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I. INTRODUCTION

Seeing is believing—this simple cliché is the reason why all good introductory chemistry courses have a laboratory component. There is nothing—no lecture, no photo, no simulation, no homework problem—that conveys the idea of “acid reacts with carbonates” as effectively as actually watching hydrochloric acid react with sodium carbonate. Here in Lyman Briggs we consider the laboratory to be an essential part of your education in chemistry, equal in status and well-connected to the lecture. Our hope is that you will find the laboratory interesting as well as useful for increasing your understanding of chemistry.

Helping you understand chemical principles is a very important purpose of the lab, however an equally important function of this course is to give you experience with a variety of techniques. These include: safe lab practices, keeping a laboratory notebook, proper handling of chemicals, performing dilutions, and using spectros copy (the interaction of light with matter) analytically. It is expected that you are familiar and comfortable with all the concepts presented in LBS 171L. Subsequent laboratory courses will assume you are proficient with all you encountered both last semester and this semester so it is important for you to learn these now.

A final purpose of LBS 172L is to help develop your communication skills, which ranges all the way from how you work with a partner (partners should share work equitably; neither partner should have the burden of all the lab or writing work), to writing clear, concise descriptions of your work. This last point is very important when one considers that the ability to write well greatly improves one’s chances of getting a scholarship, getting into a professional school, and getting a job.

Overall, through LBS 172L you will:
1. Demonstrate proficiency with some more advanced laboratory techniques such as preparing dilutions, running titrations, using spectrophotometry to analyze a solution’s concentration and changes in concentration over time.
2. Develop safe, proper laboratory working habits such as organization, cleanliness, and use of a laboratory notebook.
3. Record and present observations and other data in a scientifically acceptable fashion.
4. Present data analysis and discuss your results in a scientifically acceptable fashion.
5. Develop the ability to form hypotheses regarding chemical phenomena.
6. Design simple experiments to test these hypotheses.
7. Utilize chemical principles to analyze and evaluate these hypotheses.

Of course we, as instructors, have goals as well. Our goal is to provide a safe, collaborative, supportive environment in which you and the rest of your class can achieve the above goals and get the most out of your Briggs chemistry experience. We will also try to provide you some opportunities to ask and explore your own questions about the world around you.

Finally, we think chemistry and the chemistry laboratory in particular is fun! (Who
doesn’t like to see colored flames or solutions that change colors unexpectedly?) Although we can’t promise that every minute of your laboratory experience will be greatly exciting—we don’t know anyone who enjoys washing glassware—we do hope you will find LBS 172L enjoyable and useful.

II. HOW THE LAB WORKS

The laboratory periods are two hours and fifty minutes long. This time should be sufficient time to collect data and record all observations necessary to perform the lab assignment. Usually there will be time for you to perform any calculations or redo a part of the lab. If you finish early you are strongly encouraged to start your calculations in the laboratory while the experiment is fresh in your mind and your learning assistant is nearby (though clearly many people opt to flee the lab.) Each lab section will be supervised by one or two undergraduate learning assistants (LA) who will be responsible for assisting and evaluating the students in their sections. Most of the LA’s are junior or senior Briggs students with outstanding academic and personal qualifications; their competence and enthusiasm for teaching makes them an invaluable learning resource for the Lyman Briggs learning community. Each LA will have one office hour which will be held either in the laboratory or in W-40. The LA office hours and room numbers will be posted on the course web page (http://www.msu.edu/course/lbs/172l/) no later than the second week of class. Feel free to seek help from any LA, the graduate assistants (Lei Feng, fenglei@msu.edu; Yiqian Lian ylian@msu.edu), or Dr. Sweeder (Sweeder@msu.edu). If you cannot meet with your LA during their regularly scheduled office hour, contact them to make an appointment. Remember, though, that your LA is a student like yourself and is also very busy—please respect their time.

Role of the LA

It is important that you realize the role of the LA. They are not instructors in quite the manner that you may expect. Their job is to do exactly what their title describes, which is to assist your learning. You are the one who is ultimately responsible for your own education. You are expected to come into lab having read the instructions for the day and be prepared to work on the lab. If you have questions about what you are supposed to do in lab, you should seek out your LA, the graduate TAs or your professor prior to your lab time. Your LA will help you with answering questions about techniques and hopefully be able to provide you with tips and food for thought during the lab. If you come in to the lab without having any idea about what to do in the lab, the LA may ask you to leave the lab until you have read the instructions and have a sense of what to do. One of the LAs tasks is to provide a safe working environment for the students, and having someone who doesn’t know what is going on is potentially one of the most dangerous things in lab.

Safety

The chemistry lab contains many things which by themselves are not harmful, but through carelessness or inattention can become very dangerous. YOUR PRESENCE IN THE LABORATORY IMPLIES THAT YOU UNDERSTAND AND WILL FOLLOW THESE PRECAUTIONS:
1. Come to lab appropriately dressed. Clearly you will not want to wear your best clothes. Shorts, skirts, and sandals are absolutely forbidden in the laboratory (you may store a pair of sweats or running pants in your drawer to change into). Long hair must be tied back.

2. Contact lenses are not to be worn in the laboratory, even under your goggles. This is because solvents can diffuse through the contact and get trapped between the contact and your cornea. Save your eyes and wear glasses instead.

3. Absolutely no food, drinks, or gum are allowed in the laboratory. Smoking is prohibited.

4. All chemicals must be disposed of in their proper waste containers unless you are instructed otherwise by your LA. Spills or breakages should be reported to your LA immediately. Spills of solids or powders should be cleaned up using the dustpan and brush and then placed in a plastic bag and properly marked. Broken glassware should be deposited in the “broken glassware” container.

5. Report all accidents, no matter how minor, to your LA.

Safety Glasses:

Yes, this topic is important enough to warrant its own section. Eye protection is required at all times that you are in the laboratory. Splash-proof goggles (the kind that completely cover your eyes and fit snugly on your face) are required. If you regularly wear glasses, you may request from your LA to be able to wear prescription impact resistant glasses. Any such glasses must have impact resistant side shields. The class will operate on a “five strikes and you are out” policy (what do you expect? This isn’t baseball.) Your strike count accumulates over the entire semester, not just during one session.

Strike 1: A gentle private reminder to wear eye protection.

Strike 2: A harsh public order to put your goggles on, as well as a written copy of the Braille alphabet, because you’ll obviously need an early start learning this.

Strike 3: Loss of all subjective evaluation points, and a visit to Lyman Briggs Safety coordinator Sue Rose. She will not be in a good mood.

Strike 4: Dismissal from the lab for the day, and a grade of “0” for the lab you were working on, with no opportunity for make-up work.

Strike 5: Failure of the course.

YOU ONLY GET TWO EYES. PRESERVE THEM.

Other safety rules

Your LA will give you specific safety instructions appropriate for each laboratory. Here are some general rules which you should be aware of for each lab:

$ Never handle/touch any solid or liquid chemical with your bare hands.
$ If any dangerous reagent splashes or spills on you or your clothing, wash it off immediately with plenty of water. For large-scale accidents remove all contaminated clothing and use the safety shower. An eyewash station is also located by the shower–
make sure you know where it is and how to use it.

$ \text{Do not handle broken glassware with bare hands.}$
$ \text{Always handle hot crucibles, beakers, etc. with a wire gauze or tongs.}$
$ \text{Clean your work area when you are finished and wash your hands after finishing the lab.}$
$ \text{Do not use stressed, chipped or broken glassware. Give the damaged item to your LA and request a replacement.}$

**Lab Notebook**

You are required to have a lab notebook with fixed pages (not spiral bound), which is available at the University bookstore. If you have sufficient room in your notebook from LBS 171L, you may continue to use that notebook. In this notebook you should write what is the purpose of each lab, as well as include all procedures, data, and observations. It is highly recommended that you also include any conclusions that you make (though these might not be added until after you work on the lab report.) Always use pen (pencils smear easily) and make sure you write clearly so that it is legible when you analyze your data. If you make a mistake, record data incorrectly, or otherwise need to change something, draw one line through the entry you wish to change and record the correct entry the next line down, if appropriate. Do not erase or make the incorrect entry hard to read since you might need this seemingly “incorrect” reading. You need to have title on the first page of each lab in the designated area (usually at the top of the page) and record the date on every page. You should also maintain an up to date contents page at the front of the book. At the end of the semester you will be instructed to turn in your lab notebook in so that your LA can evaluate it. During the first two weeks of lab, the LA will examine your notebook to ensure you are writing it correctly, though it should be maintained in the same manner as LBS 171L. Original data should be handwritten in the notebook, or if it is computer generated then the original data sheet should be taped in your lab notebook. Remember that this book will be in the lab with you, so it is likely (probably expected) that it will pick up random stains and other signs of use. These kinds of stains will not affect your notebook grade.

III. LABORATORY REPORTS

As was stated earlier, being able to communicate well in writing is a critically important skill to learn. To help you develop this skill, you will usually have to turn in a lab report describing what you did and found in the laboratory. Some reports will be short though most will be of medium length, consisting of an abstract, procedure, discussion, results, calculations and conclusions. Two or three will be full write-ups which will also include an introduction. While we recognize that this is more work than that done in the university general chemistry laboratory, we know you will reap the benefits from this experience in later classes (students who have taken this lab class before have stated that in later classes they felt they had an advantage over those who had little experience with writing scientific reports). In order to temper this difference and not require too much work, many of the lab write-ups will be done with a partner. You are expected to be familiar with the full write-up from each lab (the excuse of “my partner wrote up that part” is really lame anyway.)
Policies Regarding Lab Reports

Lab reports are generally due *one week* from the day you completed the laboratory. Late laboratories will lose a full grade for each partial day they are late.

Your lab report should be word-processed. It is strongly recommended that you *back-up* your lab report!!! Having to type up an entire lab report from memory in one night is not a pleasant scenario—backing up your files will prevent this from occurring (besides, no good scientist would ever leave their data on only one computer). Furthermore, there will be no special deadlines if your computer crashes or if your roommate deletes your files.

This semester there will rarely be formal prelab activities, though you are still expected to write a purpose for each lab PRIOR to coming to lab. This may be checked periodically at the beginning of lab. It is expected that you come in prepared for class (this means having already read the lab materials.) Being unprepared will result in a loss of the subjective points for the day. Excessive ill-preparedness will result in a decrease in your lab report grade. If classes are regularly unprepared, then the prelab exercises will be reinstated for those sections.

A typical lab report will have the following format:

- Title Page
- Abstract
- Introduction (if required)
- Procedure (if required)
- Data
- Calculations
- Results
- Discussion (if required)
- Questions (if required)
- Conclusion (if required)

Components of the Lab Report

**Title Page:** The title page should have a title for the experiment, the date you performed the experiment, your name, your partner’s name if applicable, your LA’s name, and section number.

**Abstract:** An abstract is a brief summary of your study. It states what was studied, what method was used to study it, and what the results (including standard deviations) were. With the enormous volume of scientific papers published, abstracts are necessary to convey the essence of your study to a person who does not have time to thoroughly read your report. Keep in mind that reports are not mysteries. You are allowed to give away the ending in the first paragraph.

**Introduction:** The introduction is the section where you should provide the necessary background for the reader to understand your lab. This may include a bit of contextual information (what was the general purpose/goal or why should we care) but it should also
contain the necessary chemical background information. This section is what allows us to really get feel of if you understand the chemistry or not. So if the lab involves heavily upon redox chemistry, then you should remind the reader of what oxidation and reduction is.

**Procedure:** A procedure is the description of your scientific work in such a manner that the experiment can be independently repeated and verified. As such, the amount of detail of your procedure should be such that someone would be able to carry out the laboratory on their own. Remember though that this is still a report of what you did, not instructions on how someone else should do it. Thus you must keep good notes in your lab book so you can write up exactly what you did. Since you have done this in the past, your lab report should be written in the past tense (remember to avoid the 1st person too.) In writing your procedure some steps will be implied. For example saying you dissolve 4.20 g of NaCl in 40.02 mL of water implies that you carefully measured both the quantity of salt and water.

**Data:** All experimental measurements, observations, and results should be tabulated in a “data” section. Units should be included for every quantity and follow guidelines for significant figures (your textbook talks about significant figures if you don’t remember them.) Remember that the data will likely include both measured and calculated numbers. Keep in mind that each bit of data need not have its own table, but often it will make sense to combine a number of table together to both put together useful information, and make comparisons easier.

**Calculations:** This section is necessary for your LA and instructor to follow your work. Show one example of every kind of calculation (even unit conversions and standard deviation) and remember to use the correct number of significant figures. Use a one line descriptor for each calculation so the instructors know what you are trying to find.

**Results/Discussion:** In these sections, you should summarize what was found by your study and discuss any possible sources of errors. When you discuss your results, remember to mention applicable theories or hypotheses you might have initially made. Remember that your discussion should be based on the results you actually obtained, not the results that you think you should have obtained. Overall, this section helps you take the data that you collect, and using the information provided in the introduction, shows the logic of how you reach the conclusions. You should also discuss any sources of error, general problems with the method, improvement, and/or future directions for research as appropriate.

**Questions:** There may be a few questions at the end of the laboratory. Answer these here, showing examples of calculations (if different from earlier calculations) if necessary. In formal labs, these questions should be simply folded into the discussion, rather than giving them their own section.

**Conclusion:** This is the final section and is exactly what it sounds like. You should be summarizing what you did and your findings that you just presented in your discussion. Also including any next direction to go based on your findings is appropriate. Often this section looks
very much like your abstract.

Text and all data submitted are expected to show professionalism in both presentation and grammar; points may be deducted otherwise. This should be considered a formal English paper after all. You are also expected to cite any reference materials used and give credit to any other students with whom you worked. There is no specific formatting necessary for this, though chemists will typically use numerated end notes for their citation. **Copying part or all of another student’s report will minimally earn you a zero for that laboratory; more severe repercussions (failure in the lab, expulsion) will result for repeated or egregious cases of plagiarism.**

*Academic honesty policy*

Be sure to read the academic honesty policy online at:
http://www.msu.edu/course/lbs/172l/Academic%20honest.htm

IV. GRADING

Lab reports will be graded in a holistic manner. That is that they will receive a single overall grade. Formal lab reports will be given twice the weight of the smaller reports in the final course grade. Each lab report will be given one of the following grades (expected quality suggested afterward):

- 4.0 – Outstanding report – a basically perfect report with no significant errors
- 3.7 – Excellent – a few minor mistakes no significant errors
- 3.3 – Very Good – one or two small errors
- 3.0 – Good – a well written/understandable report at effectively communicates ideas. Some errors present.
- 2.5 – Fair – writing or conceptual errors present, but the general idea is correct
- 2.0 – Minimally acceptable – significant errors present. Some effort demonstrated.
- 1.0 – Poor – At least you handed in something, but there are major errors present.
- 0.0 – Did you not show up?

Please not that the LAs may opt to give other grades that fall between these levels if they so choose.

There will also be postlab quizzes. These quizzes are designed to test the underlying basis of the lab and acts as the individual accountability portion of the lab. If you understood everything that went into your lab report you should do quite well. If on the other hand your lab partner wrote much of it, then…. These quizzes will be worth 10 points each and will occur prior to each lab. There are also 50 subjective points for the semester. Your LA will evaluate your performance in lab each week and assign these points as appropriate (for example, a loss of points could result from not reading the laboratory beforehand, not cleaning your lab bench, from using poor technique, using poor laboratory safety practices, or other issues). Points will be deducted from the entire class if common areas are left messy. Notebook collection will be worth 20 points.
Grades are decided by the laboratory coordinator (Dr. Sweeder). Grading differences among LAs will be accounted for by standardizing everyone’s grades at the end of the semester though comparison of the grades assigned on lab reports by the instructor and LA. Keep in mind that the expectations of quality for the lab reports will continue to increase from last semester.

V. GRAPHS AND TABLES

You will be making quite a few tables and graphs. Here are some guidelines:

$ Each graph/table should have a title. Graph titles are always numbered and state the dependent variable versus the independent variable, or “y vs. x”, i.e., *Graph 1. Absorption vs. Concentration* (see example below). Tables should also always be numbered and have titles (see below).

$ Graphs and tables should always have correct units and significant figures on them.

$ Do not play “connect the dots” with your data points on a graph. Usually you will have to perform a least squares analysis (Excel does this fairly easily) to obtain a trendline which shows the general pattern of your data.

$ Label the ordinate and abscissa axes (the y and x axes), including units.

$ On graphs, choose your axis scale such that any trend is clear. You don’t want a scale so large the data are scrunched together; you don’t want a scale so small your data appear randomly scattered.

Here is a sample data table:

**Table 1.** Absorption of various [Fe$^{3+}$] solutions at 540 nm.

<table>
<thead>
<tr>
<th>Concentration of Fe$^{3+}$, mol/L</th>
<th>Absorption, arbitrary units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100</td>
<td>0.008</td>
</tr>
<tr>
<td>0.250</td>
<td>0.027</td>
</tr>
<tr>
<td>0.500</td>
<td>0.045</td>
</tr>
<tr>
<td>0.750</td>
<td>0.080</td>
</tr>
<tr>
<td>1.00</td>
<td>0.098</td>
</tr>
<tr>
<td>unknown</td>
<td>0.031</td>
</tr>
</tbody>
</table>
Here is a sample graph from the above data:

Figure 1a.
Accurate but imprecise data.

VI. ACCURACY AND PRECISION

The accuracy of an experiment is a measure of how close the result of the experiment comes to the “true” value. Of course, in most experiments we do not know what the “true” value is; this makes accuracy determinations difficult at times. Precision is a measure of how well the result has been measured, independent of how closely the measurement agrees with a “true” value. It also is a measure of how reproducible the experiment is. Figures 1a and 1b below show the difference between accuracy and precision.
Figure 1b. Precise but inaccurate data.

**Exact numbers**

Exact numbers are those that have defined values or are integers that result from counting numbers. Examples are 1 m = 1000 mm, 2.54 cm = 1 in., and 4 wheels on a car.

**Inexact numbers**

Numbers obtained by measurement are always inexact because error is inherent in every measurement. Human error results from mistakes in measurement or computation; they are usually apparent either as obviously incorrect data or as results that are not reasonably close to expected values. Situations causing human error include trying to measure 50 mL of a liquid in a graduated cylinder and not drying the cylinder out beforehand, or using an incorrect conversion factor.

Systematic errors affect the accuracy of an experiment—they make results different from the “true” values with reproducible discrepancies. They can result from faulty calibration of an instrument (note that this is not a human error) or personal bias. Discovering sources of systematic error is an important task of the scientist and is not always obvious. When planning an experiment, spend time considering ways to reduce the sources of systematic error.

Random errors affect the precision of an experiment. These errors are the reason why experiments may yield slightly different results from day to day or from lab to lab. Reducing these errors usually means repeating the experiment to obtain better statistics, but using more precise instruments or a more refined technique are other ways to reduce random errors.
VII. SIGNIFICANT FIGURES

Measurements are generally reported in such a way that only the last digit is uncertain. All digits including the uncertain one are called significant figures (another way to think of this is that the number of significant figures is “every one you can read plus one you guess at”). The numbers of significant figures indicates the exactness of the measurement. A measurement of 3748.952 has seven significant figures and the uncertainty of the measurement is $\pm 0.001$.

Math and significant numbers

The precision of the result is limited by the precision of the measurements. Thus, it is important to use the proper amount of significant figures in the results of calculations. In multiplication and division the result must be reported with the same number of significant figures as the measurement with the fewest significant figures (remember that converting a fraction to a number is division). In addition and subtraction the result cannot have more digits to the right of the decimal point than any of the original numbers. Your textbook has a discussion of significant figures in sections 1.7; refer to these if you would like a review of significant figures.