Designing and Recording Laboratory Experiments
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Laboratory experiments allow scientists to test hypotheses, observe scientific phenomena, and discover relationships. Most experiments consist of the following steps:

1. Forming a hypothesis that predicts *what* will occur, or that describes *why* or *how* something occurs.
2. Designing an experiment to test the hypothesis
3. Performing the experiment
4. Recording the data and observations
5. Summarizing the results and communicating them to other scientists

1 Experimental Design

Obviously, the better an experiment is designed, the easier it is to perform the experiment, obtain data, and draw conclusions. Most successful experiments are the result of careful planning, attention to detail, multiple attempts, and learning from past mistakes. The more careful you are about designing and performing your experiments, the more sense your results will make, and the easier it will be to describe your experiment in a report.

Chemistry experiments generally involve the use of specific laboratory techniques applied in a manner that enables the researcher to collect data. Researchers should therefore understand and be comfortable with techniques before using them in an experiment.

1.1 The Goal or Objective

This should be obvious, but you should have a goal or objective in mind before you plan your experiment. Every step of the experiment should take you closer to achieving the goal.

As you are designing your experiment, you may think of extra steps or measurements you can perform along the way that will give you additional useful data, even if those data don't meet the primary goal of the experiment. When this happens, you have two options:

1. Add secondary goals to the experiment. If you do this, you will need to re-visit your experimental plan to make sure all of the necessary elements are there to meet your secondary goals, as well as the primary goal.

2. Use the secondary goals to design future experiments. If the secondary goals end up making the experiment too large or complex, or make it more difficult to obtain the data you need, it's a sign that you need to turn these secondary goals into a separate experiment.

1.2 The Experimental Plan

Your experimental plan, is an overview or "scheme" for the experiment—usually an outline or flow chart describing what you intend to do. The better you can understand and keep track of the flow of your experiment, the less likely you will be to lose your place and miss an important detail or data point.

1.3 Performing the Experiment

The carpenter's adage, "Measure twice; cut once." applies to lab experiments. Because you will be performing your own experiment (and not somebody else's from their detailed write-up), you will not have a step-by-step procedure to make sure you haven't forgotten anything. Before you perform each step, double-check:

1. Am I in the right part of my plan?
2. Is there anything I need(ed) to do before this step?
3. What will I be doing next? Should I do anything special in this step to set myself up for the next step?
4. Am I ready to record the procedure and data?

When you believe you have finished performing your entire experiment, go back and re-read your objective and plan to make sure you haven't left anything out.

Recording the Procedure

By the time you have finished your experiment, you need to have a detailed record of everything you did. As you perform each step, be sure that you have recorded all of details you think may be relevant before going on to the next step. (In a closely-timed experiment, you may want to write out the steps for the timed part before performing them, and then make any corrections as you go.)

Read over your procedure while it is still fresh in your mind (between the time you finish your experiment and the end of the day) so that you can add any missing details before you forget them.

Taking Data

The success of your experiment relies on the data and observations that you record. *Every* detail that you think might possibly be significant should be recorded in your notebook. After you finish your experiment, glance over your data tables to make sure you haven't missed any data points.

1.4 Analysis

After your experiment is complete and you have finished filling in the details of your procedure and data points, you are ready to begin analyzing your data. In general, your analysis will be whatever you need to do to use your data to answer your objective. If the experiment involved measurements, the data analysis will usually involve calculations and error analysis.

Your analysis should also consider any possible sources of error (especially any errors that you believe actually occurred), considerations to keep in mind the next time you perform a similar experiment, and suggestions for future related experiments.

2 The Laboratory Notebook

You will record your data and observations in a laboratory notebook. We will use the same same principles and guidelines for laboratory notebooks that are used in colleges and in industry. The purpose of a laboratory notebook is to show *exactly* what you did and when you did it, in case you need proof to back up a claim of a new discovery or to patent an invention.

Your lab notebook must be a separate notebook. (*I.e.,* you may not use one section of a multi-subject notebook.) It should have the pages bound into it in a way that they cannot be easily removed (such as a composition notebook). Composition notebooks are ideal; loose-leaf notebooks are not acceptable.

2.1 Goals

Your laboratory notebook is a diary of your experiment. The goal of a laboratory notebook is to be able to go back to it later to answer *any* question you might have about the experiment.

Every teacher, professor, manager, boss, or company has specific laboratory notebook formats and guidelines. Not only isn't there any one right way to keep a lab notebook, there isn't even a compromise format that will satisfy *almost* everyone. As you are getting used to using a laboratory notebook, keeping the *goals* in mind instead of the specifics of the particular format will make it a lot easier to adapt to someone else's style in the future.

In this class, the sections of your lab notebook write-up will exactly follow the steps of designing an experiment, because the most important elements you will want to recall about an experiment are usually the ones that went into designing it:

- What were the objectives of the experiment?
- What was the overall plan?
- What, exactly, did I do? (*I.e.,* what were the specific details?)
- What actually happened? What did I observe? What did I measure?
- What could I conclude from the data? What are the results of any calculations based on the data?
- How well did the experiment meet the objective? What went wrong? What should I do differently next time?

2.2 Sections

To make it easy to find information, you will want each experiment to be recorded in an organized fashion. For this class, we will use the following system:

Title

The title of the experiment and the date should appear at the top of the page where the experiment starts. A good title should describe the relationship between the independent and dependent variables. (For example, "The Effects of ______ on ______".)

Objective

This is a short description of what you are trying to do. Your description can be words, chemical reactions, diagrams, or a combination of all of these. If you are testing a hypothesis, you would state the hypothesis in this section. The only requirement is that anyone knowledgeable about chemistry must be able to tell from looking at this section what your intent was. This section can also include your motivations (why you are doing the experiment), if they are relevant.

Overview/Plan

This is a short description of how you intend to accomplish your objective. It should *not* be a *detailed* step-by-step procedure, though it should give a basic overview of the procedure you intend to use. This section can include an outline, flow chart, and/or labeled diagram(s).

Relevant Information

This optional section is a place to list any information you might want to have readily at hand during your experiment, such as physical constants or other data about the compounds and materials that you are working with. For example, if you were doing a calorimetry experiment to determine the specific heat of an unknown metal, you would include the specific heat of water, so you would have it handy for your calculations.

Procedure

You will write this section *as you perform the experiment*. It needs to include:

- the names of your lab partners
- the names, concentrations, and quantities of each substance that you used. (In industry, you would also include the manufacturer and grade of each chemical.)
- the name & description of any major equipment used, where "major" means anything larger than an electronic balance. (In industry, you would also include the manufacturer and model number for major equipment.)
- a detailed description of each step *exactly as it is performed*.

Because this is the only time you will actually write the detailed description of your procedure, you need to allow yourself enough time to write down each step before going on to the next one. Do not leave anything for later, because you are likely to forget important details.

Data & Observations

You will also write this section as you perform the experiment. It needs to include everything you think might be relevant to your experiment.

In general, it is easiest to create a table for recording data. Most data tables should be set up so that the columns represent each of your independent and dependent variables, and the rows represent each data point.

Record all analog measurements to one more (estimated) decimal place than the finest marking. For example, if you have a graduated cylinder that is marked to the nearest 1 $m\ell$, you would estimate and record the volume to the nearest 0.1 $m\ell$. (If the last digit is zero, be sure to record it, as it is significant.)

You can record observations either in the data table, or in a separate section. If observations in a separate section refer to entries in a data table, be sure to include some sort of cross-reference.

Note that you do not have to use complete sentences or worry about spelling or grammatical errors in this section, though it does need to be legible and comprehensible. The goal is for anyone reading this section to be able to verify *exactly* what you did, and *exactly* what happened, with a minimum of assistance or explanation from you.

Analysis

You will write this section after completing the experiment. As described above, this section includes everything you need to answer your objective, using your data. If the experiment involved measurements, this section will include calculations from the experiment (show all work) and your experimental yield (if relevant).

You should always round your calculations off to the appropriate number of significant figures. Keep a minimum of one extra digit during your calculations to minimize accumulated round-off errors. If published data are available, you should always reference the published data and calculate your percent error.

Your analysis should also consider any possible sources of error (especially any errors that you believe actually occurred), considerations to keep in mind the next time you perform a similar experiment, and suggestions for future related experiments.

If your objective included a hypothesis or goal, you should finish with a quick mention of whether or not your hypothesis was correct, or whether or not you accomplished your goal.

2.3 Rules

The general rules and guidelines for writing in lab notebooks are:

- All entries in a lab notebook must be hand-written, in ink.
- All pages *must* be numbered consecutively, to show that no pages have been removed. If your notebook did not come with pre-numbered pages, you need to number *all of them* by hand *before* using the notebook.
- Start each experiment on a new page.
- At the end of each experiment, sign and date the bottom of the last page. (In industry, every single page would have its own box for your signature and the date.)
- When crossing out an incorrect entry in a lab notebook, *never* obliterate it. Always cross it out with a single line through it, so that it is still possible to read the original mistake. (This is to prove that it was a mistake, and you didn't change your data or observations. We all make silly mistakes, so you don't need to feel embarrassed about the original text still being legible.) If you accidentally scribble something out, write your initials next to the change.
- *Never* remove pages from a lab notebook for any reason. If you need to cross out an entire page, you may do so with a single large "X". If you do this, write a brief explanation of why you crossed out the page, and sign and date the cross-out.
- *Never, ever* change data after the experiment is completed. Really. I mean it. Your data, right or wrong, is what you actually observed. Changing your data constitutes fraud, which is a form of cheating that is every bit as bad as plagiarism. You can still get an A on an experiment that didn't work; changing or faking your data will get you the full penalty for cheating, including a zero for the experiment.

  This also means that you should never change anything on a page you have already signed and dated. If you realize that an experiment was flawed, leave the bad data where it is. Just add a note that says "See page ___." with your initials and date next to the addendum. On a new page, refer back to the page number of the bad data and describe briefly what was wrong with it. Then, give the correct information and sign and date it as you would an experiment.

2.4 In Conclusion

Remember that your laboratory notebook is your only record of what you actually did. If you worked for a company that was applying for a patent, your notebook might be the only proof that someone from your company had actually invented the substance or process. The more information you record in your notebook, the more useful it will be. If you need a more immediate incentive, the more information you have in your notebook when you are writing that 3–5 page lab report at 3:00 a.m. the night before it's due, the less work you'll have to do to find everything, and the more sleep you'll get.

3 Works Cited

Pavia, Donald L., Gary M. Lampman, George S. Kriz, and Randall G. Engel. *Introduction to Organic Laboratory Techniques, A Microscale Approach.* (Philadelphia: Saunders College Publishing, 1990). Pp. 16–22.