The Care and Feeding of Laboratory Data
By
Michael A. Morgan

The most important type of work that you can do in a laboratory science class is laboratory experiments. The majority of these will require you to write a formal laboratory report. The purpose of this handout is to acquaint you with the structure of a lab report, how to write it, and the most common mistakes that are made when writing one and how to avoid them.

Why Do Lab Experiments?

This is a science class! The whole field of science is based upon experimental results and you need to become familiar with the process of generating data to prove a hypothesis or determine a fact. We use labs as our teaching tool to accomplish these tasks. No matter how much lecture material you sit through you will not understand the delicate points of science until you try to work through them yourselves. Homework problems are a good start to this but they do not finish the job. Homework can get you through about 30% of what you truly need to understand. It takes a good experiment for all of these ideas to come together. You must get your hands wet, experience some set backs, and realize the importance of each step of the lab to get the whole point.

It turns out that in this class 90% of the experiments we do will have a specific mathematical/numerical fact that is the overall goal of the experiment itself. There are many steps involved in getting to this fact, or more likely, to the data that you use to calculate the fact itself. Much of the time students will just read the lab procedure and follow it as if it were a cookbook. They perform each step, write down each number for which they see a blank space or line in the data table, and calculate an answer for each post lab question. Through all of this time they have never once paused to think about why they are doing each step. What is its significance? Why do we do this? You must question the procedure. Try to understand the necessity of the measurement. Are you calibrating a machine? Are you taking the magical measurement right now? Are you just filling in a blank for no real reason?

Why write lab reports?

Okay so you just found the cure to cancer, the common cold, and world hunger in one day. What do you next? Order your tuxedo for your trip to Stockholm? No! You have to communicate your findings to the target audience. They are the judges of what you have done. This will be your teacher if you are a student. This could be a journal report to a scientific society if you are a researcher. This could also be a notice to the world that you have the cure. But no matter what it is, someone grades it. A teacher grades a student's report for the benefit of the grade in the class. A scientific journal has another member of your field repeat your research to make sure it is accurate.

Right now your target audience is the instructor for your course. That person determines your grade. Maybe sometime soon your audience will be a little larger than that. You have a research project and you need the members of the scientific community who work in your

field to know the fact that you now know. Maybe it is a big enough discovery that a general audience needs to hear it. This can be accomplished by a laboratory report. They take pretty much the same format no matter who your audience will be. But each audience has a slightly different set of rules to follow. Different audiences may require you to follow different sets of rules when it comes to preparing your report. Know these rules before you start writing. In general some common sense can tell you the mistakes not to make. Conclusions don't come at the beginning of a report. Data does not follow conclusions. Think of it in this logical order: Idea (purpose), experiment (procedure), data (facts), questions, and analysis including calculations to explain how you reached your conclusion, and a conclusion (statement of fact). It seems that the report will in essence follow the steps of the scientific method.

The Structure of a Laboratory Report

First let us understand that someone is judging you! If you do not put your best effort forward you will not get your best result back. A poor grade, a mediocre paycheck, or losing your job are all possibilities. In the worst case scenario people die if you do not put your best effort forward. So understand some major points here. Lab reports should be printed by a computer on a laser or ink jet printer. Nowhere in the report is there something added in by hand. The formatting is key to the presentation. A poorly formatted piece of work (this means ugly) is going to get a bad grade. Somewhere, someone told you that it does not matter whether or not something looks good only that it is correct. Well the truth is it does matter how it looks. If it does not look good it will get a bad grade!

Integrity

In the wonderful world of technology that we now live in it is very tempting to sit down with your lab partner and create a lab report together. You might even be tempted to help out a struggling lab partner by simply switching the name at the top of the report and printing them a copy for them to turn in. Under no circumstances should you ever do this. It is mandatory that you create your lab report completely on your own. There should not be any sections copied and pasted from your partner's report. This includes making your own data tables and writing your own theory section.

Working with your lab partner is very valuable to the whole laboratory experience. During the experiment that person is a sounding board for ideas on what is happening and how to record it. While it is very valuable and almost necessary to talk to each other while working through the data the first time, you should then walk away from each other to do the actual calculations and writing of the report. Once you have finished then you go back and check to make sure you got the same results.

The Lab Report Format
Now to the actual sections of a lab report, they are:

1. Heading
    Name
    Your partner's name (distinguish which is which)
    Date of the experiment
    Period
2. Title
3. Answers to the prelab questions
4. Purpose of the experiment (a single complete sentence)
5. Procedure for the experiment (just reference to a book/page)
6. Data Tables, Observations, and Graphs
7. Analysis: Calculations and Answers to follow up questions and possible discussion
8. Conclusion (one sentence only)

We need to take a look at each one of these in detail to see how we write them.

1. The heading in the upper right had corner of the page should look like this:

Starkey, Richard (me)
Andrews, Frank (him)
October 8, 2004
Period 1

This identifies the writer and the partner, the date they did the experiment, and what period they are in.

2. The title should be centered, maybe bold or italics, and must be relevant to the lab:

The Formula of a Hydrate

3. Prelab questions should be answered in a complete sentence. There is no need to retype a question if you incorporate it into the answer.

4. The purpose is difficult for many students. In one sentence you are trying to state what it is you are trying to do in the lab experiment. The majority of the time you are trying to measure a physical quantity and can express it in the purpose. Read through the lab and get a feel for what you are doing. Look at the data table and see that it is really going to tell you what the final outcome of the experiment is.

Examples:
Purpose:
To determine the formula of a hydrate.
-or-
To determine the concentration of an unknown sample using titration.
-or-
To measure the densities of various materials.

Never have two sentences in a purpose. Do not run on with it. Don't try to practice your creative writing. You will see later that the conclusion of the lab is mandated by the purpose.

5. The procedure is not supposed to be a play by play of what you did. In this course you will only design the procedure yourself in one or two labs. You will be following detailed procedures that are provided to you, so learn to reference them.

Procedure:
I followed the procedure on the handout called "The Formula of a Hydrate" provided by Mr. Morgan on July 10, 2001.

-or-

I followed the procedure on the handout called "Molar Volume of a Gas" provided by Mr. Morgan on July 10, 2001. Three trials instead of one were conducted.

-or-

I followed the procedure on the handout called "Redox Titration" provided by Mr. Morgan on July 10, 2001. Sodium oxalate instead of oxalic acid was used as the primary standard.

You may have to write out the procedure if it was one you invented yourself.

6. Data should always be presented in table format. These tables should be created with neat straight edges and should not contain any handwritten information. The information should be aligned neatly and consistently in your table to make it easy to follow. Units must be included, but may be placed in column headings. If your experiment has three trials of the same measurement all three should be shown side by side. If you have observations that need to be included they should be typed in complete sentences. A typical data table may look like this:

	Trial 1	**Trial 2**	**Trial 3**
Mass of Empty Beaker	24.55 grams	24.55 grams	24.55 grams
Mass of Beaker and Substance	25.55 grams	25.55 grams	25.55 grams
Mass of Beaker After Reaction	24.95 grams	24.95 grams	24.95 grams
Temperature of Substance	27^{o}Celsius	27^{o}Celsius	27^{o}Celsius

Never let a data table spill over on to two pages. This makes it very hard to read since you will be constantly turning pages back and forth to check column headings or looking for related data. Center your data and keep the column and row widths evenly distributed. Line up the decimal places in columns just as your second grade teacher taught you to do.

Graphs must be prepared on a computer. All of the information presented in class on how to prepare a graph should be adhered to. The basic things to keep in mind are (a) it should fill

the whole page, (b) have labeled axes, (c) be titled, (d) show units, (e) your name and (f) be uncluttered.

7. Analysis and Answers to post lab questions should take the form of complete sentences. It is not necessary to rewrite the question but it is acceptable if you wish. The way that these are presented is very dependent on the experiment itself. Sometimes it is possible to make tables to do this.

This would also be a very appropriate place to write a discussion of what may have gone wrong in your lab if your data seems to have an error in it.

8. The conclusion should be one sentence long and state a specific fact measured or discovered in the lab. It should also look just like the answer to the purpose of the lab. Do not get into long-winded discussions in your conclusion. On some occasions the data for the conclusion may be presented in a table. If you were performing multiple trials in one experiment you would only report the average value in the conclusion.

Conclusion:
The formula of the hydrate is $Ni(OH)_2 \bullet 4H_20$
Or
The average densities were determined as follows:

Wood	Water	Glass marbles	Unknown Material
0.805 g/cm^3	1.01 g/cm^3	2.70 g/cm^3	3.55 g/cm^3

References

Although they are not always required we sometimes include references. References are listed as the very last section of the report. It should follow standard bibliographic format and also have a brief description of why it was included. It may say that you got a number from a standard reference book or if it is a person they may have shown you how to do the calculations. In some rare instances you may even lift several sentences or a figure or diagram from a book or CD and include them in you report. This should be acknowledged.

References

Andrews, Frank C. “Thermodynamics: Principles and Applications”, Wiley Interscience Publications, 1971 Page 50 was used to help me understand the Celsius temperature scale for my theory section.

Ellerby, H. Michael showed me how to present a scatter graph using Microsoft Excel

Most CD’s like Microsoft Encarta automatically include the reference for your convenience. Use it!

The Laboratory Notebook

There are a host of considerations to keep in mind when recording your data in a laboratory notebook. These rules are pretty universal and should apply to almost all research you come in contact with. Typically Regular and Honors Chemistry classes do not use laboratory notebooks unless a student is doing a science fair project. AP Chemistry always uses a laboratory notebook.

1. The book should be a bound composition book and not a loose-leaf volume. Quadrille ruled (graph paper) is always best but you may use a lined page also. Never remove a page from the book. Just draw a single line diagonally across the unwanted, unused, or discarded page. Number every page.

2. All entries need to be in blue or black ink. *There should be no use of pencil anywhere in your lab book.* Do not start recording your data in pencil thinking that you will "ink it in" at a later time. This will make your lab book invalid and your research will not get any Nobel Prizes.

3. Never obliterate anything in a lab notebook. Never use correction fluid. Just simply draw a neat line through any data to be ignored.

4. Two blank pages should be left at the front of the book for a table of contents and miscellaneous data table. The inside front cover should contain your name, phone number, teacher's name, and your email address. Decorate the front cover so you can identify your book at a distance. All lab books look pretty much the same on the lab table top.

5. Only write on the right hand pages and leave the left-hand pages for "emergency" use. Many times you will find that your data table is not long enough and you need space for more data. Other times you will need scratch space for calculations or for note taking during lab lectures. This is what the left-hand side of the book will be used for.

6. Do not lose your lab book. It is the legal record of your lab work and can never be replaced.

7. Put the date at the top of each page as you use it.

8. The format for the lab book is basically the same as the format for a formal report but has one major difference. Instead of a theory section there will be a detailed step by step procedure for your experiment. You will be given outlines of the lab procedures before each experiment and you will work it up in your lab book prior to coming to lab. If you come to lab without the procedure in your lab book you will not be admitted to the room. You will not be able to read from the handout given to you before the lab. You must have the procedure and data tales prepared prior to the day of your experiment.

9. When it is the day of your experiment you will use your lab book in the experiment. You perform the calculations that night in the lab book and then you have the weekend to write your formal report. Never put off doing the calculations in your lab book beyond the night of the experiment. This is when everything is still fresh in your mind and you will be able to comprehend the material the best.

Special Instructions for AP Chemistry Lab Reports

If you are writing a lab report for AP Chemistry there are two more items that must be included in your lab report. The Theory and Reference sections. You may follow the examples above for the reference section

There is no question that the most challenging part of writing a lab report is creating a theory section. It is written in a very specific way and must always conform to a set of rules. The theory section is a mini textbook of the topic that the experiment deals with. It is always written in the third person. Never use phrase like "I learned" or "we used". Only include relevant topics and never discuss the procedural details of the experiment. A sample theory section for a separation techniques lab is shown here. It starts with general detail and gets more specific to the lab performed near the end.

Theory

Separation techniques are based on two substances having at least one fundamental property different from the other. Phase, boiling point, and polarity are properties that can all be used to help separate two substances from each other. Separation techniques can be very useful for unknown analysis and to purify mixtures.

When two substances are mixed and have different phases it is relatively easy to separate them. A bottle of soda pop contains a mixture of liquid and gas. The tiny bubbles in the soda are made of carbon dioxide gas and can be separated from the liquid by heating. If a beaker contains a precipitated solid in water the solid can be filtered out using filter paper and a funnel. Both of these cases illustrate how it is possible to separate two substances in different phases.

Two liquids mixed together to form a homogenous substance can be separated if the two liquids have different boiling points. In a mixture of alcohol and water as an example you have two liquids that have similar polarities and can not be separated by any other means than to boil then off. Since the alcohol boils at a lower temperature it can be collected kept separate from the water.

If two liquids mixed together have very similar boiling points it is possible to separate them if they have different polarities. A mixture of water and oil can easily be separated by allowing them to sit undisturbed for a long period of time. Two layers will form with a diving line between the two that is visible to the eye. If one of the layers is drained from the other a relatively accurate separation will occur. However if the two substances are relatively heterogeneous it may be possible to use chromatography to separate them.

Chromatography is based on a mobile phase and a stationary phase. A sample is carried over a stationary phase by the mobile phase and is deposited on the stationary phase based on its properties. As an example if you had two inks of different colors mixed together to form a third color it is possible to put a spot of the mixed ink on a piece of filter paper(the stationary phase) and allow water(the mobile phase) to carry the two inks on the paper. The ink with the greater affinity for the paper will travel a shorter distance and the ink with the lower affinity

for the paper will travel a longer distance. Methods like this are very useful for identifying unknown samples.

A second theory section is presented here based on a lab with a very different topic, Stoichiometry.

Theory

Measuring the number of atoms or molecules that react with each other is practical impossibility. Atoms and molecules are so small that counting them or even a relatively large number of them is an impossibility. Therefore when working in a laboratory situation it is necessary to employ an indirect method of measurement. In the 1800's Amadeo Avogadro developed his hypothesis that at constant temperature and pressure two equal volumes of gases will have an equal number of particles. This was the beginning of the mole.

Stoichiometry is the area of chemistry where we "measure out" numbers of molecules based upon their masses and the Avogadro Number that says one mole of any substance contains 6.022×10^{23} pieces of that substance. Based upon this number it is possible to assign values for the molar masses (mass of one mole of a substance measured in grams) of any compound. The relationship between moles, mass, and molecules is shown below utilizing a roadmap:

Molecules A <--------> Moles A <--------> Mass A <--------> Volume A

Balanced Chemical Equation

Molecules B <--------> Moles B <---------> Mass B <---------> Volume B

When we write the chemical equation for a given reaction what we are doing is representing the number of molecules of a substance that are needed to react with a given number of molecules of another substance. Since the number of moles of a substance is based on the number of molecules the ratios represented by the balanced chemical equation is also a mole ratio. In the equation shown below:

$$2H_2O + O_2 \rightarrow 2H_2O$$

Two molecules of hydrogen are needed to react with one molecule of oxygen to produce two molecules of water. It also shows that two moles of hydrogen are needed to react with one mole of oxygen to produce two moles of water.

In a laboratory situation you can not measure moles directly. There is no such device as a mole meter, but since grams can be measured it is possible to keep track of these stoichiometric relationships by measuring grams and converting to moles.