raster formats, make sure that dpi (dots per inch) is at least 300 so the image does not appear grainy when printed.
Quantities and Equations

36. Format quantities appropriately: $h = .221$ is wrong, $h = 0.221 \text{ W/(m}^2\text{K)}$ is right; $k = 1.2 \times 10^{-3} \text{ W/(m} \cdot \text{K)}$ is wrong, $k = 1.2 \times 10^{-3} \text{ W/(m} \cdot \text{K)}$ is right. Notice that numbers and corresponding physical units are not italicized. If possible place a “hard” or non-breaking space (ctrl+space) between the number and its unit—this prevents them from being placed on different lines of text.

37. Confidence intervals are typically presented in the form best estimate $\pm$ margin of error. Round off your margin of error to one or two significant digits: generally if the leading digit is a smaller number (1 or 2) then use two significant digits and otherwise use one significant digit. You should then round off your best estimate (typically a sample mean) so its precision matches the precision of your margin of error. For example, $t = 131.773 \pm 2.4329 \text{ s}$ becomes $t = 131.8 \pm 2.4 \text{ s}$. Notice how the revised best estimate and margin of error don’t have the same number of significant digits as each other, but they do have the same level of precision (i.e. decimal place of least-significant digit), and that the sample mean was appropriately rounded off to that level of precision.

38. All symbols or variables should be italicized with the following noted exceptions.

(a) Greek-letter variables and named dimensionless numbers (e.g. Re, Pr, Nu) should not be italicized.

(b) Chemical formulas and common mathematical functions should not be italicized.

(c) Vectors and matrix variables should be in bold font, unless one is referring to an element: $v_i$ is scalar element $i$ of vector $\mathbf{v}$.

(d) Descriptive subscripts and superscripts that contain multiple letters that form a word or an abbreviation should not be italicized (e.g. $k_{\text{eff}}^i$, $x_{a,b}^{\text{max}}$, $t_{\text{avg}}$). Numerical subscripts or superscripts should not be italicized (e.g. $t_0$, $g^{(2)}$)

39. When a symbol is used in a title or heading or sentence, it must remain in the same case (capitalized or not capitalized) as it was originally defined. If you start a sentence with a symbol that is not capitalized, it will look odd and so this should avoided when possible.

40. Whenever an equation is given, all symbols or variables contained in it should be defined if they have not been defined previously. If you introduce a symbol not familiar or intuitive to your audience, and it is not used for some time in your document, as a courtesy redefine it on the second instance of use. Strive to choose symbols that will be familiar to your audience, e.g. $k_B$ for Boltzmann’s constant, $\sigma$ for stress, $q$ for heat flux.

41. In addition, for a long and math-heavy document (such as a dissertation with lots of equations), as a courtesy you should include a List of Symbols, a table
that defines symbols and associated superscripts and subscripts for the entire document.

42. An important equation should occupy its own line and be numbered. For most journals an equation is not explicitly punctuated with a comma or period, but is still considered part of a sentence. Example: “The ideal gas law is

\[ PV = nRT \] (1)

where \( P \) is absolute pressure, \( V \) is volume, \( n \) is number of moles, \( R \) is the universal gas constant, and \( T \) is absolute temperature.” Use the same equation editor when defining and using variables in the text as is used for the full equation, so that they appear with the same font.

43. Do not reference the equation number in the same sentence that contains the equation. Also, do not indent the line of text that follows the equation, unless it is part of a different paragraph. For instance, don’t do this: “The ideal gas law is given by Equation 2:

\[ PV = nRT \] (2)

where \( P \) is absolute pressure, \( V \) is volume, \( n \) is number of moles, \( R \) is the universal gas constant, and \( T \) is absolute temperature.”

44. Do not format your equations how they would look in computer code. Instead learn how to use an equation editor so that parentheses, integrals, fractions, and other elements are sized appropriately. For complicated expressions nest parentheses inside of brackets inside of braces, i.e. \{[[(...)]]\}. Compare the two ways of formatting the following equation:

\[
(f((n - 1)/(n + 1) + n^3)dn)^2
\]

vs.

\[
\left[ \int \left( \frac{n - 1}{n + 1} + n^3 \right) \, dn \right]^2
\] (3)

Similarly, with the exception of named dimensionless numbers (e.g. Re, Pr), avoid using symbol names with multiple letters, like you might do in computer code (e.g. \( C_{test} \) is better than \( Ctest \)).

45. A less-important or smaller equation can be given as part of a line of text (a so-called in-line equation) and must be formatted so that it is not too tall or the font too small. For instance, the in-line expression \( \frac{N^2}{3} \) could be better formatted as \( \frac{1}{3} N^2 \) or \( N^2/3 \), and \( \frac{d(1-\beta)}{dt} \) is better formatted as \( \frac{d}{dt} (1 - \frac{\beta}{t}) \) or \( \frac{d}{dt}(1 - \beta/t) \).