Odom Group: Writing a Paper

What is a scientific paper? A paper is an organized description of hypotheses, data, and conclusions, intended to instruct the reader. Papers are a central part of research. If your research does not generate papers, it might just as well not have been done. *"Interesting and unpublished"* is equivalent to "*non-existent*."

Realize that your object in research is to formulate and test hypotheses, to draw conclusions from these tests, and to teach these conclusions to others. Your objective is not to "collect data."

A paper is not just an archival device for storing a completed research program, it is also a structure for planning your research in progress. If you clearly understand the purpose and form of a paper, it can be immensely useful to you in organizing and conducting your research. **A good outline for the paper is also a good plan for the research program.** You should write and rewrite these plans/outlines throughout the course of the research. At the beginning, you will have mostly plan; at the end, mostly outline. The continuous effort to understand, analyze, summarize, and reformulate hypotheses on paper will be immensely more efficient for you than a process in which you collect data and only start to organize them when their collect is "complete."

The reason for outlines. The outline is central in writing papers, preparing seminars, and planning research. It is most efficient to write papers from outlines. An outline is a written plan of the organization of a paper, **including** the data on which it rests. You should think of an outline as a carefully organized and presented set of data, with attendant objectives, hypotheses and conclusions, rather than an outline of text.

An outline itself contains little text. If we agree on the details of the outline (i.e., the data and organization) the supporting text can be assembled fairly easily. If we do **not** agree on the outline, any text is useless. Much of the time in writing a paper goes into the text; most of the thought goes into the organization of the data and into the analysis. It can be relatively efficient in time to go through several cycles of an outline before beginning to write text; writing many versions of the full text of a paper is slow.

How should you construct an outline? The classical approach is to start with a blank sheet of paper and write down, in any order, all important ideas that occur to you concerning the paper. Ask yourself the obvious questions: *Why did I do this work? What does it mean? What hypothesis did I mean to test? What ones did I actually test? What were the results? Did the work yield a new method or compound? What measurements did I make? What compounds? How were they characterized?* Sketch possible equations, figures, and schemes. It is essential to try and get the major ideas. If you start the research to test one hypothesis, and decide, when you see what you have done, that the data really seem to test some other hypothesis better, don't worry. Write them both down, and pick the best combinations of hypotheses, objectives and

data. Often the objectives of a paper when it is finished are different from those used to justify starting the work. **Much of good science is opportunistic and revisionist.**

When you have written down what you can, start with another piece of paper and try to organize the jumble of the first one. Sort your ideas into three main categories:

1. **Introduction**
    a. Why did I do the work?
    b. What were the central motivations and hypotheses?
2. **Results and Discussion**
    a. What were the results?
    b. How were the compounds made and characterized?
    c. What was measured?
3. **Conclusions**
    a. What does it all mean? What hypotheses were proved or disproved?
    b. What did I learn? Why does it make a difference?

Next take each of these sections and organize it on yet a finer scale. Concentrate on organizing the data. Construct figures, tables, and schemes to present the data as clearly and compactly as possible. This process can be slow—often it takes 5-10 times in different ways to try to decide what is the most clear (and aesthetic).

Finally, put everything—outline of sections, tables, sketches of figures, equations—in good order.

When you are satisfied that you have included **all** the data (or that you know what additional data you intend to collect), and have a plausible organization, give the outline to me. Simply indicate where missing data will go, how you think (hypothesize) they will look, and how you will interpret them if your hypothesis is correct. I will take this outline, add my opinions, suggest changes, and return it to you. It usually takes 4-5 iterations (often with additional experiments) to agree on an outline. When we have **agreed**, the data are usually in (or close to) final form (that is, the tables, figures, etc., in the outline will be the tables, figures, etc., in the paper.)

You can then start writing with some assurance that much of your prose will be used.

The key to efficient use of your time and my time is that we start exchanging outlines and proposals as early in a project as possible. **Do not wait until the collection of data is "complete" before starting to write an outline.** No project is ever complete, and it saves enormous effort and much time to propose a plausible paper and outline as soon as you see the basic structure of a project. Even if we decide to do significant additional work before seriously organizing a paper, the effort of writing an outline will have helped to guide the research.

The Outline

1. **Title.**

2. **Authors.**

3. **Abstract.** Do **not** write an abstract. That can be done when the paper is complete.

3a. Journal. Propose some journals for which you think the work is appropriate.

4. **Introduction.** Ideally, this section should state concisely the objective of the work, and indicate why this objective is **important**. Include:
    - ***Objectives.*** The objectives of the work.
    - ***Motivation.*** Why is the work important?
    - ***Background.*** Who else has done what? How?
    - ***Guidance to the reader.*** What should the reader watch for in the paper? What are the interesting high points? What strategy did we use?
    - ***Summary conclusion***. What should the reader expect as a conclusion?

    The first paragraph or two should be written out completely by the third or fourth outline. Pay particular attention to the opening sentence.

5. **Results and Discussion.** The results and discussion are usually combined. This section should be organized according to major topics. The separate parts should have subheadings in boldface to make this organization clear, and to help the reader scan through the final text to find the parts of interest. The following list includes examples of phrases that might plausibly serve as section headings:
    - Synthesis of Alkane Thiols
    - Characterization of Monolayers
    - Dependence of the Rate Constant on Temperature
    - The Rate of Self-Exchange Decreases with the Polarity of the Solvent

    Try to make the section headings as specific and information-rich as possible. For example, the phrase “The Rate of Self-Exchange Decreases with the Polarity of the Solvent” is obviously longer than “Measurement of Rates” but is much more useful to the reader.

    In general, try to cover the major common points:
    - Synthesis of starting materials
    - Characterization of products
    - Methods of characterization
    - Methods of measurement
    - Results

Important: in the outline, do not write any significant amount of text, but get all the data in their proper place. Any text should simply indicate what will go in that section. In this section of the outline, be sure to include:

- Section Headings
- Figures (**with** captions)
- Schemes (with captions and footnotes)
- Equations
- Tables (correctly formatted)

Remember to think of a paper as a collection of experimental results, summarized as clearly and economically as possible in figures, tables, equations, and schemes. The text in the paper serves just to explain the data, and is secondary. The more information that can be compressed into tables, equations, etc., the shorter and more readable the paper will be.

6. **Conclusions.** In the outline, summarize the conclusions of the paper as a list of short phrases or sentences. ***Do not repeat what is in the Results section unless special emphasis is needed.*** The conclusions section should be just that, and not a summary. It should add a new, higher level of analysis, and should indicate explicitly the **significance** of the work. You should address explicitly six questions:
    - What is new?
    - Why is it important?
    - To whom?
    - Advantages of your work
    - Disadvantages of your work
    - Implications of your work

In Summary:

- Start writing possible outlines for papers **early** in the project. Do not wait until the "end" since it may never come.
- Organize the outline and paper around easily assimilated data—tables, equations, figures, schemes—rather than around text.
- Organize in order of importance, not in chronological order. An important detail in writing papers concerns the weight to be given to topics. Neophytes often organize a paper in terms of chronology; that is, they give a recitation of their experimental program, starting with their cherished initial failures and leading up to a climactic successful finale. ***This approach is completely wrong. Start with the most important results***, and the put the secondary results later, if at all. The reader usually does not care how you arrived at your big results, only what they are.

Some Points of Style

1. **Do not use nouns as adjectives.**

NOT	BUT
ATP formation	formation of ATP
Reaction product	product of the reaction

2. **The word "this" must always be followed by a noun so that its reference is explicit.**

NOT	BUT
This is a fast reaction	This reaction is fast
This leads us to conclude	This observation leads us to conclude

3. **Describe experimental results uniformly in the past sense.**

NOT	BUT
Addition of water gives product	Addition of water gave product

4. **Use the active voice whenever possible.**

NOT	BUT
It was observed that the solution turned red.	The solution turned red. OR We observed that the solution turned red.

5. **Complete all comparisons.**

NOT	BUT
The yield was higher using bromine.	The yield was higher using bromine than chlorine.