# Writing Research Papers

*Writing is easy. All you do is stare at a blank sheet of paper until drops of blood form on your forehead. --- Gene Fowler*

Written and oral communications skills are probably the most universal qualities sought by undergraduate, graduate, and professional schools as well as by employers. You alone are responsible for developing such skills to a high level.

## Resources for learning technical writing

Before you begin your first writing assignment, please consult all of the following resources, in order to gain the most benefit from the experience.

- General form of a typical research article
- Specific guidelines (if any) for the assignment – see the writeups on individual lab studies
- McMillan, VE. "Writing Papers in the Biological Sciences, Third Ed." New York: Bedford/St. Martin's, 2001. ISBN 0-312-25857-7 (REQUIRED for Bios 211, 311, recommended for other science courses that include writing)
- Writing portfolio examples (pdf)

### As you polish up your writing skills please make use of the following resources

- Instructor feedback on previous assignments
- Common errors in student research papers
- Selected writing rules (somewhat less serious than the other resources)

For Biosciences majors the general guidelines apply to future course work, as can be seen by examining the guidelines for the advanced experimental sciences research paper (Bios 311). Instructions for authors from the Journal of Biological Chemistry editorial board may be helpful as well. Their statement of editorial policies and practices may give you an idea of how material makes its way into the scientific literature.

## General form of a research paper

An objective of organizing a research paper is to allow people to read your work selectively. When I research a topic, I may be interested in just the methods, a specific result, the interpretation, or perhaps I just want to see a summary of the paper to determine if it is relevant to my study. To this end, many journals require the following sections, submitted in the order listed, each section to start on a new page. There are variations of course. Some journals call for a combined results and discussion, for example, or include materials and methods after the body of the paper. The well known journal *Science* does away with separate sections altogether, except for the abstract.

Your papers are to adhere to the form and style required for the Journal of Biological Chemistry, requirements that are shared by many journals in the life sciences.

### General style

Specific editorial requirements for submission of a manuscript will always supercede instructions in these general guidelines.

### To make a paper readable

- Print or type using a 12 point standard font, such as Times, Geneva, Bookman, Helvetica, etc.
- Text should be double spaced on 8 1/2" x 11" paper with 1 inch margins, single sided
- Number pages consecutively
- Start each new section on a new page
- Adhere to recommended page limits

# Writing Research Papers

### Mistakes to avoid

- Placing a heading at the bottom of a page with the following text on the next page (insert a page break!)
- Dividing a table or figure - confine each figure/table to a single page
- Submitting a paper with pages out of order

### In all sections of your paper

- Use normal prose including articles ("a", "the," etc.)
- Stay focused on the research topic of the paper
- Use paragraphs to separate each important point (except for the abstract)
- Indent the first line of each paragraph
- Present your points in logical order
- Use present tense to report well accepted facts - for example, 'the grass is green'
- Use past tense to describe specific results - for example, 'When weed killer was applied, the grass was brown'
- Avoid informal wording, don't address the reader directly, and don't use jargon, slang terms, or superlatives
- Avoid use of superfluous pictures - include only those figures necessary to presenting results

## Title Page

Select an informative title as illustrated in the examples in your writing portfolio example package. Include the name(s) and address(es) of all authors, and date submitted. "Biology lab #1" would not be an informative title, for example.

## Abstract

The summary should be two hundred words or less. See the examples in the writing portfolio package.

### General intent

An abstract is a concise single paragraph summary of completed work or work in progress. In a minute or less a reader can learn the rationale behind the study, general approach to the problem, pertinent results, and important conclusions or new questions.

### Writing an abstract

Write your summary after the rest of the paper is completed. After all, how can you summarize something that is not yet written? Economy of words is important throughout any paper, but especially in an abstract. However, use complete sentences and do not sacrifice readability for brevity. You can keep it concise by wording sentences so that they serve more than one purpose. For example, "In order to learn the role of protein synthesis in early development of the sea urchin, newly fertilized embryos were pulse-labeled with tritiated leucine, to provide a time course of changes in synthetic rate, as measured by total counts per minute (cpm)." This sentence provides the overall question, methods, and type of analysis, all in one sentence. The writer can now go directly to summarizing the results.

### Summarize the study, including the following elements in any abstract. Try to keep the first two items to no more than one sentence each.

- Purpose of the study - hypothesis, overall question, objective
- Model organism or system and brief description of the experiment
- Results, including <u>specific data</u> - if the results are quantitative in nature, report quantitative data; results of any statistical analysis shoud be reported
- Important conclusions or questions that follow from the experiment(s)

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**Style:**

- Single paragraph, and concise
- As a summary of work done, it is always written in past tense
- An abstract should stand on its own, and not refer to any other part of the paper such as a figure or table
- Focus on summarizing results - limit background information to a sentence or two, if absolutely necessary
- What you report in an abstract must be consistent with what you reported in the paper
- Corrrect spelling, clarity of sentences and phrases, and proper reporting of quantities (proper units, significant figures) are just as important in an abstract as they are anywhere else

## Introduction

Your introductions should not exceed two pages (double spaced, typed). See the examples in the writing portfolio package.

### General intent

The purpose of an introduction is to aquaint the reader with the rationale behind the work, with the intention of defending it. It places your work in a theoretical context, and enables the reader to understand and appreciate your objectives.

### Writing an introduction

The abstract is the only text in a research paper to be written without using paragraphs in order to separate major points. Approaches vary widely, however for our studies the following approach can produce an effective introduction.

- Describe the importance (significance) of the study - why was this worth doing in the first place? Provide a broad context.
- Defend the model - Why did you use this particular organism or system? What are its advantages? You might comment on its suitability from a theoretical point of view as well as indicate practical reasons for using it.
- Provide a rationale. State your specific hypothesis(es) or objective(s), and describe the reasoning that led you to select them.
- Very briefy describe the experimental design and how it accomplished the stated objectives.

**Style:**

- Use past tense except when referring to established facts. After all, the paper will be submitted after all of the work is completed.
- Organize your ideas, making one major point with each paragraph. If you make the four points listed above, you will need a minimum of four paragraphs.
- Present background information only as needed in order support a position. The reader does not want to read everything you know about a subject.
- State the hypothesis/objective precisely - do not oversimplify.
- As always, pay attention to spelling, clarity and appropriateness of sentences and phrases.

## Materials and Methods

There is no specific page limit, but a key concept is to keep this section as concise as you possibly can. People will want to read this material selectively. The reader may only be interested in one formula or part of a procedure. Materials and methods may be reported under separate subheadings within this section or can be incorporated together.

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### General intent

This should be the easiest section to write, but many students misunderstand the purpose. The objective is to document all specialized materials and general procedures, so that another individual may use some or all of the methods in another study or judge the scientific merit of your work. It is not to be a step by step description of everything you did, nor is a methods section a set of instructions. In particular, it is not supposed to tell a story. By the way, your notebook should contain all of the information that you need for this section.

### Writing a materials and methods section

### Materials:

- Describe materials separately only if the study is so complicated that it saves space this way.
- Include specialized chemicals, biological materials, and any equipment or supplies that are not commonly found in laboratories.
- Do not include commonly found supplies such as test tubes, pipet tips, beakers, etc., or standard lab equipment such as centrifuges, spectrophotometers, pipettors, etc.
- If use of a specific type of equipment, a specific enzyme, or a culture from a particular supplier is critical to the success of the experiment, then it and the source should be singled out, otherwise no.
- Materials may be reported in a separate paragraph or else they may be identified along with your procedures.
- In biosciences we frequently work with solutions - refer to them by name and describe completely, including concentrations of all reagents, and pH of aqueous solutions, solvent if non-aqueous.

### Methods:

- See the examples in the writing portfolio package
- Report the methodology (not details of each procedure that employed the same methodology)
- Describe the mehodology completely, including such specifics as temperatures, incubation times, etc.
- To be concise, present methods under headings devoted to specific procedures or groups of procedures
- Generalize - report how procedures were done, not how they were specifically performed on a particular day. For example, report "samples were diluted to a final concentration of 2 mg/ml protein;" don't report that "135 microliters of sample one was diluted with 330 microliters of buffer to make the protein concentration 2 mg/ml." Always think about what would be relevant to an investigator at another institution, working on his/her own project.
- If well documented procedures were used, report the procedure by name, perhaps with reference, and that's all. For example, the Bradford assay is well known. You need not report the procedure in full - just that you used a Bradford assay to estimate protein concentration, and identify what you used as a standard. The same is true for the SDS-PAGE method, and many other well known procedures in biology and biochemistry.

### Style:

- It is awkward or impossible to use active voice when documenting methods without using first person, which would focus the reader's attention on the investigator rather than the work. Therefore when writing up the methods most authors use third person passive voice.
- Use normal prose in this and in every other section of the paper – avoid informal lists, and use complete sentences.

### What to avoid:

- Materials and methods are not a set of instructions.
- Omit all explanatory information and background - save it for the discussion.
- Omit information that is irrelevant to a third party, such as what color ice bucket you used, or which individual logged in the data.

# Writing Research Papers

## Results

The page length of this section is set by the amount and types of data to be reported. Continue to be concise, using figures and tables, if appropriate, to present results most effectively. See recommendations for content, below.

### General intent

The purpose of a results section is to present and illustrate your findings. Make this section a completely objective report of the results, and save all interpretation for the discussion.

### Writing a results section

IMPORTANT: You must clearly distinguish material that would normally be included in a research article from any raw data or other appendix material that would not be published. In fact, such material should not be submitted at all unless requested by the instructor.

### Content

- Summarize your findings in text and illustrate them, if appropriate, with figures and tables.
- In text, describe each of your results, pointing the reader to observations that are most relevant.
- Provide a context, such as by describing the question that was addressed by making a particular observation.
- Describe results of control experiments and include observations that are not presented in a formal figure or table, if appropriate.
- Analyze your data, then prepare the analyzed (converted) data in the form of a figure (graph), table, or in text form.

### What to avoid

- Do not discuss or interpret your results, report background information, or attempt to explain anything.
- Never include raw data or intermediate calculations in a research paper.
- Do not present the same data more than once.
- Text should complement any figures or tables, not repeat the same information.
- Please do not confuse figures with tables - there is a difference.

### Style

- As always, use past tense when you refer to your results, and put everything in a logical order.
- In text, refer to each figure as "figure 1," "figure 2," etc. ; number your tables as well (see the reference text for details)
- Place figures and tables, properly numbered, in order at the end of the report (clearly distinguish them from any other material such as raw data, standard curves, etc.)
- If you prefer, you may place your figures and tables appropriately within the text of your results section.

### Figures and tables

- Either place figures and tables within the text of the result, or include them in the back of the report (following Literature Cited) - do one or the other
- If you place figures and tables at the end of the report, make sure they are clearly distinguished from any attached appendix materials, such as raw data
- Regardless of placement, each figure must be numbered consecutively and complete with caption (caption goes under the figure)
- Regardless of placement, each table must be titled, numbered consecutively and complete with heading (title with description goes above the table)
- Each figure and table must be sufficiently complete that it could stand on its own, separate from text

## Discussion

Journal guidelines vary. Space is so valuable in the Journal of Biological Chemistry, that authors are asked to restrict discussions to four pages or less, double spaced, typed. That works out to one printed page. While you are learning to write effectively, the limit will be extended to five typed pages. If you practice economy of words that should be plenty of space within which to say all that you need to say.

### General intent

The objective here is to provide an interpretation of your results and support for all of your conclusions, using evidence from your experiment and generally accepted knowledge, if appropriate. The significance of findings should be clearly described.

### Writing a discussion

Interpret your data in the discussion *in appropriate depth*. This means that when you explain a phenomenon you must describe mechanisms that may account for the observation. If your results differ from your expectations, explain why that may have happened. If your results agree, then describe the theory that the evidence supported. It is never appropriate to simply state that the data agreed with expectations, and let it drop at that.

- Decide if each hypothesis is supported, rejected, or if you cannot make a decision with confidence. Do not simply dismiss a study or part of a study as "inconclusive."
- Research papers are not accepted if the work is incomplete. Draw what conclusions you can based upon the results that you have, and treat the study as a finished work
- You may suggest future directions, such as how the experiment might be modified to accomplish another objective.
- Explain all of your observations as much as possible, *focusing on mechanisms*.
- Decide if the experimental design adequately addressed the hypothesis, and whether or not it was properly controlled.
- Try to offer alternative explanations if reasonable alternatives exist.
- One experiment will not answer an overall question, so keeping the big picture in mind, where do you go next? The best studies open up new avenues of research. What questions remain?
- Recommendations for specific papers will provide additional suggestions.

### Style:

- When you refer to information, distinguish data generated by your own studies from published information or from information obtained from other students (verb tense is an important tool for accomplishing that purpose).
- Refer to work done by specific individuals (including yourself) in past tense.
- Refer to generally accepted facts and principles in present tense. For example, "Doofus, in a 1989 survey, *found* that anemia in basset hounds *was correlated* with advanced age. Anemia *is* a condition in which there *is* insufficient hemoglobin in the blood."

The biggest mistake that students make in discussions is to present a superficial interpretation that more or less re-states the results. It is necessary to suggest *why* results came out as they did, focusing on the mechanisms behind the observations.

## Literature Cited

Please note that in the introductory laboratory course, you will not be required to properly document sources of all of your information. One reason is that your major source of information is this website, and websites are inappropriate as primary sources. Second, it is problematic to provide a hundred students with equal access to potential reference materials. You may nevertheless find outside sources, and you should cite any articles that the instructor provides or that you find for yourself.

List all literature cited in your paper, in alphabetical order, by first author. In a proper research paper, only primary literature is used (original research articles authored by the original investigators). Be cautious about using web sites as references - anyone can put just about anything on a web site, and you have no sure way of knowing if it is truth or fiction. If you are citing an on line journal, use the journal citation (name, volume, year, page numbers). Some of your papers may not require references, and if that is the case simply state that "no references were consulted."

## Common Errors in Student Research Papers

This is not an exhaustive list. With every new lab protocol, you folks come up with the darnedest ways of messing up a perfectly good paper. However, if you heed the comments here your reports stand a much better chance of being mistaken for professionally written research papers.

### Quotes

When you write a paper related to literature, history, current events, and many other fields, direct quotes may be essential to a full discussion of the subject. In science, there is very rarely any call for a direct quote. On student papers, there is no reason at all to include direct quotes, except in the case when the student doesn't understand the concept and uses the quote to avoid having to explain it his/herself. Obviously, this doesn't go over too well with the grader. As a rule, do not use direct quotes in a scholarly technical paper. Your own thoughts must be expressed, not those of someone else.

### Verb tense

Use of the wrong verb tense, at best, is irritating to read and reflects poorly on the student's writing skills. At worst, the reader can be confused as to what facts are already known and what was newly discovered in the actual study that is the subject of the paper. As a rule, use past tense to describe events that have happened. Such events include procedures that you have conducted and results that you observed. Use present tense to describe generally accepted facts.

> *We **sought** to determine if mating behavior in Xiphophorus helleri **is** related to male tail length by placing combinations of two male fish with different length tails in the same tank with a female fish.*
>
> *We **found** that protein synthesis in sea urchin embryos treated with actinomycin D **was** considerably less than in untreated embryos. This finding agrees with the model stating that protein synthesis in 24 hour sea urchin embryos **is** dependent on synthesis of new messenger RNA.*

Reference to results of a specific study should also be in past tense.

> *Abercrombie and Fitch **reported** that 30% of the public is allergic to wool.*

Mixing tenses is even worse - this sort of thing hurts my ears. Unfortunately, the people who read the news in television and radio broadcasts are frequently unaware of verb tense at all.

> *Two guys **rob** a liquor store downtown. The robbery **occurred** at midnight last night.*
>
> *[from a newspaper article] Two inmates **hide** in trailer to escape S.C. prison.*
>
> *The last one had me puzzled. I was thinking if they know the inmates are in the trailer, why don't they just go in and get them? What the article actually reported was that the two had hidden in a trailer which was driven out of prison, allowing them to escape. I grew up speaking and reading English (the American version that is). Imagine the difficulty faced by a non-native speaker who learns proper English and then reads the local rag or tries to make sense out of reports by "talking heads" on new shows.*

### Proofread!

Incomplete sentences, redundant phrases, obvious misspellings, and other symptoms of a hurriedly-written paper can cost you. Please start your work early enough so that you can proofread it. Check spelling of scientific names, names of people, names of compounds, etc. Spelling and grammatical errors can be embarrassing. Since many very different terms have similar names, a spelling error can result in a completely incorrect statement.

When you print off your paper, please make sure that tables are not split over more than one page, that headings are not "orphaned," pages submitted out of sequence, etc. Remember, someone has to read this thing! If the reader is an editor or reviewer, you might get a rejection notice because you were too sloppy.

## Irrelevant information

### Anecdotal information

Sometimes you may feel the need to justify a statement or procedure by stating "'the instructor told us to do this instead of that." You might think it appropriate to write "we used Microsoft Excel to produce a graph of x versus y." Such information is anecdotal and is considered to be superfluous. In some cases omission of anecdotal information is unfortunate. Papers in the older literature tend to be a lot more exciting and often more informative for those not 'in the know,' because the researcher could report how a conclusion was reached, including the reasoning and various sidetracks that led him/her to conclusions. The writer could actually tell the story of the investigation process. Modern papers omit such information because the volume of literature is so great, most of us doing a search don't have time to wade through more material than we need. Publication costs are too high to permit printing of superfluous information.

A research paper summarizes a study. It does not identify who did what. Reference to instructors, fellow students, teams, partners, etc. are not appropriate, nor is it appropriate to refer to "the lab."

### Unnecessary background

If you state facts or describe mechanisms, do so in order to make a point or to help interpret results, and do refer to the present study. If you find yourself writing everything you know about the subject, you are wasting your time (and that of your reader). Stick to the appropriate point, and include a reference to your source of background information if you feel that it is important.

### Including material that is inappropriate for the readership

It isn't necessary to tell fellow scientists that your study is pertinent to the field of biochemistry. Your readers can figure out to what field(s) your work applies. You need not define terms that are well known to the intended readership. For example, do you really think it is necessary to define systolic blood pressure if your readership consists of physicians or cardiovascular physiologists?

### Subjectivity and use of superlatives

Technical writing differs from the writing of fiction, opinion pieces, scholarly English papers, etc. in many ways. One way is in the use of superlatives and subjective statements in order to emphasize a point. We simply do not use such writing styles in science. Objectivity is absolutely essential.

Subjectivity refers to feelings, opinions, etc. For example, in your discussion you might write, "We felt that the fixative was bad, because we had difficulty finding flagella on our Chlamydomonas." Another researcher is unlikely to risk time and resources on the basis of your "feeling." On the other hand, you might write, "The percentage of cells with flagella was inversely proportional to the time they spent in fixative, suggesting that the fixative was causing cells to shed flagella." This is information that another scientist can use.

Superlatives include adjectives such as "huge," "incredible," "wonderful," "exciting," etc. For example, "the mitochondria showed an incredibly large increase in oxygen consumption when we added uncoupling agent." Your definition of incredible might be different from that of someone else - perhaps a five fold increase is incredible to you, but not for the next person. It is much better to use an objective expression, such as "Oxygen consumption was five fold greater in the presence of uncoupler, which is a greater change than we saw with the addition of any other reagent."

Similarly, we don't write that we believe something. We present the evidence, and perhaps suggest strong support for a position, but beliefs don't come into play. In particular, we do not "expect" a particular set of results, or "wire" a hypothesis so that it appears that we correctly predicted the results. That sort of practice is another example of lack of objectivity.

**Proof**

See my essay on fact, hypothesis, and theory. The requirements for scientific proof are extremely rigorous. It is highly doubtful that any single experiment can be so well controlled that its conclusions can be regarded as proof. In fact, for any result to be accepted it must be confirmed independently. In fact, we can never know if a model as we describe it presents an accurate picture of any natural process. We can never look at the original blueprint to check our conclusions. So... your data may strongly support a position, or they may allow you to reject a hypothesis, but they aren't likely to provide anything close to proof.

**Grammar and spelling**

Please avoid obvious grammatical errors. Granted, you aren't writing an English paper (heck, an English teacher would tear my own writing style to shreds). However, clear written communication requires proper sentence structure and use of words. Make sure that your sentences are complete, that they make sense when you proofread, and that you have verb/subject agreement.

Spelling errors in a paper make you look amateurish. For example, *absorbance* is read from a *spectrophotometer*. You don't read *absorbency*from a *spectrometer*. Worse, they can change the entire meaning of your writing. One letter changes the chemical compound you describe. I know the action of *cycloheximide* in eukaryotic cells, but I do not know the action of *cyclohexamide*.

**Inaccurate word or phrase**

> *Changing temperature had the following affect on the subject.*

'Affect' is a verb. 'Effect' is a noun. What happened to the subject was an effect. The temperature change affected the subject. Please learn the difference.

> *The data lead to the assumption that x has no relationship to y.*

If you base a conclusion on data, then your conclusion is a deduction, not an assumption. In fact, in experimental science assumptions are usually avoided. A purpose of controls is to eliminate the need to assume anything.

> *Our inability to ensure that all cells in the population were in the same stage of development skewed our data.*

This statement doesn't reveal very much. The writer intended to say that the data points were more scattered, that is, the non-uniformity of the population resulted in unacceptably high experimental error. The word 'skew' means 'having an oblique position; turned or twisted to one side; slanting; sloping.' It can be used as an adverb or noun as well. In statistics, the word refers to an asymmetric distribution of data. Nowhere in the definition is there any reference to the state of being incorrect or more scattered. Thus, not only is the word overused, it is also misused.

> *We rationalized the finding that blocking the sodium pump had no affect on uptake of glucose by suggesting that the symport mechanism depends solely on the sodium gradient, which persists long after the pump is shut down.*

A definition of 'rationalize' is 'to explain or justify.' Another is 'to attribute logical or creditable motives to actions that result from other, perhaps unrecognized, motives.' In short, to make excuses. As I learned in English class a long time ago, the term's principal usage is to attempt to justify something on dubious grounds. For example, 'he rationalized his poor behavior by saying that he had just broken up with his girlfriend and was distraught.' The definition does not include anything about the explanation being valid, therefore another word would be preferable. Try

> *A likely explanation for the finding...is that...*

The word 'data' is plural. However since investigators usually refer to sets of data, there is a tendency to use the word as though it was singular. Hence a writer will state, 'the data was affected by the phase of the moon,' or 'the data suggests that phase of the moon has no effect on mood.' As awkward as it may seem to you, the proper phrases are, 'the data *were* affected...,' and 'the data *suggest*...' By the way, the singular form is 'datum.'

**Oversimplification**

> *We used a spectrophotometer to determine protein concentrations for each of our samples. We used an oscilloscope to measure resting potentials in crayfish muscle.*

The spectrophotometer or oscilloscope may be a novel, mysterious, and versatile device to you, but I suspect that even an expert biochemist would have a hard time finding a protein concentration using only a spectrophotometer. The first statement leaves out the dye reagent, standards, pipettors, etc. that are required to perform the assay. The second statement omits any reference to the micropipets or the specialized electronic instrumentation that is required in order to measure transmembrane potentials.

What information did you intend to convey? If you intend to describe the methodology, then write a complete description. If you intend only to summarize the procedures then you might seek a phrase that sums up what was done without oversimplifying. For example, "We used a colorimetric assay to determine protein concentrations in each of our samples." Or, "We measured resting membrane potentials using KCl-filled micropipets with a microprobe system from [supplier and/or reference].

**Superficiality**

The purpose of a discussion is to interpret the results, not to simply state them in a different way. In most cases a superficial discussion ignores mechanisms or fails to explain them completely. It should be clear to the reader why a specific result came to pass. The statement, "The result agreed with the known theoretical value," tells us nothing about the mechanism(s) behind the result. What is the basis for expecting a particular result? Explanations may not be easy and your explanation may not be correct, but you will get most or all of the available credit for posing a reasonable explanation, even if it is not quite right. Superficial statements, on the other hand, will cost you.

### Anthropomorphism

Sometimes you cannot easily find the right wording in order to explain a cause and effect relationship, or you may not understand the concept well enough in order to write an explanation. Anthropomorphism is a type of oversimplification that helps the writer avoid a real explanation of a mechanism. A couple of examples should make the point for you.

*Sodium wants to move down the chemical gradient toward the compartment with the lower concentration.*

The thought behind the statement is correct, but the statement does not represent the correct mechanism. Sodium has no free will. It tends to move toward the compartment with lower concentration because the probability of a sodium ion moving through a channel on the more concentrated side of the membrane exceeds the probability that an ion will move through a channel on the less concentrated side. If you don't want to explain the principle behind osmosis, you can simply state that osmotic pressure tends to drive sodium from the more highly to less highly concentrated side of a membrane.

*The ETS works furiously in a vain attempt to restore the chemiosmotic gradient*

Wow. Well, the adverb "furiously" is not only subjective, but it normally applies to a deliberate action. We know that the ETS (electron transport system) is a set of carrier complexes embedded in a membrane, and that it cannot be capable of a deliberate action. Something that cannot act deliberately cannot think, either. There is a physical cause and effect relationship between the ETS and the chemiosmotic gradient that does not require attributing a free will to any part of the system.

### Common mistakes in reporting results

*Converted data* are data that have been analyzed, usually summarized, and presented in such a way that only the information pertinent to the objectives of the study is presented. *Raw data* refers to results of individual replicate trials, individual observations, chart records, and other information that comes directly from the laboratory.

Once you have presented converted data, do not present the same data in a different way. For example, if the data are plotted, then don't include a table of data as well. Present a figure (such as a graph) if appropriate. If the data are better represented by a table, then use a table. The caption with any figure or table should include all pertinent information. One should not have to go into the body of the paper to find out the results of statistical tests on the data, or the rationale behind a curve fit.

Raw data are not usually included in your results. Raw data include lists of observations, meaurements taken in order to obtain a final result (e.g., absorbance, relative mobility, tick marks on a microscope reticule).

Use an appropriate number of decimal places (if you need decimal places at all) to report means and other measured or calculated values. The number of decimal places and/or significant figures must reflect the degree of precision of the original measurement. See our analytical resources for information on uncertain quantities and significant figures. Since the number of significant figures used reflects the level of precision of the measurement or calculation, there is never any need to qualify a measurement or calculation as 'about' or 'approximate.'

Graphs and other pictures that represent data are called figures, and are numbered consecutively. Tables are distinguished from figures, and are numbered consecutively as well. For example, a paper with two graphs, a reproduction of a segment of chart record and two tables will have figures 1, 2, and 3, and tables 1 and 2. Do note that I distinguished graphs from chart records. Not everything with gridlines is a graph. Graphs are analytical tools. Chart records are raw data (which may be presented in results as an example, if appropriate).

Do not draw conclusions in the results section. Reserve data interpretation for discussion.

**The significance of 'significance'**

We have a statistically significant difference when analysis yields a very low probability that the difference was due to sampling error (random error) alone. If sufficient data are collected, and statistical significance is not achieved, the investigator can conclude that the null hypothesis is supported ñ there is no significant difference.

Lack of a significant difference does not mean that the result itself is insignificant. A finding, for example, that there are no intrinsic differences in fundamental mathematical ability among racial groups would be a very significant finding. Significance in this study refers to the importance of the result. "It is significant that we found no significant differences among the groups studied" is a valid, though perhaps confusing, statement.

There is a tendency among students to reject a study as inconclusive just because no statistically significant differences were found. Such rejection suggests a misunderstanding of the scientific method itself. You can conclude something from even the most poorly designed experiments. In fact, most well-designed experiments result in support for the null hypothesis. Be prepared to interpret whatever you find, regardless of what you think you should find. The purpose of experimental science is to discover the truth - not to make the data conform to one's expectations.

## Writing and Analytical Resources

As reference materials, the pages presented here are generic in nature rather than course specific. They include universal truths and practices, and are used not only in this course but by other courses in the program and even by programs elsewhere.

**Analytical resources**

All of the analytical resources were developed for the natural sciences and engineering laboratory program and are shared by multiple courses in several disciplines. These shared resources are written as portable document files (pdf) and are stored on a different server from the one supporting this course web site. When you follow a link to such a file it should appear in a new window.

- [Dimensions and units] Examples of dimensions, units, and dimensionless quantities; conventional choices for units; using prefixes; dimensional consistency; units conversion
- [Fundamentals of graphing] overview; purpose, data, and variables; anatomy of a graph; scales, axes, and proportions; symbols, error bars, and fit lines; labels, legends, and captions; computer graphics
- ["Graphical errors"] To plot or not to plot; a set of common mistakes; misleading scales; computer fits; guiding experimentation; transformation of variables
- [Example: plotting data with a computer program (Microsoft Excel] Program default; about line graphs and curve fitting; add essentials, remove non-essentials; proportion and orientation
- [Error analysis and significant figures] Significant figures; absolute and relative errors; systematic errors; random errors; estimating random errors; propagation of errors

- [Error representation and curvefitting] When to report random error; representing random error (assumptions, errors to use, reporting data in text or tables, representation with error bars); curvefitting (trendlines, true curvefiting)

## Keeping a laboratory notebook

This section presents guidelines and examples for starting and keeping a laboratory notebook in the introductory laboratory course. Requirements are probably more rigid than what would be expected for a notebook in a typical academic research laboratory. On the other hand, they are definitely less rigid than requirements for recordkeeping in a research department in industry, or for any type of proprietary research for that matter.

### Research papers

The guidelines presented on these pages would apply to a typical manuscript to be submitted for publication in a scientific journal. The specifics do not necessarily apply to all journals, however the guidelines do introduce and reinforce the need to follow editorial requirements and adhere to general principles for effective writing. Each part of a journal article accomplishes a specific and unique purpose, allowing a person to read selectively. Such writing is good practice for specialized forms of written communication that will very likely be expected of the student some time in the future.

### Statistical methods

This section addresses very specific objectives. It introduces the importance of statistical methods in addressing the uncertainty contributed by experimental error. Probability values and hypothesis testing are introduced using only two types of statistical tests as examples: 'Student's t-test and the Chi-squared goodness of fit test.'

> **Experimental error**: Under "Analytical resources," review "error analysis and significant figures" and "error representation and curvefiting."
> **Statistical tests**: [Unpaired (independent) t test] [paired t test] [Chi-squared test] [sample problems] [solutions to sample problems]
> **Tables**: ['Student's' t distribution] [Chi-squared critical values]

### Selected Statistical Methods for the Biosciences

*Errors using inadequate data are much less than those using no data at all. --- Charles Babbage (1792-1871)*

Statistics are designed to draw conclusions from data that are subject to experimental error. When replicate sampling is necessary, a carefully chosen statistical analysis can save the investigator the trouble of performing unnecessary experiments, or the embarrassment of drawing a premature or inappropriate conclusion. Statistics generally yield a probability value for a particular outcome. As a rule, scientists accept a probability of 0.05 or less as convincing evidence that a particular outcome is unlikely.

Information on selected types of statistical analysis is presented on these pages. Do not expect a rigorous explanation of the theory behind each type of analysis. The articles will focus on an understanding of the principles behind the analyses, and on their proper use.

### Guidelines for Keeping a Laboratory Record

*If you have build a perfect demonstration do not remove all traces of the scaffolding by which you have raised it.*
*Clark Maxwell*

The following is a general description of how to keep a proper laboratory notebook. Requirements for different teaching, research, clinical, or industrial labs will most likely vary. Some institutions/labs will require less stringent record keeping, others will hold you to a very strict protocol. A well kept notebook provides a reliable reference for writing up materials and methods and results for a study. It is a legally valid record that preserves your rights or those of an employer or academic investigator to your discoveries. A comprehensive notebook permits one to reproduce any part of a methodology completely and accurately.

**Choosing a notebook**

For most purposes you may select a *bound* notebook, quadrille-ruled. A teaching lab may require tear-out duplicate pages for making carbon copies. An engineering or industrial research/development lab will likely require a specific type notebook with prenumbered pages and places for date and investigator's and supervisor's signatures on each page. Pads of tear-out graph paper or spiral bound notebooks without pre-numbered pages are not acceptable. It must be impossible to tear out a page without leaving evidence. It is safest to select something that is clearly labeled as a *laboratory* notebook.

**Preparing the Notebook**

Please use a ball point pen for all entries, so that the marks will not smear nor will they be erasable.

Put your name, a telephone number and/or address, and project name or course number on the outside front cover of the record. Put that same information on the first page inside, or on the inside front cover. If your notebook does not include a prelabeled table of contents section, then reserve the next several pages for a table of contents by labeling the top of each page as *Table of Contents* and numbering each page. If your notebook does not have prenumbered pages, you may wish to use lower case Roman numerals, as in a standard publication. Next, number the next several pages with Arabic numerals in sequence, and you are ready to begin recording data.

**What to enter**

Above all, it is critical that you enter all procedures and data directly into your notebook in a timely manner, that is, while you are conducting the actual work. Your entries must be sufficiently detailed so that you or someone else could conduct any procedure with only the notebook as a guide. Few students (and not that many researchers for that matter) record sufficiently detailed and organized information. The most logical organization of notebook entries is chronological. If a proper chronological record is kept and co-signed by a coworker or supervisior, it is a legally valid record. Such a record is necessary if you or your employer is to keep your rights to your discoveries.

Depending on requirements set by a teacher, superivsor, company, or whatever, you may not have to confine your notebook entries to lab notes only. On the other hand a student might record your class lecture notes, lab lecture notes, ideas, questions, library research notes, and notes that are part of any pre-lab preparation. The bare minimum entries for an academic lab course, for each lab study, should include title of the lab study; introduction and objectives; detailed procedures and data (recorded in the lab itself); summary.

We usually record a lot more information in a laboratory notebook than we would report in a research paper. For example, in a published article we don't report centrifuge type, rpm, rotor type, or which machine was used. However, if a procedure is unsuccessful you may want to check to see that you used the correct rpm or correct rotor. Perhaps the centrifuge itself was miscalibrated. You would need to know which machine you used. In a research paper one does not report which person performed which tasks, because such information is useless to a third party. However in the notebook it is important to note who was responsible for what procedure. Again, you may need such information to troubleshoot your experiments.

**Making entries**

Someone else may need to consult your notebook sometime, so please make your entries clear and legible.

When you make your first entries of the day, start by entering the date, writing out the month or abbreviation for the month (e.g., 5 Apr '04, or April 5, 2004, but not 4/5/04). The use of numerals only can cause confusion. For example, in Europe the day comes before the month. Thus April 5, 2004 would be written as 5/4/04. When you start each new page of a notebook enter the date next to the page number. Each page should be numbered and dated consistently. Most of us use the upper right corner of each page for date and page number.

Depending on how your notebook is designed you may choose whether or not to use the backs of pages. If you leave them blank, put a corner-to-corner line through them to void all blank spaces. Some people use the backs for rough calculations, then void remaining blank space. You might also decide to save space (and trees) and use both sides of each page. Obviously you cannot use both sides with notebooks that are designed to make duplicate copies. In situations where you turn in duplicate copies to a supervisor, you obviously must start each new set of entries on a new page.

Write a title for each and every new set of entries. Distinct sets of entries should be separated by using informative headings and by leaving a single space or two between individual sets of entries. Specific information can be more readily located that way. For a new laboratory study, write down a *very brief* introduction to the study, and list the objectives. If you have a specific hypothesis, write it down. The object is to make it completely clear what you intend to do.

Record everything you do in the lab, even if you are following a published procedure. For example, if you started by obtaining a quantity of tissue from an instructor, then write down that you obtained tissue, describe it, note how much, what condition, etc. How much you write down is up to you, but any *relevant* information should be there. For example, it doesn't matter much if you received a chunk of liver in a red ice bucket or a black one. However, it *does* matter that the material was on ice. **If you change a protocol in any way or decide between alternative methods, then the correct information must be recorded in the notebook.** For example, a protocol for tissue fractionation may recommend centrifugation at 9400 x g, but we may decide to use 12,000 x g in the lab. The correct g force must be noted.

If you make a mistake, put a line through the mistake and write the new information next to it. *Never* erase or obliterate an entry. When you finish a page, put a corner-to corner line through any blank parts that could still be used for data entry. Every bit of every page must be legible and filled, either with information or with a mark that voids the section (see examples).

**The summary**

When you have finished a project, summarize what you have accomplished. You don't have to draw conclusions, just indicate what sort of data or observations you collected, samples you saved (and where and how you saved them), or any other relevant information that wraps up the study. For a continuing study keep the summary extremely brief. In fact, if the notes are well organized and it is obvious where the study left off, you need write nothing more than "To be continued..." Summaries help maintain continuity. They indicate where the work left off and how it might resume.

# Writing Research Papers

## Organization

### Doing two things at once?

What if you are conducting two long procedures at once, each with long waiting periods? For example, suppose you are conducting a protein assay and preparing a gel for your samples out in the laboratory. Back in the cell culture room, you are harvesting and processing tissues for primary culture. Both procedures involve waiting periods, yet you will complete both tasks by the end of the day.

Simply use your best judgment. You could divide each page into columns and keep your two records side-by-side. You might date two consecutive pages, keeping both records separately. In either case, when you leave the laboratory for the day cross out any unused parts of a page that precede the last entry.

### Continuation pages

What if you need more than one page for a project? With continuing research, that will always be the case. Proper use of continuation notes makes it possible to follow your path through a long experiment or series of experiments without having to leaf through every page of your notebook.

For example, let's say you labeled some protein samples with the radioisotope S-35, ran a gel, and placed the gel in a film cassette in order to produce an autoradiograph. During the two days your film is in the freezer, you devote all of your time to a cloning project that is part of an unrelated study. After you put your film cassette in the freezer, simply write *Continued, page* ___, then enter the date and title of your other project, and continue to record information.

When you resume work on the protein samples, enter the date, write *Continued from page* ___, and enter your autoradiography results. This way, everything you do in the laboratory is recorded chronologically, yet someone interested in following your progress could start from the beginning and follow every procedure on just that one study, from start to finish.

### Are things getting too sloppy?

Perhaps your data records are scattered throughout the notebook, and you would like to summarize them. Go ahead. You may re-enter tables or figures any time you wish to organize your work a bit better. To prevent confusion over duplication of data you may put a line through a table or figure you intend to re-draw, initial and date the change, and note the page on which the re-organized data can be found. Just don't obscure any of the original entry.

### Repeated procedures

So far you have been advised to record each step you perform in the laboratory, regardless of whether the procedure is published somewhere. However, once you carry out a procedure, you can refer to that part of your notebook, and only note changes you make. For example, the first time you prepare a sequencing gel you should write down the exact formulation, how you mix the gel, how long you let it cure, etc. The next time, just refer to the name of the procedure and the appropriate page(s) of your notebook.

### Loose materials

Suppose you enter raw data into a computer and have a printout with 400 pieces of data. Or, suppose you generate a graph using a software program. You might even have a silver-stained gel that you wish to refer to frequently, or a fluoroescence photomicrograph that sums up your results nicely. Some investigators prefer to attach such materials to the notebook itself, but too many such items make a sloppy notebook and can stress the binding. Loose data should be kept in a separate folder or notebook, with location noted in the book.

### Table of Contents

Record all entries in the table of contents as you go along. You can organize it anyway you like but it is advisable to include multiple levels in a table of contents, that is, indicate where a new study starts and include subheadings for specific parts of a study, methods, sets of data, etc. The idea is to enable someone (such a supervisor, grader, or yourself a year from now) to find anything quickly. List each set of entries with dates and page numbers. If you are seriously anal-retentive, you might record every experiment in chronological order, than use the remaining blank space to cross reference the contents experiment by experiment.

For a teaching lab you might list each and every set of entries made in your notebook, in chronological order, including complete and informative titles. Examples of sets of entries include an introduction, a summary, a set of procedures for a specific preparation, a complete data set, calculations for diluting samples or preparing assay standards, etc. A grader should be able to find any specific entry quickly, without flipping through pages.

### Notebook Checklist

As you record your activities in the laboratory, ask yourself, "Did I..."

- Keep up with the table of contents?
- Date each page?
- Number each page consecutively?
- Use continuation notes when necessary?
- Properly void **all** blank pages or portions of pages (front and back)?
- Enter all information **directly** into the notebook?
- Properly introduce **and** summarize each experiment?
- Include complete details of all first-time procedures?
- Include calculations?


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*Updated 20 Aug 07*

## Selekted Riting Wrules

**Okay — so we don't always have to be serious. It's about time I found a good use for some of the internet jokes that appear on the e-mail in box.**

1) Verbs HAS to agree with their subjects.
2) Prepositions are not words to end sentences with.
3) And don't start a sentence with a conjunction.
4) It is wrong to ever split an infinitive.
5) Avoid cliches like the plague. (They're old hat)
6) Also, always avoid annoying alliteration.
7) Be more or less specific.
8) Parenthetical remarks (however relevant) are (usually) unnecessary.
9) Also too, never, ever use repetitive redundancies.
10) No sentence fragments.
11) Contractions aren't necessary and shouldn't be used.
12) Foreign words and phrases are not apropos.
13) Do not be redundant; do not use more words than necessary; it's highly superfluous.
14) One should NEVER generalize.
15) Comparisons are as bad as cliches.
16) Eschew ampersands & abbreviations, etc.
17) One-word sentences? Eliminate.
18) Analogies in writing are like feathers on a snake.
19) The passive voice is to be ignored.
20) Eliminate commas, that are, not necessary. Parenthetical words however should be enclosed in commas.
21) Never use a big word when a diminutive one would suffice.
22) Use words correctly, irregardless of how others use them.
23) Understatement is always the absolute best way to put forth earth-shaking ideas.
24) Eliminate quotations. As Ralph Waldo Emerson said, "I hate quotations. Tell me what you know."
25) If you've heard it once, you've heard it a thousand times: Resist hyperbole; not one writer in a million can use it correctly.
26) Puns are for children, not groan readers.
27) Go around the barn at high noon to avoid colloquialisms.
28) Even IF a mixed metaphor sings, it should be derailed.
29) Who needs rhetorical questions?
30) Exaggeration is a billion times worse than understatement.

**And the last one...**

**31)** Proofread carefully to see if you any words out.