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PREFACE

Chemistry is an experimental science. Thus, it is important that students of chemistry do experiments in the laboratory to more fully understand that the theories they study in lecture and in their textbook are developed from the critical evaluation of experimental data. The laboratory can also aid the student in the study of the science by clearly illustrating the principles and concepts involved. Finally, laboratory experimentation allows students the opportunity to develop techniques and other manipulative skills that students of science must master.

The faculty of the Chemistry Department at U.C. Davis clearly understand the importance of laboratory work in the study of chemistry. The Department is committed to this component of your education and hopes that you will take full advantage of this opportunity to explore the science of chemistry.

A unique aspect of this laboratory program is that a concerted effort has been made to use environmentally less toxic or non-toxic materials in these experiments. This was not only done to protect students but also to lessen the impact of this program upon the environment. This commitment to the environment has presented an enormous challenge as many traditional experiments could not be used due to the negative impact of the chemicals involved. Some experiments are completely environmentally safe and in these the products can be disposed of by placing solids in the waste basket and solutions down the drain. Others contain a very limited amount of hazardous waste and in these cases the waste must be collected in the proper container for treatment and disposal. The Department is committed to the further development of environmentally safe experiments which still clearly illustrate the important principles and techniques.

The sequence of experiments in this Laboratory Manual is designed to follow the lecture curriculum. However, instructors will sometimes vary the order of material covered in lecture and thus certain experiments may come before the concepts illustrated are covered in lecture or after the material has been covered. Some instructors strongly feel that the lecture should lead the laboratory while other instructors just as strongly believe that the laboratory experiments should lead the lecture, and still a third group feel that they should be done concurrently. While there is no "best" way, it is important that you carefully prepare for each experiment by reading the related text material before coming to the laboratory. In this way you can maximize the laboratory experience.

Questions are presented throughout each experiment. It is important that you try to answer each question as it appears in the manual as it will help you understand the experiment as you do it. In addition, you are encouraged to complete the report as soon after laboratory as possible, as this is much more efficient than waiting until the night before it is due.

In conclusion, we view this manual as one of continual modification and improvement. Over the past few years many improvements have come from student comments and criticisms. We encourage you to discuss ideas for improvements or suggestions for new experiments with your TA. Finally, we hope you find this laboratory manual helpful in your study of chemistry.

ACKNOWLEDGMENTS

This manual is the culmination of the efforts of many individuals. Many faculty members have provided ideas for the creation of these laboratories and have made numerous suggestions regarding their implementation. Additionally, the Stockroom Dispensary Supervisors, both past and present, have had a role in helping to develop these experiments and, in particular, helping to ensure that the experiments are tailored to our laboratories here at U.C. Davis. In addition, many undergraduates have been involved in the development of experiments as part of undergraduate research projects.

INTRODUCTION

A) Time Allocation and Grading of the Experiments

Below is an indication of the time allocation and point value of each experiment. These can sometimes change due to unusual and unforeseen circumstances. In addition, due to holidays, not all experiments are done every quarter. At the end of the quarter your TA will sum your scores and give this to the instructor, who will modify it as described in the course syllabus.

Title of Experiment	Lab Periods Allocated	Total Points
Introductory Exercise	1	25
Nomenclature Workshop	1	20
Observing Chemical Reactions	1	15
Reactions of Copper	1	15
Spectroscopic Analysis	1	25
Volumetric Analysis (I & II)	2	40
Analysis of an Alloy	1	25
Determination of Avogadro's Number	1	25
Quizzes (five)		10*

Total Points = 200

*Laboratory Quizzes: Five unannounced lab quizzes will be given by the TA after the pre-laboratory discussion. These 2-point quizzes will cover material relevant to the current laboratory experiment. These quizzes will be straightforward and easy for those students who have carefully read the experiment. No make-up or late quizzes will be given. Students who fail these quizzes are considered to be unprepared and unsafe to work in the laboratory and will be asked to leave the laboratory to read the experiment. The TA will then verbally ask them another question and will allow entry into the laboratory only if the student answers the question correctly. This policy will be strictly enforced.

B) Safety Policy

It is critical that you prepare for each experiment by reading it carefully before entering the laboratory. Not only will this ensure that you get the maximum benefit of the experience, but it also makes for a safer environment in the laboratory. This is important not only for your own safety but also for those around you. A number of policies have been developed in order to make sure that the laboratory is safe and that it runs smoothly.

In each experiment specific hazards are indicated by bold type and procedures are described that must be adhered to. In addition, accidents commonly occur when the following rules, as approved by the Chemistry Department Safety Committee, are not followed.

SAFETY RULES FOR LABORATORY WORK

The following rules are designed for your safety in the laboratory. The Laboratory Instructor has complete authority for enforcement of these rules and any other procedures to ensure safe practices in carrying out the laboratory work. Violations of these rules are grounds for expulsion from the laboratory.

1. Approved safety goggles must be worn at all times. At NO time are safety glasses of any kind acceptable in the laboratory. Goggles will be worn by EVERY student in the lab until EVERYONE has finished with the experimental procedure and has put away all glassware. Safety goggles should not be modified in any manner.

2. Shoes must be worn at all times. It is strongly recommended that you wear clothing that completely covers your arms, legs, and feet while working in the laboratory. Inadequate protection often leads to injury. Avoid wearing expensive clothing to lab as it may get damaged.

3. Laboratory areas must never be used for eating or drinking.

4. Smoking is not permitted in the laboratory.

5. Learn the location and how to operate the nearest eyewash fountain, safety shower, fire extinguisher, and fire alarm box.

   First aid for acid or base in the eyes is to wash with copious amounts of water using the eyewash fountain for 15 minutes. Then immediately go to the Student Health Center for further treatment.

   First aid for acid or base on skin or clothing is to wash thoroughly with water. Use the emergency shower if appropriate. For any acid or base burns on skin wash thoroughly with water for 15 minutes.

6. All operations in which noxious or poisonous gases are used or produced must be carried out in the fume hood.

7. Confine long hair while in the laboratory. Hair can catch on fire while using open flames.

8. Mouth suction must never be used to fill pipets. Always use a bulb to fill pipets.

9. All accidents, injuries, explosions, or fires must be reported at once to the laboratory instructor.

   The laboratory instructor (TA), faculty instructor, or Dispensary Supervisor will decide in all cases whether the extent of an injury is serious enough to warrant inspection and treatment by the Student Health Service. The student must visit these facilities if requested to do so by the TA. The laboratory instructor (TA), faculty instructor, or Dispensary Supervisor will decide in all cases whether the student should be accompanied to the Student Health Center by someone. In cases of serious injury, the laboratory instructor (TA), faculty instructor, or Dispensary Supervisor will call 911 for an ambulance.

10. Specific permission from the faculty instructor is required before you may work in a laboratory other than the one to which you have been assigned. Only laboratory rooms where the same laboratory course is currently operating may be used for this purpose.

11. Perform only authorized experiments. Chemicals are not to be removed from the laboratory.

12. Horseplay and carelessness are not permitted. You are responsible for everyone's safety.

13. Maintain your working area in a reasonable state of neatness. If you spill water or a reagent or break a piece of glassware, clean it up immediately. Any spilled reagents must also be wiped up immediately, exercising the appropriate care to protect yourself from skin contact with the substance. Clean off your desktop before leaving the laboratory.

14. Put all toxic or flammable waste into the appropriate waste container(s) provided in your laboratory.

15. Containers of chemicals may not be taken out of the laboratory except to the dispensary for refilling or replacing laboratory chemicals and exchanging full waste jugs for empty ones. If you need a cap, cork, parafilm, etc. for stoppering glassware-containing chemicals, please inform the dispensary of the type of glassware you are using and they will provide you with the appropriate cover for it.

16. No laboratory work will be done without supervision.

17. You must sign a copy of this Safety Sheet before you may work in the lab. If you have questions about these rules and procedures, please ask your laboratory instructor.

C) Dispensary Procedures

1. Locker Inventory

Procedure for beginning of quarter

(1) Replace broken or missing items in your locker in the first two weeks. They may be checked out from the stockroom (Room 39). All excess equipment should be placed in the extra glassware box in the back of the lab room.

(2) When checking out supplies from the stockroom after the first two weeks, be sure to fill in your complete locker number, course number and date on your checkout slip.

(3) Safety goggles must be supplied by the student and worn when working in the laboratory, including during locker check out. Only safety goggles which have been approved by OSHA are acceptable. Approved safety goggles are available at the student bookstore.

(4) Keep this locker list until the end of the quarter.

CHEMISTRY 2 LOCKER LIST

GLASSWARE
1 100 ml Beaker
1 150 ml Beaker
1 250 ml Beaker
1 400 ml Beaker
1 800 ml Beaker
1 50 ml Erlenmeyer Flask
2 125 ml Erlenmeyer Flasks
2 250 or 300 ml Erlenmeyer Flasks
2 500 ml Erlenmeyer Flasks
1 100mm Watch Glass
2 Glass Stir Rods
10 Test Tubes (rounded end)
6 Centrifuge Tubes (pointed end)
1 250 ml Volumetric Flask
1 10 ml Volumetric Pipet

METAL EQUIPMENT
1 Test Tube Clamp
1 Clamp Holder
1 Small Support Ring
1 Large Support Ring
1 Crucible Tongs
1 Scoopula
1 Beaker Tongs

PORCELAIN
1 Small Casserole
1 Large Casserole
1 Evaporating Dish
2 Crucibles
2 Crucible Covers

PLASTIC WARE
1 250 ml Washing Bottle
1 25 ml Graduated Cylinder (may be glass)
1 Short Stem Funnel (may be glass)
2 1 L Bottles
1 Desiccator
1 Pipet bulb w/ Tip

OTHER
1 Centrifuge Tube Brush (pointed end)
1 Test Tube Brush (rounded end)
2 Match Books
1 Vial, Alkacid Test Paper
1 Wooden Test Tube Rack
1 Sponge
2 Rubber Policemen
1 Wire Triangle, Pipe Stem Covered
1 Wire Gauze Square
1 Thermometer

COMMUNITY SUPPLIES KEPT ON BENCH TOP
1 Bunsen Burner with 2-3 feet of Black Rubber Tubing

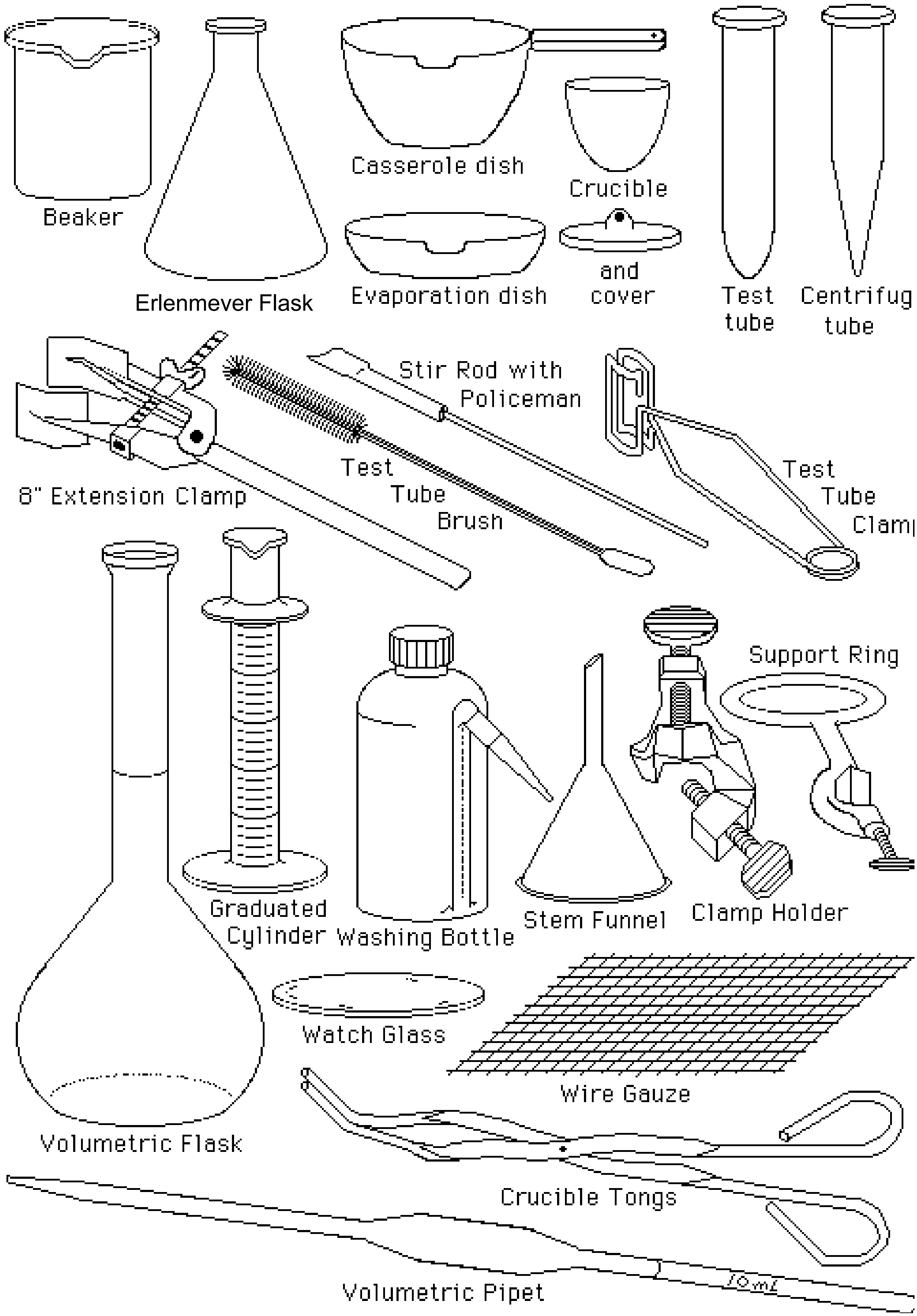
Procedure for end of Quarter

(1) Clean and dry all equipment.

(2) Replace all broken or missing items by checking them out from the stockroom. Return all extra equipment to the extra glassware box in lab.

(3) Have your TA check your equipment and initial below.

Student Name____ T.A.__________________
(Print) (initial)


Beaker
Erlenmever Flask
Casserole dish
Crucible
and
cover
Evaporation dish
Test
tube
Centrifug
tube
Stir Rod with
Policeman
8" Extension Clamp
Test
Tube
Brush
Test
Tube
Clam
Support Ring
Graduated
Cylinder
Washing Bottle
Stem Funnel
Clamp Holder
Watch Glass
Wire Gauze
Volumetric Flask
Crucible Tongs
Volumetric Pipet
10 ml

2. Dispensing Policies

The following outline concisely describes the various stockroom dispensary procedures that will be used this quarter. Please read this over carefully, and discuss any questions you may have with the teaching assistant.

I. Policies at Beginning of Quarter

Goggles will be supplied to each Chemistry 2A student. Please store them in your locker until the end of the quarter. At the end of the quarter, please take them with you. You will not be given a new pair of goggles in any of the subsequent Chemistry laboratory course.

Locker Supplies. There will be a two week grace period for filling out dispensing room slips when checking out supplies from the dispensary for your locker. Make sure that you have everything on your locker list by the end of the second week of instruction.

II. Policies During the Quarter

Locker Supplies. After the initial two-week period you must bring the dispensary the broken item or a representative portion thereof and fill out a dispensing slip for a replacement. If for some reason you are not able to bring the broken item, you must fill out a dispensing room slip and have your T.A. sign it before you may obtain a replacement.

Equipment on Loan from the Dispensary. All equipment which is on loan from the dispensary must be returned to the dispensary at the end of each laboratory period.

Refilling of Chemical and Supply Containers. When replacing or refilling general laboratory chemicals or supplies, be sure to bring the empty containers to the dispensary. In the case of chemical containers, be sure to return the tops or caps with the containers.

Waste Containers. Full waste containers may be exchanged for empties located below the fume hoods. Additional containers by also be obtained from the dispensary.

III. Policies at the End of the Quarter

Surplus Stores. Any item you may have in surplus should be placed in the area set aside for surplus items in the laboratory. This is usually a box at the back of the laboratory.

Filling Locker Requirements. If your locker is short of any items when you are checking your locker equipment against your locker list, obtain the missing items from the surplus items in the laboratory. If the missing item is not in the surplus area, obtain it from the dispensary.

Preparing Your Locker for Check-In. Clean and dry all equipment. Replace all broken or missing items by checking them out from the stockroom. Return all extra equipment to the extra glassware box in lab. Have your TA check the contents of the locker and if everything is present and clean then they will lock the drawer.

D) Common Laboratory Procedures

1. Using the Balance

A balance is used to measure the mass of an object. Each laboratory room contains three electronic balances which are very easy to use. A diagram of a balance is shown in Figure 1. To use the balance, turn it on by pushing the tare bar down. The electronic readout should then be lit. Open one of the sliding doors and be sure the balance pan and surrounding area is clean. You can clean it with a balance brush or Kimwipe. Next shut the doors and press the tare bar to set the balance at zero. Now simply place the object to be weighed on the balance and measure the mass to 0.001 grams.

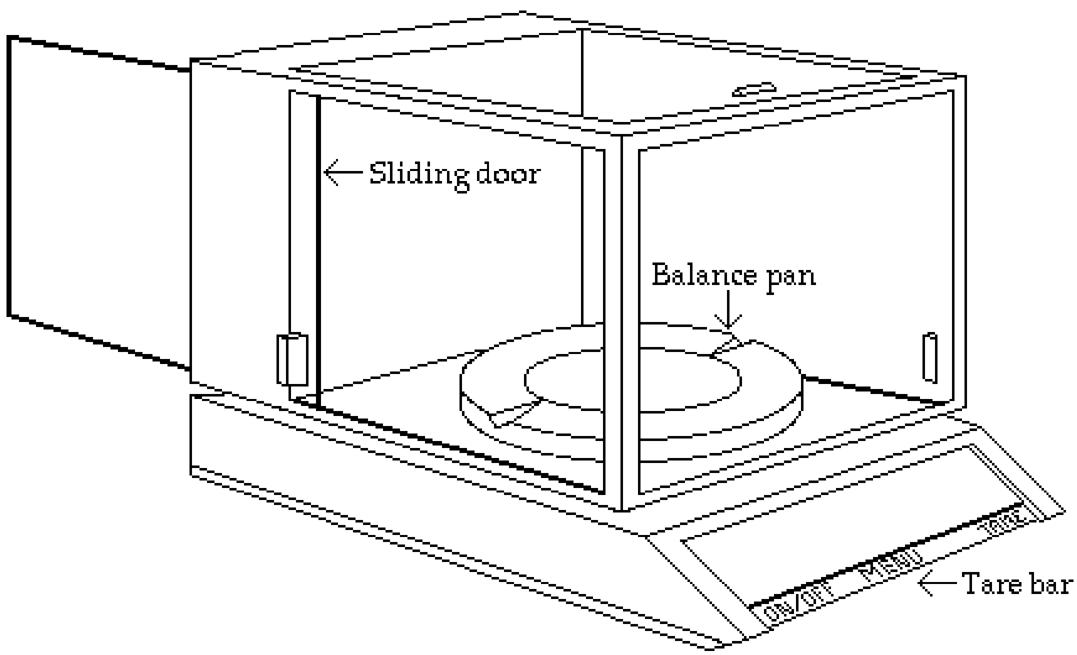


Figure 1: The Balance

Always use weighing boats when weighing solids to protect the balance. To do this simply place the weighing boats on the balance pan and be sure it is not touching the side. Press the tare bar on the right side and the balance will then read 0.000 g. Now add the desired mass of solid and record the mass. Always clean the balance carefully after use. At the end of the laboratory period, turn off the balance by raising the tare bar. Always use the balance with extreme care as it is very expensive.

2. Handling Solids

Use a clean spatula to transfer solid from bottles. Never use a contaminated spatula. Also, never return unused solid to the reagent bottle. Simply discard it. To avoid waste, never remove more solid from a bottle than is necessary. Below in Figure 2 is an illustration of how to properly weigh and transfer a solid using weighing paper. In the Chemistry 2A laboratories we are presently using weighing boats rather than weighing paper, however the techniques shown in the Figure are still useful and should be carefully examined.

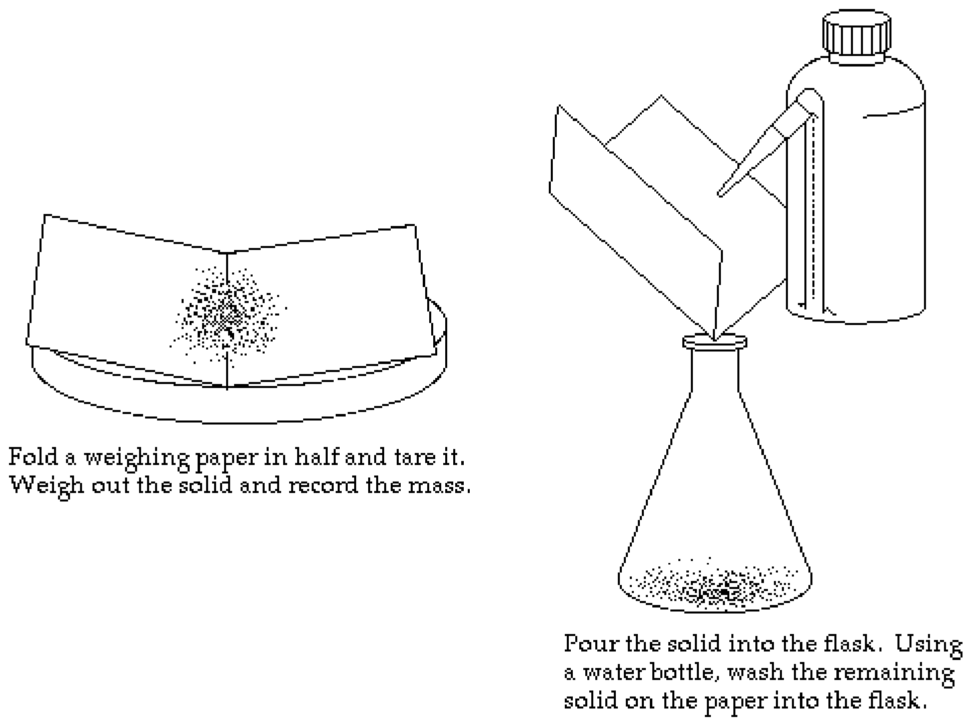


Figure 2: Solid Transfer

3. Handling Liquids

When transferring liquids from a reagent bottle, always remove the cap/stopper and hold it in your hand. Never place the cap/stopper on the bench or contamination could result. Pour the liquid slowly and carefully to avoid spillage. You may find the use of a glass rod helpful, as is shown below in Figure 3.

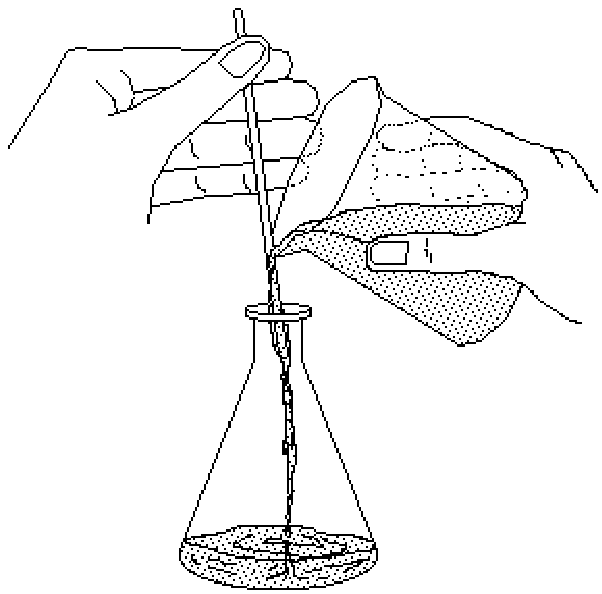


Figure 3: Liquid Transfer

4. Capping a Flask

During many experiments you will have to cap a flask to protect the contents from contamination. Figure 4 illustrates the proper method using Parafilm.

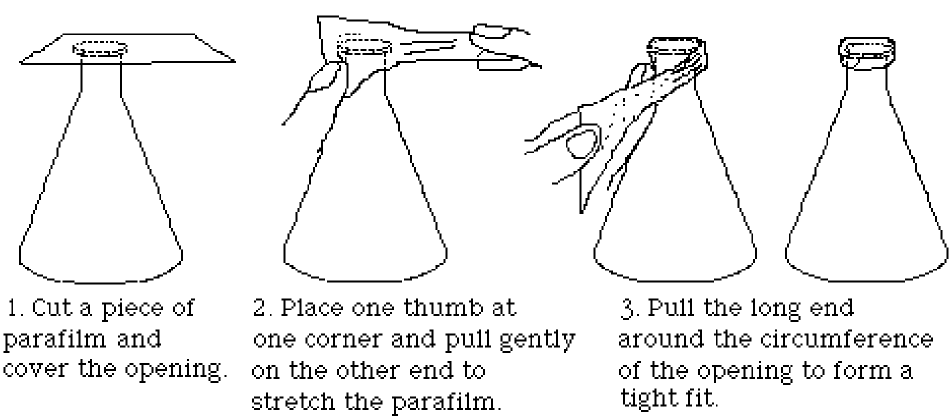


Figure 4: Capping a Flask

5. Measuring Liquid Volumes

Many glassware items have volume marks printed on them. Before using a piece of glassware to make a volume measurement, you should take a moment to study its calibrations to insure that you know how to read them properly. A beaker or Erlenmeyer flask can be used for rather rough measurements . A graduated cylinder of the appropriate size can be used for measurements of moderate accuracy. A pipet is commonly used to transfer an accurately known volume of a liquid from one container to another. However, the accuracy of such a transfer is only as good as the technique of the operator will allow.

In making any volume measurement, the liquid level should always be the same as your eye level. Erlenmeyer flasks and graduated cylinders are usually filled/read by raising them to your eye rather than by squatting down to bring your eye level to the bench top. The liquid level in a pipet is always lowered to the mark while the mark is held steady at eye level.

BURETS: With practice, the position of the meniscus of a liquid in the 25 mL burets used in the Chem 2 labs can be estimated to within 0.02 mL. Figure 5 shows the use of a card with a dark strip on it to sharpen the image of the meniscus. You will find by experiment that if the top of the strip is positioned slightly below the level of the liquid in the buret, the bottom of the meniscus will be very easy to see.

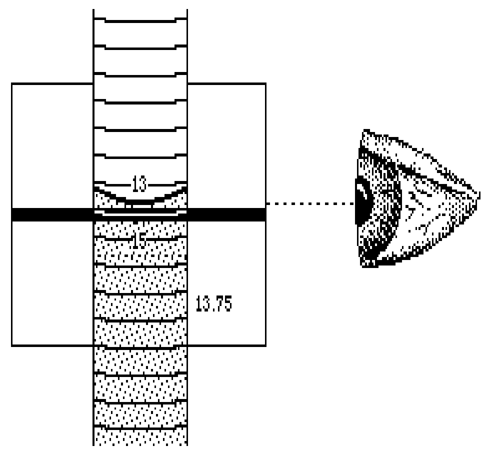


Figure 5: Reading the Meniscus

You should always use the following procedure when changing the solution in a buret. First, empty the buret out the top and half-fill it with deionized water. Open the stopcock and drain about 5 mL out of the tip. Over the sink, empty the buret out the top by inverting it swiftly, and then repeat the water washing, this time also opening the stopcock when the buret is inverted to allow most of the water to drain back out of the tip. Wait about 30 seconds for drainage and then close the stopcock. While it is still upside down, blot/wipe off the top of the buret with a laboratory tissue. Then turn it upright, and using a clean, dry beaker for the transfer, add enough of the new solution to bring the liquid level up to about the 48 mL mark. Next, drain part of the liquid out of the tip into a waste receiver, close the stopcock, and wipe off the tip with a laboratory tissue. Then, at the sink, cradle the top of the buret between the thumb and index finger of one hand and while holding it by the tip with your other hand, turn the buret horizontal. While twirling the buret by the tip, slowly empty it through the top, being careful to wet the entire interior wall with the new solution. Repeat this operation two more times. Finally, fill the buret above the zero mark and drain the excess out the tip until the meniscus is within the calibrated portion of the buret. Be sure that no air bubbles are trapped in the tip. Do not attempt to bring the meniscus to 0.00. This is both time consuming and unwise, since the 0.00 line may not be in precisely the right place.

PIPETS: Students often experience some initial difficulty in using a pipet. The following instructions, the illustrations in Figure 6 and some hands-on practice using deionized water should help you to become proficient fairly quickly. In what follows, we assume that the pipet has been prerinsed with the solution you want to transfer following essentially the same procedure as that described above for burets, except that you must use a bulb to suck the small doses of water or the new liquid into the pipet rather than pouring them in from a beaker.

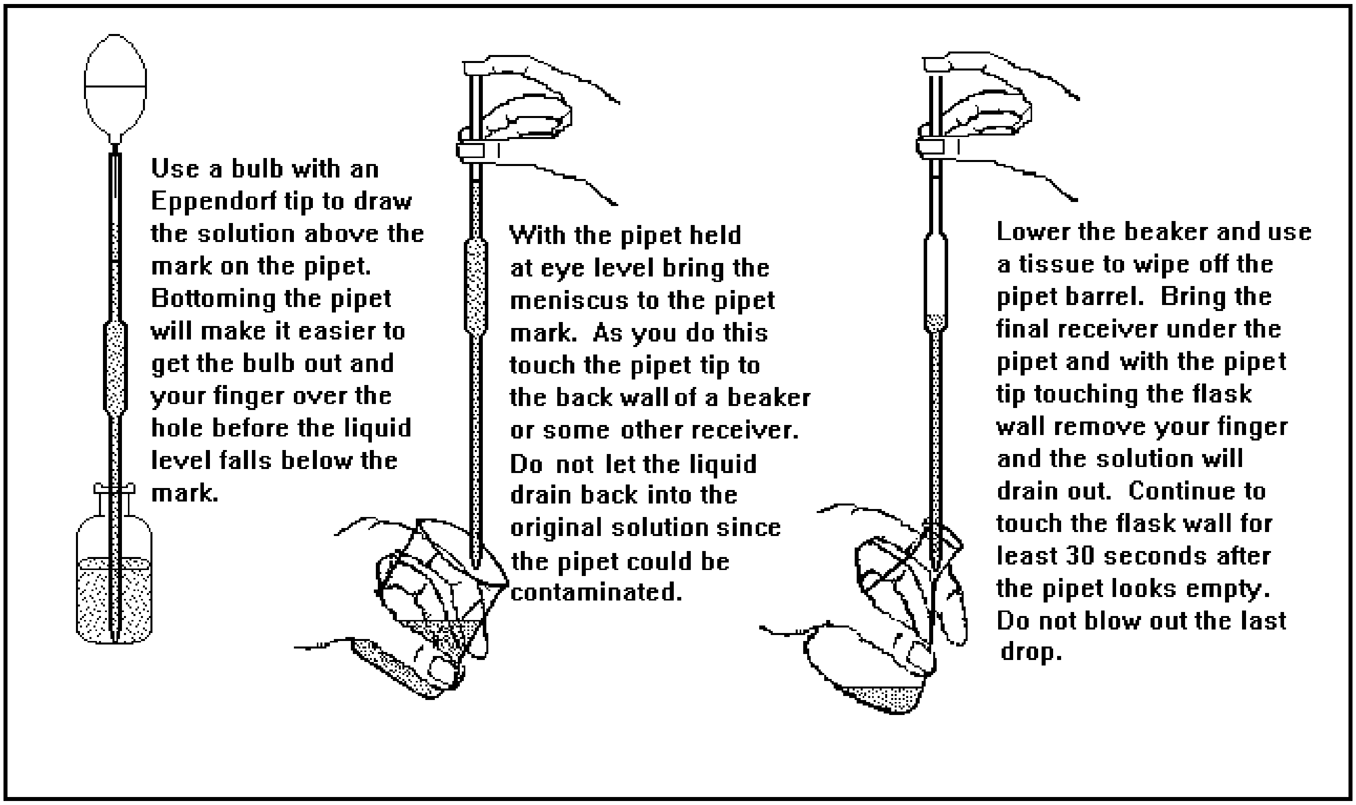


Figure 6: Using a Pipet

To begin a pipetting operation hold the pipet vertical and rest the pointed end on the bottom of the container from which you want to transfer a sample. With your least-dexterous hand, use a rubber bulb fitted with an Eppendorf tip to draw the liquid a few centimeters above the mark on the pipet. If you keep the pipet bottomed, you can then remove the bulb and quickly seal the pipet mouth with the index finger of your "better" hand before the liquid level falls below the mark. You might try conditioning your index fingertip first by rubbing it gently in the palm of the other hand. If your finger is too wet, you can't create a small enough crack (see below), and if it is too dry, you can't get a good seal.

Raise the (over)filled pipet vertically out of the vessel from which you are taking the measured sample and quickly put a beaker or some other waste receiver under it. Raise the mark on the pipet to your eye level, tilt the receiver slightly, and touch the pointed tip of the pipet to a dry spot on its side wall.

If you now slightly rock your index finger you can open and close a tiny crack at the mouth of the pipet and thereby allow the liquid level in the pipet to fall exactly to the mark on its shaft. (In this step some individuals have more success by slowly rotating the pipet using the thumb and the other fingers on the hand holding it.) Be patient because if you overshoot the mark you must begin the whole process again.

Remove the accurately-filled pipet from its container and while still tightly sealing its top with your finger, quickly dry the lower portion of the shaft with a single downward stroke of a laboratory tissue. Tilt the final receiver slightly and while holding the pipet vertical, place its tip against the receiver wall so that when take your finger off of the pipet mouth, liquid will flow smoothly down to the bottom of the vessel. You want to avoid splashing as much as possible. Keep the tip of the pipet in contact with the flask side wall for at least 30 seconds after it looks empty, then remove it from the receiver.

The pipets in the Chem 2 laboratories are calibrated "to deliver" the specified quantity of liquid rather than "to contain" it. What this really means is that you should never blow the last drops out of them.

6. Filtration

You will often need to separate a liquid from a solid. At times you will simply decant, that is, you will carefully pour out the liquid, leaving the solid behind. At other times you will need to filter the solution. To do this you will use filter paper and a funnel. You must first flute the paper in order to accelerate the process; this is shown in Figure 7.

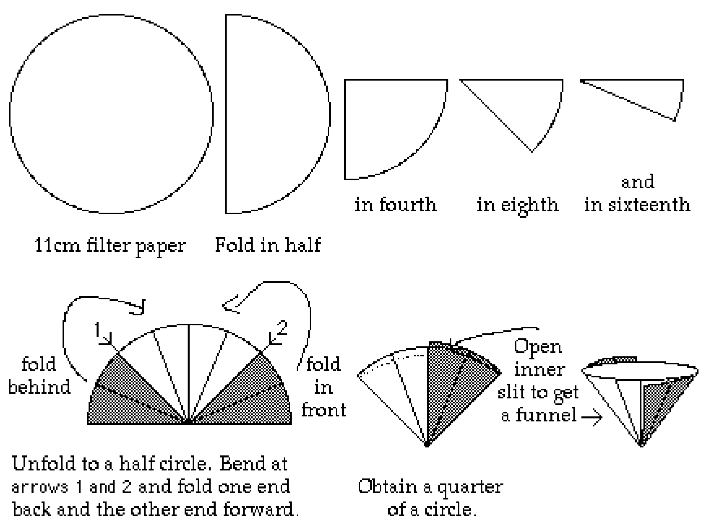


Figure 7: Fluting the Filter Paper

You will then set the paper in the funnel using your wash bottle. To do this simply place the paper into the funnel and add a small amount of water to the bottom of the filter. Slowly add water to the sides with a circular motion to avoid air bubbles between the paper and the funnel. Once the paper has set, transfer the solution to be filtered. If the solid has settled, decant the liquid through the filter first in order to save time. Never overwhelm the filter; don't add the solution too quickly and never come to within one centimeter of the top of the paper. Transfer the solid using a wash bottle and rubber policeman, then wash the solid as directed by the experimental procedure.

7. Heating

You will use both a hot plate and a Bunsen burner to heat solids and solutions. Always be careful to avoid burns and never heat a material too quickly or explosive "bumping" can occur. When using a hot plate always begin at the setting indicated in the manual. However, this setting may vary depending on the hot plate so you will have to experiment. In using a Bunsen burner always use a tight blue flame as shown in Figure 8. Control the heat transfer by adjusting the distance from the burner to the object. Note that the distances suggested in the manual are measured from the hottest part of the flame to the object.

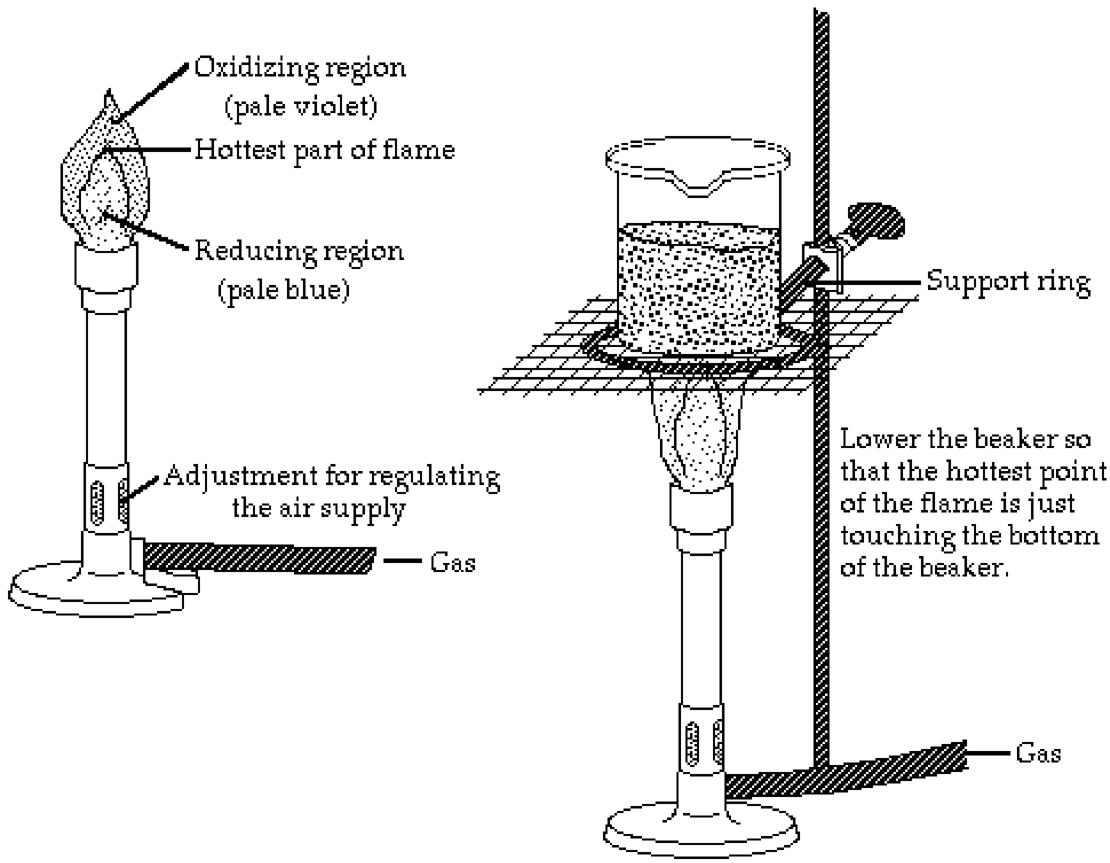


Figure 8: The Bunsen Burner

E) General Experimental Guidelines

The laboratory is a critical component of your study of chemistry. **Therefore, a student must complete all of the assigned laboratory work, including all laboratory reports, in order to pass this course.**

1. Pre-Laboratory Preparation

Many of the Chemistry 2A laboratory experiments are long and many use chemicals that could present a hazard if used improperly. Thus, students are required to judiciously prepare for each experiment by carefully reading the experiment and writing a Title, Purpose, Procedure (brief outline), and Data (outline) section before arriving at the laboratory. A detailed description of each section is described below under, "Writing a Laboratory Report". Any student without these sections completed at the beginning of the period is deemed unsafe and will have to leave the laboratory until these sections are completed. In this situation the student will still be required to complete the experiment in the allocated time and no extra time will be granted.

2. Data Collection

All data must be recorded in ink directly into your laboratory notebook. At the completion of the experiment the TA may collect a copy of the data section before you leave the laboratory and/or sign your data sheet. No laboratory report will be accepted without a TA signature by the data section.

3. Unknowns

Students will obtain all unknowns from the TA. Students must be explicit in their request for an unknown; that is, they must know the name of the experiment and unknown. If a student needs more unknown, they should notify the TA who will then write a note of explanation which the student can take to the stockroom. The note should contain the student's name, the student's locker number, the laboratory section number, the TA's name, the experiment name, and the name of the unknown.

4. Writing a Laboratory Report

You will report your experimental findings in the form of a laboratory report. Below is the suggested format that your report should follow. The report should be written in your laboratory notebook. You will turn in the report at the beginning of the period following the one which was allocated for the completion of the experiment, or at a time designated by the TA.

Below is a general outline of a common format that is often used in science laboratory courses. **Discuss this format with your TA during the first laboratory period so that you clearly understand what will be expected.**

Title: The report should have a title that concisely describes the experiment.

Purpose: This is a brief and concise statement that describes the goals of the experiment and the methods which are employed. Any pertinent chemical reactions are generally indicated. State the purpose of the experiment in the form of a complete sentence. Do not start with the word "To."

Procedure: A brief and concise outline of each step of the experiment should be included. If you are using a published procedure, you should also cite the literature or laboratory manual. A drawing of an unusual or hard to describe apparatus can also be included.

Data and Observations: Report all measurements and observations which are pertinent to the experiment. Be sure to note any problems or unexpected occurrences. It is important that this section be as neat and as organized as possible. The use of tables will often help in this regard. **All data must be recorded in ink directly into the notebook at the time it is collected.** A severe penalty will be imposed for pencil or transcribed data entries. Mistakes are not deleted. Simply draw a line through the error and record the correction. Your notebook is subject to examination at any time.

Calculations: This section generally includes any complicated calculations which are involved in the experiment. Again, it is important to use foresight when organizing this section.

Results: Report the outcome of the experiment. Brief interpretations of observations and results may also be discussed in this section.

Questions: All assigned questions are answered in this section.

Conclusions: Discuss the outcome of the experiment and any consequences the results might have. Discuss any sources of error in the experiment and your confidence in the results. Describe any practical methods which could be used to improve the experiment.

All reports must be written in non-erasable ink. A date should be indicated on each report, especially in the Data section. You must prepare for each experiment by writing the Title, Purpose, and Procedure before coming to the laboratory. It is also important to organize and prepare the format of the Data section before coming to the laboratory so that you will only need to neatly record your data and observations during the experiment. Each section should be clearly marked with a proper heading. Your notebook should be organized and written in such a manner that another chemist could read it and repeat the experiment in precisely the same way. It is also important to complete the report as soon as possible after the completion of the experiment as this is much more efficient than waiting until the night before the experiment is due.

5. Statistical Treatment of Data

Every measurement made in the laboratory is subject to error. Although you should try to minimize error, two types of errors will occur. Systematic or Determinate Errors are those errors which are reproducible and which can be corrected. Examples are errors due to a miscalibrated piece of glassware or a balance which consistently weighs light. Random or Indeterminate Errors are due to limitations of measurement that are beyond the experimenter's control. These errors cannot be eliminated and lead to both positive and negative fluctuations in successive measurements. Examples are a difference in readings by different observers, or the fluctuations in equipment due to electrical noise.

You will be graded by your ability to obtain accurate results. Accuracy describes how close your result is to the true value. Another related term is precision. Precision describes how close your results from different trials are to each other. Data of high precision indicates small random errors and leads experimenters to have confidence in their results. Data that is highly accurate suggests that there is little systematic error. A well designed experiment (and a well trained experimenter!) should yield data that is both precise and accurate.

In an effort to describe and quantify the random errors which will occur during the course of the Chemistry 2A laboratory you will be asked to report an average, a standard deviation, a 90% confidence limit, and a relative deviation. You may also have to analyze multiple trials to decide whether or not a certain piece of data should be discarded. The following sections describe these procedures.

Average and Standard Deviation

The average or mean, *x*, is defined by

$$x = \frac{\Sigma x_i}{N}$$

where each x_i is one measurement and N is the number of trials or samples.

The standard deviation, σ, measures how close values are clustered about the mean. The standard deviation for small samples is defined by

$$\sigma = \sqrt{\frac{\Sigma (x_i - x)^2}{N - 1}}$$

The smaller the value of σ the more closely packed the data is about the mean, or we say that the measurements are more precise.

Confidence Limits

Confidence limits provide an indication of data precision. For example, a 90% confidence limit of ± 2.0 indicates that there is a 90% probability that the true average of an infinite collection of data is within ± 2.00 of the calculated average of a limited collection. Clearly the more precise a set of data is, the smaller the confidence interval. Thus, a small confidence interval is always the goal of any experiment. In Chemistry 2A you will be required to calculate the 90% confidence interval for all experimental collections of data. The formula to do this is:

$$\text{Confidence Limit} = \frac{t\,\sigma}{\sqrt{N}}$$

where t varies with the number of observations. For the 90% confidence limits you are asked to calculate, t = 6.314 when N = 2, t = 2.920 when N = 3 and t = 2.353 when N = 4. You should always report your result as the average ± the 90% confidence limit.

Relative Deviation

The relative average deviation, *d*, like the standard deviation, is useful to determine how data are clustered about a mean. The advantage of a relative deviation is that it incorporates the relative numerical magnitude of the average. The relative average deviation, *d*, is calculated in the following way.

a) Calculate the average, x, with all data that are of high quality.
b) Calculate the deviation, $|x_i - x|$, of each *good* piece of data.
c) Calculate the average of these deviations.
d) Divide that average of the deviations by the mean of the *good* data. This number is generally expressed as parts per thousand (ppt). You can do this by simply multiplying by 1000.

Please report the relative average deviation (ppt) in addition to the standard deviation in all experiments.

<u>Analysis of Poor Data</u>

Sometimes a single piece of data is inconsistent with other data. You need a method to determine, or test, if the data in question is so poor that it should be excluded from your calculations. Many tests have been developed for this purpose. One of the most common is what is known as the Q test . To determine if a data should be discarded by this test you first need to calculate the difference of the data in question from the data closest in value (this is called the "gap"). Next, you calculate the magnitude of the total spread of the data by calculating the difference between the data in question and the data furthest away in value (this is called the "range"). You will then calculate the Q_{Data}, given by

$$Q_{Data} = \frac{\text{gap}}{\text{range}}$$

and compare the value to that given in the table below. The values in the table below are given for the 90% confidence level. If the Q_{Data} is greater than the $Q_{Critical}$ then the data can be discarded with 90% confidence (the value has a less than 10% chance of being valid).

Number of Observations	$Q_{Critical}$
3	0.94
4	0.76
5	0.64
6	0.56

While the Q test is very popular, it is not always useful for the small samples you will have (you will generally only do triplicate trials).

Keep in mind that you also always have the right to discard a piece of data that you are sure is of low quality. That is, when you are aware of a poor collection. However, beware of discarding data that do not meet the Q test. You may be discarding your most accurate determination!

<u>6. Barometric Readings and Unit Conversions</u>

There are barometers placed in each laboratory room that give the barometric pressure readings in inches of Hg. This measurement must be converted to mmHg. The conversion factor is 1.00 inch = 25.4 mm.

F) Late Reports & Make-Up Policy

1. Late Reports

Laboratory reports are due at the beginning of the period after the one allocated for the completion of the experiment. The last report each quarter is due at the time indicated by the TA. **Late reports will be met with a 5 point deduction for every calendar day the report is late.**

2. Laboratory Make-Up Policy

If a student misses a lab, **it must be made up before the end of the following week of laboratory** unless otherwise instructed by your TA. See the schedule below for exceptions to this policy. No further opportunity for make-up will be provided to the student who fails to make up the lab by the following week. **If a student misses the last lab of the quarter, it must be made up immediately. No laboratory make-ups will be offered after the last day of laboratory.** Students who have missed making up the lab within the allotted time period and can present proof of an extended illness or family emergency must contact the head teaching assistant as soon a possible to make arrangements regarding the missed labs. If you cannot present this proof you may receive a failing grade in the course.

3. Laboratory Make-up Procedure

NOTE: You are required to complete all labs in order to pass the course and it is your responsibility to make up any missed labs promptly. Failure to make up a lab may result in a failing grade for the course.

If you miss a lab, you must make it up by attending another scheduled laboratory section. Consult the Class Schedule and Room Directory for a listing of rooms and times. Go to the selected laboratory section and ask the teaching assistant if you may be admitted to make up a lab. You must be on time for the start of the lab period. If there is room in the class, the teaching assistant will allow you in, unlock your locker, and allow you to do the lab. Make sure to record the teaching assistant's name and have your **data signed** so that it will be accepted by your regularly assigned teaching assistant. **No laboratory report will be accepted without a valid TA's signature.**

4. Plagiarism and Unauthorized Collaboration

Some of your experiments will be done with lab partners. You are encouraged to discuss your data and its analysis and interpretation with your lab partner, other students and the TAs. However, the actual data analyses and the written reports must be done entirely independently of your lab partner or other students. Make sure that you avoid unauthorized collaboration and plagiarism. All suspected violations of the Code of Academic Conduct will be referred to Student Judicial Affairs.