# GUIDE FOR WRITING CHEMISTRY AND CHEMICAL ENGINEERING LAB REPORTS

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# General

This guideline is meant to be a blueprint for good lab reports in 3rd and 4th year Chemistry and Chemical Engineering. Included within discussions on each of the various components of a lab report, are discussions on a number of common shortcomings. Common problematic areas with grammar are also addressed in the scientific word usuage section.

When writing your lab reports, the two most important pieces of advice are:

- **Prepare well**. You should master the background material before ever setting pen to paper. Also, you should **outline** the main points that you will make in each section before you begin writing the report.
- **Edit, edit, edit**. You need to edit and re-edit your report. First (or second or third) drafts are *never* - without exception - as clear as they should be. This step is where you "clean up" your writing. Professionals spend much of their time revising reports and papers to prepare the best possible product.

The two fundamental concepts to keep in mind while writing are (i) your message, and (ii) your audience.

### Your Message: What do you wish to communicate?

Your message should basically answer the following three questions:

- What did you do? You should provide enough detail about your experiment so that the reader can reproduce your results.
- What were your results? This consists of your data and the analysis of that data.
- What is the significance of your results? Explain why your results are important and provide a context for your experiment. In other words, describe how your work fits into the "big picture."

Your must always keep in mind the main point(s) you mean to communicate. Keep your writing simple and to the point. In particular, extensive rambling is a sign that you either don't know the material, or that you have not organized your ideas well. Don't try to impress your audience with your extensive knowledge of peripheral topics.

## Your Audience: Who is reading your report?

As you compose your report, you must always keep your audience in mind. And I don't mean your course instructor! Lab reports are meant to be read by your academic peers. Although you must assume that your readers have general training in science and engineering, don't assume a familiarity with details that are very specific to your experiment. For example, if you were to write a report on a *Gravimetric Determination of Sulfate*, you would assume that your average reader would only need to be *reminded* of the general principles of gravimetric analysis -- so you need only provide a brief (1 paragraph) summary of those principles. However, details that pertain to your specific experiment -- analysis of sulfate using a certain reagent -- might need to be explained more fully.

The following format is standard for 3$^{rd}$ and 4$^{th}$ year science/engineering labs in our department:

1. **Title page**
2. **Abstract** to summarize the experiment and important results.
3. An **Introduction** section to describe the purpose of the work and provide necessary background information.
4. A section to present the **Results**, often with tables and charts.
5. A **Discussion** of results is necessary to present conclusions and the significance of the work.
6. A list of **Conclusions and Recommendations**.
7. A separate appendix for **Raw Data**
8. A separate appendix for **Sample Calculations**
9. A separate appendix for **Error Analysis.**

<u>Note</u>: Some lab courses may require a Materials/Method section, depending on the nature of the lab. For example, if the lab did not include a detailed procedure in the précis, and students had to create their own procedure and test plan, they would describe the materials and methods they used to obtain their results. In cases where the précis is detailed, the student simply derives the section from the précis itself. A Materials/Method section is therefore not generally required.

A good lab report does more than present data; it demonstrates the writer's comprehension of the concepts behind the data. Merely recording the expected and observed results is not sufficient; you should also identify how and why differences occurred, explain how they affected your experiment, and show your understanding of the principles the experiment was designed to examine.

Bear in mind that a format, however helpful, cannot replace clear thinking and organized writing. You still need to organize your ideas carefully and express them coherently. A good report is a pleasure to read; conversely, a poorly written one requires excessive and frustrating levels of effort just to make some sense of it. At all times, your report should be written in the third person. That is, do not use “I” or “we.”

Laboratory report writing guidelines from the websites of the following universities: U of T, Virginia Tech, Iowa State, and Richmond were sources for this guideline and specific samples came from Pechenik, Jan A. *A short guide to writing about Biology.*, Tufts University: Harper Collins*College Publishers*. 1993, pp. 54-102.

Finally, remember to submit your lab reports typed, double spaced, and inside of a RMC lab folder. Make sure all your pages are numbered and stapled together!

# Title Page

The Title Page needs to contain the name of the experiment, the names of lab partners, the lab course # and the date. Titles should be straightforward, informative, and less than ten words. Use the following format:

| |
|---|
| Experiment #3<br>Injection Moulding<br>CCE 421<br><br>Ocdt J. Bloggins<br>10 Jan 05<br><br>Engineering Laboratory<br>Royal Military College of Canada<br>Kingston Ontario |

# **Abstract Section**

Many students may be unfamiliar with the concept of an abstract in a lab report. It is the first part of your report, directly following the title page and proceeding the introduction. The abstract, although it comes first logistically, **always should be written last**. It needs to be written last because it is the essence of your report, drawing information from all of the other sections of the report.

The purpose of an abstract is to summarize the purpose, results and significance of your work. By reading the abstract, and perhaps glancing at the figures and tables, the reader gains a brief overview of paper. It should answer the following questions:

- why the experiment was conducted?
- what methods were used to solve the problem?
- what was measured?
- how was it measured?
- how reliable are the results?
- what were the major results obtained?

In addition to answering these questions, you should state any other conclusions warranted by your results. If the sole purpose of the experiment was to say measure a concentration in some sample, then it is sufficient to report the concentration, with its uncertainty, and perhaps make a statement about the suitability of the analytical technique used for the analysis of the sample. Your experiment may have had an additional purpose (eg, to compare the characteristics of two different analytical techniques); if so, you should summarize your conclusions regarding this other goal.

All of this information should be summarized in a clear but succinct manner if the abstract is going to be successful. An estimated average length for all of this information is only a single paragraph**,** it should not exceed 200 words. Do not make reference to tables or figures in your report – this abstract must stand alone!

Although this may seem as though it is a short length to contain all of the required information, it is necessary because it forces you to be accurate and yet compact, two essential qualities.

## General questions to be addressed in the abstract section

1. **Why it was done and what is the problem being addressed?**
These two sections can be grouped together into one brief statement summarizing why the experiment was performed in the first place or what was the question trying to be answered. This should not include many details, rather it should be a simple statement.

2. **What did you do?**
This part of the abstract states what was done to try to answer the question proposed. It should in no way be very detailed. It contains a brief outline of what was done, highlighting only crucial steps. It is the materials and methods section of your abstract, but it is only one or two sentences in length. It is a description of *how* you decided to approach the problem.

3. **What did you find out?**
In other words, what did all of your hard work and preparation tell you about the question you set out to answer. This contains only the crucial results obtained. The crucial results are those that are necessary to answer your original question posed. Without these results, the experiment would have been useless. The results should be stated briefly and should not be explained; they should only be mentioned. It is very similar to the results section of your report, but it highlights only pertinent results used to draw conclusions. An average length for this section is two or three sentences at the most. This number can vary however, depending on the complexity of the experiment, and so these length guides are just that, guides, not rules.

4. **Conclusions?**
This is the end of your abstract, directly hinging on the results obtained. This is the "so what" part of your experiment. "So what" refers to what the results mean in the long run. You need not include how you drew your conclusions, only the final conclusion. This should directly follow the results so the reader knows what results led to what conclusions. This is the equivalent to the discussion part of the paper, but again, like the rest of the abstract, it needs to be stated briefly and succinctly. You do not need to explain how you deduced the conclusion from the results obtained, only the end conclusions. After you have stated this, the abstract is complete.

### Examples

The two examples are of the same abstract, sample one is an example of a badly written abstract, while sample two is a well-written abstract. Italicized underlined words have corresponding explanations describing why the sentences are a good or bad example.

**Sample 1**: **This experiment will determine what will make enzymes effective and what will make them *__ineffective__*. We tested different samples of enzymes in a spectrophotometer and recorded their absorption *__rates__*. Six samples were placed in the spectrophotometer but two contained no enzyme; these acted as blanks for the other samples. The four remaining samples contained Catecholase ranging from 0.5 ml to 1.75 ml. The second half of the experiment contained four test tubes with a constant amount of Catecholase, but the pH levels ranged from four to *__eight__*. It was found that if the enzyme was present in large amounts, then the absorption rate was high, and if the pH level ranged from 6 to eight then the absorption rate was *__high__*. Therefore it can be said that enzymes work well in neutral pH levels and in large *__amounts__*.**

*Ineffective*: This sentence is in the future tense and needs to be switched to the past tense. In addition to tense problems, the sentence does not tell the reader much about what is meant by the term effective. What exactly is an effective enzyme? The author needs to be specific and try to avoid generic terms such as effective. Also, the author never states why the experiment is being conducted. Why is enzyme effectiveness so important? What makes it important enough to be studied?

*We*: The first person should not be used in a technical report.

*Rates*: This sentence is addressing what was done, yet it barely conveys any information. The author states that different samples of enzymes were tested, but mentions nothing about the contents of the samples. Was the same enzyme used in every sample? What was in each sample, and what varied in each sample? Also, what does absorption have to do with enzyme activity? This correlation needs to be explained to the reader. One last detail that should be included is the wavelength of light that was used in the spectrophotometer. Did it remain constant or was it a variable as well?

Eight: This is too long and detailed to be in an abstract; it sounds as though it was pulled from the methods and materials section of the paper. The amounts of enzyme do not need to be stated, nor do the pH levels. The number of samples tested do not need to be included either; it is just extraneous information that is not crucial to understanding the experiment as a whole. The information contained in this sentence can be pulled out and rearranged to say that some samples had a constant pH and varying enzyme concentrations and other samples had constant enzyme concentrations and varying pH levels. With the controls and the variables stated you can move on to your results.

*High*: This is just too general, although it conveys the right information. When stating results it is okay to use actual numbers. Instead of saying that the absorption rate was high, specify how high in comparison to samples with low absorption rates.

_Amounts_: An experiment is never final, nor is it ever positive. Always avoid saying that the results you obtained are correct or definite. Instead just say that the data supported or did not support your hypothesis.

**Sample 2: This experiment was performed to determine the factors that positively influence enzyme reaction rates in cellular activities since some enzymes seem to be more effective than _others._ Catecholase enzyme activity was measured through its absorption rate in a spectrophotometer, using light with a wavelength of _540nm_. We compared the absorbance rates in samples with varying enzyme concentrations and a constant pH of 7, and with samples with constant enzyme concentration and varying pH _levels_. The samples with the highest enzyme concentration had the greatest absorption rate of 95 percent compared to the sample with the lowest concentration and an absorption rate of 24 _percent_. This suggests that a higher concentration of enzymes leads to a greater product production _rate_. The samples with a pH between six and eight had the greatest absorption rate of 70 percent compared to an absorption rate of 15 percent with a pH of 4; this suggests that Catecholase is most effective in a neutral pH ranging from six to _eight_.**

_Others_: This sentence is clear and concise, telling the reader why the experiment was carried out. It postulates the question of why some enzymes are more effective than others and it explains that the experiment was set up to determine what causes these differences.

_540 nm_: This sentence introduces the specific enzyme being studied and how it was studied. The light wavelength used in the spectrophotometer was also specified telling the reader that wavelength was not one of the variables manipulated in the experiment.

_Levels_: It is okay to use personal pronouns in the abstract and this sentence uses "we" effectively. It also defines what was done without going into great detail. The controls and the variables are stated clearly and succinctly so the reader knows what factors are being tested to determine enzyme productivity.

_Clear summary_: These two sentences combine the results with the conclusion. This helps to make the conclusions drawn from the results very clear to the reader. The author also stated concrete numbers in the results so the reader is aware of just how much the absorption rates changed in each sample.

# Introduction Section

Although this may come as a surprise to many, the introduction section of a report should be one of the last sections written. For in writing the Results and Discussion sections, you have outlined the issues that your report discusses allowing for the formulation of an introduction to set the framework for the entire report.

In the introduction you should present the background necessary to understand your work and its significance. For example, if the purpose of an experiment was to identify the specific element in a metal powder sample by determining its crystal structure and atomic radius using the Debye-Sherrer (powder camera) method of X-ray diffraction, then the introduction should include a description of the Debye-Sherrer method, and an explanation that from the diffraction angles the crystal structure can be found by applying Bragg's law.

Along with background theory, also included can be previous research and/or formulas the reader needs to know. Remember to back all statements of fact with a reference to your textbook, laboratory manual, outside reading, or lecture notes**.** Any terms that are used within the report that are necessary for understanding the report should be defined within the introduction. A good rule of thumb--if you don't understand a certain term or concept, you need to explain it in your introduction. The introduction needs to be comprehensive enough that non-experts are given enough information to understand the main points of your results and conclusions. Usually, an instructor does not want you to repeat the lab manual, but to show your own comprehension of the background. Don't try to be too comprehensive; write about topics that are most pertinent to your experiment

Introductions often create difficulties for students who struggle with verb tenses. These two points should help you navigate the introduction:

- The experiment is already finished. Use the *past* tense when talking about the experiment.

  "The objective of the experiment **was**..."

- The report, the theory and permanent equipment still exist; therefore, these get the present tense:

  "The purpose of this report **is**..."
  "Bragg's Law for diffraction **is** ..."
  "The scanning electron microscope **produces** micrographs ...

Finally, after presenting the relevant background, you should conclude the introduction describing the purpose of the experiment in one or two sentences, outlining the question(s) being addressed. Stating the question or questions that are to be answered by the experiment can easily be introduced with the phrase "In this experiment" or "In this study" and then explaining from there. These statements should be as specific as possible to explain what the experiment does and how the results will be interpreted. The objectives of the experiment are important to state because these objectives are usually analyzed in the conclusion to determine whether the experiment succeeded.

**Examples**

The following two samples are for an introduction for a biology enzyme kinetics lab. Underlined italicized words highlight sentences that are appropriate or in need of improvement.

**Sample 1**: **This study, "Enzyme Kinetics," focuses on the study of enzymes and what makes them work. *<u>Enzymes</u>* are an important part of every living organism and many studies have been performed on them to try to learn more about how they work. Enzymes are involved in a lot of the *digestion* processes in the human body. The object of this experiment, however, is to get the substrate, catechol, to the product, benzoquinone, by way of the enzyme, catecholase*<u>. Experiment</u>* one alters the amount of enzyme to prove that the more enzyme you have, the faster the reaction takes place and a greater amount of product results. Experiment two adds ascorbic acid to lower the pH. *<u>The goal</u>* of this is to prove that increased acidity stops a reaction.**

*<u>Enzymes</u>*: In sample one the writer only refers to enzymes as an "important part of every living organism." This gives no information about the later use of the terms such as enzyme and substrate and this type of specialized terminology should be defined in an introduction

*<u>Digestion</u>*: This sentence does not belong in the introduction section because the experiment does not deal with any type of digestive enzymes, nor does it matter that other studies have been performed on enzymes unless they directly relate to this particular experiment. All information presented in an introduction should be relevant to the report.

*<u>Experiment</u>*: This sentence is an attempt to state the question that the experiment tries to answer; however, it only summarizes what the experimenters actually did rather than what the purpose of the experiment was. It is true that the experiment altered the concentration of the enzyme, but the reason behind it was to observe the effects of those changes on reaction rates. Information pertaining to the purpose of the experiment is the type of information that this statement should contain.

*<u>Goal</u>*: The writer makes a serious mistake by assuming that the experiment is going to prove something about enzymes. Nothing is proven, especially not by one experiment, so in writing a report it needs to be explained that the experimenters only observed the experimental results and then interpreted them.

**Sample 2: It is well known that enzymes are catalytic proteins which function to accelerate reactions by lowering the activation energy (*Campbell*, 1996). *An enzyme* is very specific in the reactions in which it undergoes: it contains an active site that allows only certain reactants, known as substrates, to bind to it (Campbell, 1996). *In the first experiment*, referred to as the variable enzyme experiment, the rate of reaction of catechol and oxygen to form benzoquinone was examined when the amounts of the enzyme (catecholase) were varied. The hypothesis was that enzyme amount affects reaction rates and thus it was expected that reactions with increased amounts of enzyme relative to the amount of substrate will have a greater net conversion of substrates than those reactions with a lesser ratio of enzyme to substrate. Likewise, in order to maintain its specific function, an enzyme must retain the specialized shape of its active site (Campbell, 1996). *Environmental factors* such as ionic concentration and pH have been known to alter the conformation of a protein and subsequently its active site conformation. *In this experiment*, referred to as the variable pH experiment, the rate of reaction catechol and oxygen was examined again, but this time when the pH was varied. It was expected that the reactions that occurred in a fairly neutral pH would convert more substrates than those reactions which were in an acidic environment of pH 4.**

*Campbell*: In sample one there are no references to any outside sources, whereas sample two refers often to a text by Campbell. All factual statements should be backed with references to show that the information has been obtained from a credible source.

*An enzyme*: This is a good example of defining specialized terms that are important to the experiment. This definition of an enzyme gives enough information so that the reader can understand the purpose of the experiment, but not so much information that it does not apply to the experiment.

*In the first experiment*: This is a very concise statement of the question that the experiment attempts to answer, and it begins with that most commonly used convention of "in this experiment." This is an appropriate statement because it is specific about the experiment and demonstrates a clear understanding that the purpose is not only to alter the amounts of catecholase but, in addition, to observe how these changes effect reaction rates.

*Environmental:* This explanation of the relationship between the shape of a protein and the utilization of its active site is important to understanding how pH could affect enzyme activity. Introductions should always contain the information necessary to understanding the entire experiment and report. When in doubt, ask your professor how specific you should be in the introduction section.

*In this experiment:* This is also a very good example of stating the purpose of the experiment because it is specific about the experiment, varying pH, and it shows that the expected results would be a change in reaction rate.

# RESULTS SECTION

This is the section in which you will want to present your findings to the reader in the most clear, consistent, orderly, and succinct fashion. The results you collect will most likely contain a story that you want to tell to the reader in an interesting manner. Presenting these data in a clear and thorough fashion, however, is quite a responsibility, because you have many decisions to make as to how you want to tackle the ominous task. And it must be done well, because without the results being understood, the credibility of the entire paper disintegrates before the reader's eyes. But the task is a manageable one, provided that you sit down and think logically about what needs to be made unequivocally clear. It is acceptable to combine your results section with the discussion section and call it Results/Discussion. This would primarily be done in cases where there are numerous figures that each require extensive discussion; this method provides a better presentation of information.

By this we mean that common sense goes a long way. Include only what is necessary, and don't include extraneous information. If something important is missing, the omission will stare the reader viciously in the face and he or she will be lost. So be sensible, include what you feel needs to be included, and do it in a clear and understandable way, for the results are the primary ingredients upon which your entire paper is based.

## General guidelines for writing the results section

1. **Do not be ambiguous**. Do not make the reader guess at what information you are trying to present.

2. **Organize the data in a logical fashion.** The reader must be able to follow the flow of the data, otherwise the paper will mean nothing and most likely frustrate the reader.

3. **Do not describe methods used to obtain the data.**

4. **Do not attempt to interpret the data.** This belongs in the Discussion section

5. **Point out certain trends or patterns that the data follow.** Data is organized in a manner that will point out trends that you want to make clear to the reader in order to help tell your story. You must call the reader's attention to these trends or they may be missed.

The ways of presenting data vary depending upon what you want to present to the reader. You should include all the important experimental data in tabular or graphical form. This data represents all of the experimental data collected throughout the experiment but not as raw material (that is data not yet manipulated). **Raw data** must appear in a separate appendix. *Under no circumstances* should the reader have to refer back to raw data appendices in order to follow your discussion. In other words, data referred to in your discussion should appear in the results section.

Each set of data requires a logically selected label (e.g. Figure 1 or Table 1) and a descriptive title. In your discussion section you must refer to each and every table and figure! Even though tables and figures can summarize a great deal of information, you should provide a "verbal tour" of all your data and results A sentence or two of explanation should be included for each table or figure so that the reader knows exactly what he or she is looking at.

Proper labels must be assigned to each axis if you choose to use a bar or a line graph. Also with graphs, if each data point is the result of repeated measurements, then error bars should be included. The standard deviation for each datum will be required. Without the level of error provided, the reader has no idea how consistent your findings are. However, in a laboratory class, often you will not obtain the data to calculate the standard deviation. It will depend on your professor and the experiment being performed.

All calculations performed with the raw data must be shown in a separate appendix. Only one **sample calculation** is required for each different calculation.

## Examples

The following tables and figure demonstrate some points about presentation.

**Sample 1:**

**Protein Values**

| Experiment | Absorbance | Protein |
|---|---|---|
| Media | 0.57 | 2.04 |
| Media/LPS | 0.60 | 2.16 |
| Vehicle | 0.61 | 2.20 |
| Vehicle/LPS | 0.66 | 2.36 |
| Drug | 0.69 | 2.50 |
| Drug/LPS | 0.61 | 2.22 |

There are many problems with the presentation of this table, forcing the reader to guess about some of the data. First, it is not labeled as either a table or a figure. It is simply given a title (Protein Values) that doesn't describe anything. Protein values of what and under what circumstances? The reader has no idea what he or she is looking at. Also, the column labels don't have the units of measurement included. The absorbance values mean nothing if the reader doesn't know at what level they were taken, and what does proteins mean in the third column? Is that concentration, and if so, what are the units? All of these things need to be included to make clear to the reader what the data is.

Sample 2:

Table 1. Absorbance Readings and Corresponding Protein Concentration values

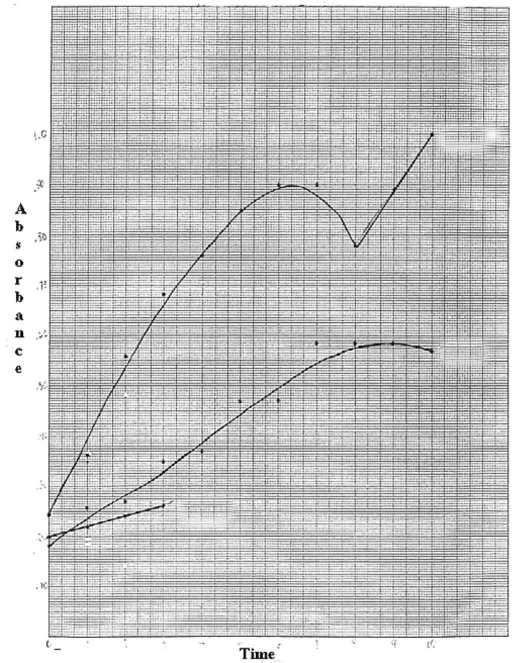
| Experimental group | Absorbance (595nm) | Protein Concentration (micg/micl) |
|---|---|---|
| Media | 0.57 | 2.04 |
| Media/LPS | 0.60 | 2.16 |
| Vehicle | 0.61 | 2.20 |
| Vehicle/LPS | 0.66 | 2.36 |
| Drug | 0.69 | 2.50 |
| Drug/LPS | 0.61 | 2.22 |

This table demonstrates the protein concentration of each sample. The concentration of protein found in each sample is similar.

This table is properly labeled Table 1, because it is the first table that appears in the report, and it also has a descriptive title. All of the columns are clearly labeled with the unit of measurement for each one, but the uncertainty is not identified. Also note that there is a brief sentence describing what the numbers are and where they came from.

**Sample 3:**

Figure One
Rate of reaction as a function of time




The title of sample 3 graph indicates Rates vs Time yet the axis indicates Absorbance versus Time. Units are missing from the axis and uncertainity is not shown on the data points. Also the reader is left wondering what the three separate plots represent as notes should have been included or a key chart on the graph.

# DISCUSSION

Discussion is the most important part of your report, because here, you show that you understand the experiment beyond the simple level of completing it. Here you must be able to explain, analyse, and interpret. Some people like to think of this as the "subjective" part of the report. By that, they mean this is what is not readily observable. The Discussion should be written after the Results section so that you have a good idea of what the experiment has demonstrated. This part of the lab focuses on a question of understanding "What is the significance or meaning of the results?" Good discussions require thought and additional reading (i.e., library work). *Go beyond the book and the lecture!*

The discussion section should definitely have a statement of your expected findings. This should include your hypothesis and a brief statement about why these types of results are expected. Then provide a comparison of how your actual results related to your expected findings. Here, you should state the degree to which the evidence supported your hypothesis. For example, were the results completely supportive, or were there variances? Point out certain trends or patterns that the data in your results section follow and point out sources of error and how they can be avoided. Also provide justification for neglecting data sets or points. In addition,there should be an explanation of unexpected results. When looking for possible explanations, consider the following:

a. Was the equipment used adequate for the task?
b. Was the experimental design valid?
c. Were the working assumptions made correct?

A common mistake that many writers make is to blame themselves for the unexpected results. Unless you actually made a mistake following the methods of the experiment, and could not go back and correct it, do not make up such errors to explain the variances you observe. Think about and analyze the methods and equipment you used. Could something different have been done to obtain better results? Another possibility to consider is if the experiment was conducted under factors that were considerably different from those described in the manual. Be sure to include ideas on how to test these explanations. Briefly explain a way to test these possible reasons for unexpected results. For example, if there is a problem with the methods, maybe the experiment should be reproduced with an added step. Also mention what kinds of experiments still need to be conducted in order to obtain more information.

Besides discussing the results individually and coming to conclusions, an overall conclusion should be discussed in the context of the entire experiment. Usually, the objectives mentioned in the "Introduction" are examined to determine whether the experiment succeeded. If the objectives were not met, you should analyze why the results were not as predicted.

## Examples

The following examples illustrate discussion points both good and bad. Refer to the explanations for each sentence with a word italicized and underlined within it.

**Sample 1**: **The *results* of the first experiment supported the specific, three dimensional shape of an enzyme. This shape is extremely important to the enzyme's catalyzing efficiency and many environmental conditions can affect the shape of enzymes and thus their efficiency. A range of pH values exists for all enzymes, between which they reach their maximum catalyzing action. This range is usually between a pH of 6-8. pH levels outside this range can denature the enzyme, thereby decreasing its catalyzing ability. The results we obtained supported this assumption for the catecholase enzyme. The catecholase samples in tubes 3 and 4 had similar *absorbance* rates and, therefore, similar enzyme activities. However, the pH of 4 in tube 2 corresponded to low absorbance and low activity of the enzyme in that tube. This is due to the fact that the *acidic* environment is harmful to the enzyme, and denatures it. Catecholase, an enzyme found in fruits in nature, is well adapted for efficiency in nature. Its range of optimal pH levels, 6-8, allows it to function in the varying pH levels of soil and those caused by acid rain.**

*Results:* This author does a good job of answering the questions that should be addressed in a discussion. For example, in the very first sentence he stated what he expected to find and also whether or not the results he obtained supported or failed to support his hypothesis. This is a good, strong way to start a discussion section. It starts off with the facts of the experiment and then later on, the author can move on to his opinions.

*Absorbance*: A good discussion includes good ideas and also exact and detailed support of these ideas. In addition to starting off well, the author also goes on to explain the specific results of the experiment that support his hypothesis. This is what defines the strength of his discussion section.

*Acidic*: After his explanation he presents the unexpected results and discusses possible reasons for this data. The author's explanation of possible reasons for unexpected results is good because it shows that he thought about the problems. He does not blame himself for the unexpected. Instead, he considers the methods used, presents a possible explanation, and then justifies his ideas.

**Sample 2: Enzymes *catalyze* reactions by lowering the activation energy of the reaction. Catecholase, an enzyme found in potatoes, converts**

**catechol to benzoquinone in the presence of oxygen. It would be expected that more benzoquinone would be formed in the presence of a greater amount of catecholase. This hypothesis was supported by the results obtained. The most enzyme was placed in tube 2. The absorbance was also highest for this tube. This means that the most product was formed in this test tube. In accordance with this, tube four, which had the least amount enzyme, also had the least amount of absorption. There were some *unexpected results*, but this is most probably due to human error; the absorbance levels were probably read wrong. *Enzymes* are affected by the environment. The pH level of the environment is one factor that can alter enzymes. The rate at which the enzyme form product is slowed or sped up depends on how close to the norm the environment is. In the second experiment, the pH of the medium was different in each of the test tubes. The general trend seen in these reactions was that the more acid added to the test tubes, the less product formed. The more acidic solution caused the enzyme to work less efficiently.**

*Catalyze*: This author does a good job outlining his discussion, however he is lacking the specifics to make a good discussion. The first two sentences are better placed in the introduction. However, he does state his expectations and whether or not his results supported these expectations. He could have made this part better by stating this more authoritatively, for example: "It was expected," and not, "It would be expected that."

*Unexpected results*: The biggest problem this author had was explaining the unexpected results. He blamed himself, saying he read the equipment wrong and passed off the unexpected results as human error.

*Enzymes*: This author does not develop his argument enough. One example of this, is the affects harsh environmental factors have on enzymes. He could have stated how the acidity caused the enzymes to denature, thus creating less efficiency.

# Conclusions/Recommendations Section

This is the simplest of all the sections to complete if you have properly completed the “Discussion” section. In this section you merely restate the conclusions made in the “Discussion” section. Number your conclusions as per the order they were presented in the “Discussion” section.

**No new material should be presented!**. A general rule is if it does not appear in the body of the report it cannot appear in the conclusions. Review your objectives and make sure that the conclusions satisfy and relate directly to your objectives. Remember conclusions should concentrate on the results of the work and not on ideas such as how useful the experiment was in your opinion.

If you have recommendations they should be included in the paragraph of the conclusion from which they logically flow. If many recommendations are suggested then they should have their own section. Remember, after the abstract, it is the conclusions section that is most often read.

# REFERENCE SECTION

The last part of a report can often be the most tedious, but it need not be the most difficult. The literature cited portion of your report is very important because it enables either you or another reader to go back and obtain the sources that you used in preparing your report. You should only include those sources that you actually used and cited in writing your report. Often one obtains many sources of data when first beginning a report, but in the end, only a few are actually incorporated into the report.

Citing your sources allows the reader to obtain additional information if he or she wants to find out about a certain topic you addressed. Another important reason for having a literature cited page is that it allows anyone who is unsure of your data to go back and verify that you reported everything correctly, thus eliminating any uncertainty. To clarify what information was obtained from what sources, you must use internal citation. Remember that individuals who you approached for a source of information can be cited as well.

## In Text Citation

This type of citation is necessary so readers know what information is factual and where it was obtained. Direct quotes are rarely used in laboratory reports and should be avoided. If you are including some general information gathered from a source, then it is acceptable to put the citation at the end of the paragraph containing the information being used. An example of this type of citation could look like this:

Polystyrene thermally degrades at 740 degrees celcius (Schnabel, 1981).

The specific page and details of the book will then appear in the "Reference" section.

It is also important to keep these in-text citations brief so that they won't take away from the content of your report. For this reason, if a source has more than one author, the last name of the first alphabetic author should be listed with an et al. following the name. Here is an example of how this can be done (Carlton et al., 1996). The reader will know that the source has many authors and that they can be found in the literature cited portion of the paper.

## Literature Cited Page

This page entitled "References" is all about copying a format. The following are examples of citation from different sources. Be sure to note punctuation when copying these formats. In addition, always list sources alphabetically according to the last name of the author.

**Listing a book or an article from a book**
Toole, B. P.. Glycosaminoglycan in morphogenesis. In: *Cell Biology of Extracellular Matrix* (E. D. Hay, editor), Plenum Press, NY, 1981, pp. 259-294.

**Listing a laboratory manual / handout**
CCE 321 Laboratory Manual. 2005. *Fuel Characterization*, pp. 16-23. Royal Military College of Canada, Ontario.

**Listing Journal references**
Stokes, V.K., “Vibration Welding of Thermoplastics. Part III: Strength of Polycarbonate Butt Welds”, Polymer Engineering and Science, **28**, 1988.15-17.

Note the titles are italicized except for Journal papers.

# <u>Error Analysis and Statistics</u>

In your math courses you will have discussed terms such as mean; standard deviation; confidence interval; F,t and z values; regression analysis; determinate or indeterminate error; significant figures; precision and accuracy. Let's briefly review the significance of some of these with respect to experimentation, for you must discuss your error analysis in your discussion section and show all calculations of error in a separate appendix.

Firstly you need to realize that every physical measurement taken by you has a degree of uncertainty. To determine what that degree is can be very time consuming and so it must be determined how important it is to know the degree of uncertainty. Uncertainty cannot be neglected entirely because results with an unknown reliability are worthless. Generally analysis requires repeating the experiments two to five times to establish a mean value that will be more reliable than a single test result. The precision describes the reproducibility of the results and is used to establish the standard deviation. Accuracy denotes the nearness of a result to its accepted value and is often described in terms of the absolute error. Thus it is possible to have high precision but completely inaccurate results.

## <u>Determinate and Indeterminate Errors</u>

Uncertainties arise due to two different types of errors: determinate and indeterminate. By repeating measurements the indeterminate errors (otherwise known as random errors) can be revealed but the source of the error cannot be positively identified. They arise from an inability to discriminate between readings differing by less than a small amount. The consequence of random errors is that they cause the data from replicate measurements to fluctuate in a random manner, in some instances causing higher results and in others low. Determinate errors (otherwise known as systematic errors) are those that have a definite value and an assignable cause which will effect all of a series of replicate analyses by causing results to be too high or too low.

So what causes random and systematic errors? There are three general sources: (1) instrument imperfections; (2) method uncertainties that arise from nonideal chemical or physical behaviour of analytical systems; and (3) personal uncertainties that are caused by physical or psychological limitations.

Systematic instrument imperfections can be quantified by calibration. You should always ask if the instruments you are using have been calibrated with a known standard and if they have been determined to deviate from the standard (too high or too low). Many scales and measuring devices have been calibrated but will still have an uncertainty (+/-) due to random errors from instrument imperfections not identifiable, ie the way in which a pipet is handled can vary its temperature and thus the volume change. This uncertainty is usually identified on the measuring device and if not the uncertainty is taken to be +/- one half of the scale increment on the measuring device.

Systematic method errors are frequently difficult to detect and are thus the most serious of the three types of determinate error. Sources of nonideality include the slowness of some reactions, the incompleteness of others and the possible occurrence of side reactions.

Many measurements require personal judgements. A systematic error example may be consistently activating a timer slow or consistently estimating the position of a pointer between two scale divisions too high. These can be minimized by care and self-discipline.

In the case of indeterminate errors, they are out of your control. Even with every effort being made to recognize and eliminate determinate errors, an experienced and competent worker will find variances in his results for the same procedure. Measurements can be affected by numerous small and individually undetectable instrument, method, and personal uncertainties caused by uncontrolled variables in the experiment. The cumulative effect of such uncertainties will be likewise variable. They can cancel one another or they can act in concert to produce a relatively large positive or negative error. Numerous empirical observations have shown that indeterminate errors most commonly distribute themselves in a manner which approaches a Gaussian distribution. In such a distribution a small indeterminate error will occur much more often than a very large one. The use of statistical techniques allows for an estimate of the limits of indeterminate error from the precision of data collected.

## Estimating Indeterminate Errors Using Statistics

The standard deviation($\sigma$) is a useful quantity for estimating and reporting the probable size of indeterminate errors. The standard deviation for a very large set of data (>20 data points) is given by

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

Here the sum of the squares of the individual deviations from the mean is divided by the total number of measurements in the set. For a smaller set of data, the standard deviation is identified as (s) and is adjusted to account for a less accurate assessment of the true mean( $\bar{x}$ ).

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}}$$

With the standard deviation, one can define a confidence interval around the mean within which the true mean can be expected to be found. The area under a normal error curve encompassed by $\pm$ 1.96σ corresponds to 95% of the total area. In this case, the confidence interval is 95% so that 95 times out of 100 the deviation from the mean for a measurement, based on a large number of measurements, will be equal to or less than $\pm$ 1.96σ. The 1.96 is the z value and this value varies from 0.67 for 50% to 3.29 for 99.9%. For small sets of data the z value is replaced with the t-value which are larger than z values and the σ is replaced with s. The confidence interval is decreased by $\sqrt{N}$ for the average of N replicates defining the confidence limit as

$$\mu = \bar{x} \pm \frac{z\sigma}{\sqrt{N}}$$

Thus if the mean weight of 30 samples was 3.12 grams with a standard deviation of 0.10 then 50 times out of a 100 we can estimate that the mass will be 3.12 $\pm$0.01 grams, in other words it will have an indeterminate error of $\pm$0.01. But with a 95% confidence limit it will have a mass of 3.12$\pm$0.03 gm.

## Accumulation of Errors

With **determinate** errors, for the sum or difference y = a+ b – c , where a,b, and c are measurable quantities, the plus or minus error in each of these quantities propogates as $\Delta y = \Delta a + \Delta b - \Delta c$. For the product or quotient y= ab/c, propagation is in accordance with the plus or minus relative error expression ( $(\Delta y / y) = (\Delta a / a) + (\Delta b / b) - (\Delta c / c)$. In exponential calculations such as $y=a^x$

The error that results from the determinate error in a is calculated as $\frac{\Delta y}{y} = x\frac{\Delta a}{a}$.

Thus the relative error in the square of a number is twice that for the number itself, etc. To show how errors are propogated when logarithms or antilogarithms are computed we take the derivative of the expression $y = \log a = 0.434 \ln a$ where ln symbolizes the natural logarithm, thus $dy = 0.434\frac{da}{a}$ or in finite increments $\Delta y = 0.434\frac{\Delta a}{a}$.

In the case of **indeterminate errors** no sign can be attached to a standard deviation (since this error is random). If several measured quantities are added or subtracted then there could be a range of possible standard deviations for a computed result since each error has an equal probability of being positive or negative. It can be shown from statistical theory that the most probable uncertainty in the case of sums or differences can be found by taking the square root of the sum of individual absolute variances. Thus for y=a+b-c, the standard deviation $s_y$ is calculated from $s_y^2 = s_a^2 + s_b^2 + s_c^2$. For a product or a quotient y=ab/c, the relative variance of the result is equal to the sum of the individual relative variances so that: $\left(\frac{s_y}{y}\right) = \sqrt{\left(\frac{s_a}{a}\right)^2 + \left(\frac{s_b}{b}\right)^2 + \left(\frac{s_c}{c}\right)^2}$ which allows for the final result of $s_y$ to be calculated. For calculations involving both sums/ differences and multiplication/division, you must calculate the standard deviation of the sum/differences first. And in the case of exponential calculations and logarithm calculations, the indeterminate error in the result is calculated in the same fashion as with determinate errors, only the standard deviation in the measured quantities are substituted for the determinate errors.

Thus to report a total uncertainity in a result, both the determinate and indeterminate errors must be combined. They are done so in quadrature to yield an overall error: $\Delta y = \sqrt{\Delta y_{random}^2 + \Delta y_{systematic}^2}$.

## Significant Figures

Common practice dictates that an experimental result should be rounded off so that it contains only the digits known with certainty plus the first uncertain one, and these are termed the significant figures. For example if the average mass was calculated to be 61.555 gm with a standard deviation of +/- 0.069, then clearly the number in the second decimal place of the average is subject to uncertainty. Such being the case, all numbers in succeeding decimal places are without meaning. Now the question remains of how to round off 61.555. A good guide to follow is to round to the nearest even number, so the mean would be reported as 61.56 +/- 0.07. If you had reason to doubt that 0.07 was a valid estimate of the precision then you might choose to present the results as 61.6 +/- 0.1.

Zeroes bounded by digits on the left may or may not be significant. For example if a volume is reported as 2.0 liters then the zero is significant and implies that the volume is known to at least +/- 0.5 liters and might be known to +/- 0.05 liters since the standard deviation has not been given. To express this in milliliters only the first 2 digits are certain of 2000 ml. By using exponential notation the significant figures are clearly stated as 2.0 X $10^3$ ml.

A certain amount of care is required in determining the number of digits to carry in the result of arithmetic. Firstly, it is good practice to carry one extra digit beyond the last significant figure, saving the rounding to the final result. For addition and subtraction the number can be visually inspected, for example when adding 3.4 + 0.02 + 1.31 = 4.7, the result is only to one decimal because 3.4 reflects certainty only in its first digit and the second digit (first decimal) remains uncertain.

When data are multiplied or divided, it is frequently assumed that the number of significant figures of the result is equal to that of the component quantity that contains the least number of significant figures. For example

$$\frac{24 \times 0.452}{100.0} = 0.108 = 0.11(rounded)$$

In this case 24 has only 2 significant figures so the result contains only two.

# **Word Usage** In Scientific Writing

This listing includes some of the troublesome words, terms, and expressions most frequently found in lab reports. Any glossary of word usage assumes that what is acceptable for some uses may not be for others. Some terms and expressions are worn-out cliches and have outlived their usefulness; other expressions and terms, though not incorrect, are not precise. In reporting and recording research, try to be as accurate and precise in describing it as in doing it. Avoid the ambiguous and "faddish."

**Above** ("the above method," "mentioned above," etc.) -- Often, you are referring to something preceding, but not necessarily *above*; a loose reference, convenient for writers, but not for readers. Be specific. You know exactly what and where, but your readers may have to search (sometimes through much preceding material).

**Affect, effect** -- Affect is a verb and means to *influence.* Effect, as a verb, means to *bring about*; as a noun, effect means *result.*

**All of, both of** -- Just "all" or "both" will serve in most instances.
**Alternate, alternative** -- Be sure which you mean.

**And** (to begin a sentence) -- Quite proper. You have been told not to do this in grade school. But teacher's purpose was to keep you from using fragmentary sentences; either "and" or "but" may be used to begin complete sentences. And both are useful transitional words between related or contrasting statements.

**Apparently (apparent)** -- means *obviously, clearly, plainly evident*, but also means *seemingly* or *ostensibly* as well as *observably.* You know the meaning that you intend, but readers may not. Ambiguity results. Use *obvious(ly), clear(ly), seeming(ly), evident(ly), observable* or *observably,* etc., as needed to remove doubt.

**Appear, appears** -- Seem(s)? "He always *appears* on the scene, but never *seems* to know what to do." "Marley's ghost *appeared* but *seemed* harmless."

**As** -- Dialectal when used in place of *that* or *whether*; do **not** use *as* to mean *because* or *inasmuch as.*

**At the present time, at this point in time** -- Say "at present" or "now" if necessary at all.

**Below** -- See comment about *above.*

**But** (to begin a sentence) -- Go right ahead (see "And" and "However").

**By means of** -- Most often, just "by" will serve and save words.

**Case** -- Can be ambiguous, misleading, or ludicrous because of different connotations; e.g., "In the case of Scotch whiskey,...." *Case* also is a frequent offender in padded, drawn-out sentences. For "in this case," try "in this instance."

**Commas and punctuation** -- Not precisely a word-usage matter except in relation to how words are put together. The trend is toward less punctuation (particularly fewer commas), but that demands careful writing, without misplaced or dangling elements. Do **not** omit commas before the conjunctions in compound sentences. Most journals, but not all, use final commas before "and" or "or" in series; check the journal.

**Compare with, compare to** -- Compare *with* means to examine differences and similarities; compare *to* means to represent as similar. One may conclude that the music of Brahms compares *to* that of Beethoven, but to do that, one must first compare the music of Brahms *with* that of Beethoven.

**Comprise** -- Before misuse, comprise meant to contain, include, or encompass (not to constitute or compose) and still does, despite two now opposite meanings. Use and meanings now are so confused and mixed that "comprise" is best avoided altogether.

**Correlated with, correlated to** -- Although things may be *related to* one another, things are *correlated with* one another.

**Different from, different than** -- Different from! Also, one thing *differs from* another, although you may *differ with* your colleagues.

**Due to** -- Make sure that you don't mean *because of.* Due is an adjective modifier and must be directly related to a noun, **not** to a concept or series of ideas gleaned from the rest of a statement. "Due to the fact that..." is an attempt to weasel out.

**During the course of, in the course of** -- Just use "during" or "in."

**Either....or, neither...nor** -- Apply to no more than two items or categories. Similarly, *former* and *latter* refer only to the first and second of only two items or categories.

**Etc.** -- Use at least two items or illustrations before "and so forth" or "etc."

**Experience(d)** -- To experience something is sensory; inanimate, unsensing things (lakes, soils, enzymes, streambeds, farm fields, etc.) do not experience anything.

**Following** -- "After" is more precise if "after" is the meaning intended. "After [not *following*] the procession, the leader announced that the ceremony was over."

**High(er), low(er)** -- Much too often used, frequently ambiguously or imprecisely, for other words such as *greater, lesser, larger, smaller, more, fewer*; e.g., "Occurrences of higher concentrations were lower at higher levels of effluent outflow." One interpretation is that greater concentrations were fewer or less frequent as effluent volume(s) increased, but others also are possible.

**However** -- Place it more often within a sentence or major element rather than at the beginning or end. "But" serves better at the beginning.

**Hyphening of compound or unit modifiers** -- Often needed to clarify what is modifying what; e.g., a small-grain harvest (harvest of small grain) is different from a small grain harvest (small harvest of *all* grain), a fast *acting* dean isn't necessarily as effective as a fast-acting dean, a batch of (say, 20) 10-liter containers is different from a batch of 10 [1-] liter containers, *and a man eating fish is very different from a man-eating fish!* Grammatically, adjectives are noun modifiers, and the problem is when adjectives and nouns are used to modify other adjectives and nouns. **Adverbs** (usually with "ly" endings), however, **are** adjective modifiers.

**In order to** -- For brevity, just use "to"; the full phrase may be used, however, [in order] to achieve useless padding.

**Irregardless** -- No, *regardless*. But *irrespective* might do.

**It should be mentioned, noted, pointed out, emphasized, etc.** -- Such preambles often add nothing but words. Just go ahead and say what is to be said.

**It was found, determined, decided, felt, etc.** -- Are you being evasive? Why not put it frankly and directly? (And how about that subjective "felt"?)

**Less(er), few(er)** -- "Less" refers to quantity; "fewer" to number.

**Majority, vast majority** -- See if *most* will do as well or better. Look up "vast."

**Myself** -- Not a substitute for me. "This paper has been reviewed by Dr. Smith and myself" and "The report enclosed was prepared by Dr. Jones and myself" are incorrect as is "Don't hesitate to call Dr. Doe or myself"; *me* would have been correct in all instances. (Use of *I* also would have been wrong in those examples.) Some **correct** uses of *myself*: I found the error myself. I myself saw it happen. I am not myself today. I cannot convince myself. I locked myself out of the car.

**Partially, partly** -- Compare the meanings (see also *impartially*). *Partly* is the better, simpler, and more precise word when partly is meant.

**Percent, percentage** -- Not the same; use percent only with a number.

**Predominate, predominant** -- *Predominate* is a verb. *Predominant* is the adjective; as an adverb, *predominantly* (not "predominately").

**Prefixes** -- (mid, non, pre, pro, re, semi, un, etc.) -- Usually not hyphened in U.S. usage except before a proper name (pro-Iowa) or numerals (mid-60s) or when lack of a hyphen makes a word ambiguous or awkward. *Recover* a fumble, but perhaps *re-cover* a sofa. *Preengineered* is better hyphened as *pre-engineered*, one of the few exceptions so hyphened. Breaking pairs such as *predoctoral* and *postdoctoral* into *pre- and post-doctoral* "forces" hyphening of both otherwise unhyphened words.

**Principle, principal** -- They're different; make sure which you mean.
**Prior to, previous to** -- Use *before, preceding*, or *ahead of*. There are *prior* and *subsequent* events that occur before or after something else, but *prior to* is the same kind of atrocious use that attempts to substitute "subsequent to" for "after."

**Proven** -- Although a *proven* adjective, stick to *proved* for the past participle. "A *proven* guilty person must first have been *proved* guilty in court."

**Provided, providing** -- *Provided* (usually followed by "that") is the conjunction; *providing* is the participle.

**Reason why** -- Omit *why* if reason is used as a noun. The reason is...; or, the reason is that... (i.e., the reason **is** the why).

**Since** -- has a time connotation; use "because" or "inasmuch as" when either is the intended meaning.

**Small in size, rectangular in shape, blue in color, tenuous in nature, etc.** -- Redundant.

**That and which** -- Two words that can help, when needed, to make intended meanings and relationships unmistakable, which is important in reporting scientific information. If the clause can be omitted without leaving the modified noun incomplete, use which and enclose the clause within commas or parentheses; otherwise, use *that*. Example: "The lawn mower, *which is* broken, is in the garage." But, "The lawn mower *that is* broken is in the garage; so is the lawn mower *that* works."...*That is broken* specifies the particular mower being discussed, whereas *which is broken* merely adds additional information to the sentence.

**To be** -- Frequently unnecessary. "The differences were [found] [to be] significant."

**Varying** -- Be careful to distinguish from *various* or *differing*. In saying that you used varying amounts or varying conditions, you are implying **individually changing** amounts or conditions rather than a selection of various or different ones.

**Where** -- Use when you mean *where*, but not for "in which," "for which," etc.

**Which is, that were, who are, etc.** -- Often not needed. For example, "the data that were related to age were analyzed first" means that the *data related to age* were analyzed first. Similarly, for "the site, which is located near Ames," try "the site, located near Ames" or "the site, near Ames." Rather than "all persons who were present voted," just say that "all persons present voted." Rephrasing sometimes can help. Instead of "a survey, which was conducted in 1974" or "a survey conducted in 1974," try "a 1974 survey."
**While** -- Preferably not if, *while* writing, you mean *and, but, although,* or *whereas*. Remember that a research report should communicate and record information as accurately and concisely as possible. The purpose is to report, not to impress with elegance. Excess wordage, tortuous construction, unnecessary detail, duplication, repetition, third-person passive pseudo-objectivism, etc., obstruct rather than facilitate communication. It's the message that is important, not sheer numbers of words. Use precise words and expressions of unmistakable meaning; avoid the clouded, ambiguous, vague, and needlessly complex.

**Beware of misplaced or dangling modifiers and pronoun antecedent problems.**
The difficulty here is that you, as the author, know exactly to which each has reference even though not explicitly stated. Your reader, however, doesn't have this advantage, and the result may be confusing, misleading, or funny.

EXAMPLES:

**Modifier problems**

*"Using multiple-regression techniques, the animals* in Experiment I were..."
"The determinations were made on *samples using* gas chromatography."
*"In assessing the damage, the plants* exhibited numerous lesions."
"The *spiders* were inadvertently discovered *while repairing a faulty growth chamber."*
*"Settling in the collected effluent, we* observed what was determined to be..."

**Ambiguous pronoun antecedents**

"The flavor was evaluated by an experienced *taste panel*, and *it* was deemed obnoxious."
"All samples in Lot II were discarded when *the authors* found that *they* were contaminated with alcohol, rendering *them* unstable." [and unable to think clearly?]
"The guidelines were submitted to *the deans*, but *they* subsequently were ignored."