General Information

You must read the following sections on emergency procedures, laboratory regulations and laboratory procedures before you do any work in the laboratory. You will be asked to sign a statement attesting to your having read these sections during the first laboratory period.

EMERGENCY PROCEDURES

Notify instructor of any accident. When in doubt about the seriousness of personal injury, seek the help of a physician immediately.

FIRE - Telephone: 9-911
SECURITY - Telephone: 4444
PHYSICIAN - Telephone: 2206
AMBULANCE - Telephone: 9-911
POISON INFORMATION - Telephone: 9-1-800-682-9211

BLEEDING - if serious, stop the flow of blood by applying direct pressure to the wound with a sterile pad or cloth. Have the patient lie down and elevate the bleeding extremity. **Avoid** a tourniquet unless the patient's life is at stake. CALL A PHYSICIAN AT ONCE.

- if minor, wash the wound, remove any pieces of glass, disinfect the wound and apply a sterile bandage.

BURNS - if serious, CALL PHYSICIAN AT ONCE. Treat as for SHOCK. Wound may be covered with several layers of sterile gauze. Avoid ointments and other medications.

- if minor, involving merely reddening of a small area, place affected part in cold water or ice for several minutes. Apply burn ointment, if desired. If blisters develop consult a physician.

CHEMICALS

A. IN EYES - flush with large amounts of cool water from the nearest source while holding the eyelid away from the eye. When the bulk of the chemical is gone, continue the washing at an eyewash fountain for at least 15 minutes. Do not attempt chemical neutralization.

B. INHALED (FUMES) - remove patient to fresh air. Keep him warm and quiet. Begin artificial respiration at once if breathing has stopped. CALL PHYSICIAN IMMEDIATELY.

C. SWALLOWED - if patient is conscious, quickly administer several (2-4) glasses of water and induce vomiting by tickling back of throat. DO NOT INDUCE VOMITING in case of acids, bases, organic solvents or petroleum products. Vomiting may be induced with lukewarm salt water (one tablespoon of salt per glass). CALL PHYSICIAN AT ONCE.

D. ON SKIN - flush away chemicals immediately with large quantities of cold water. Use the safety shower, if required. Remove all contaminated clothing. Prolonged washing is essential. For organic chemicals after an initial wash with water, scrub the skin thoroughly with soap andwater. Then treat as a thermal burn. DO NOT apply any oils or ointments.

FAINTING - lower the patient's head and raise feet. Move patient to fresh air. Do not administer liquids while patient is unconscious.

FIRE

A. CLOTHING - do not run. Avoid inhalation of fumes. Roll on floor or wrap yourself in the woolen fire blanket to smother the flames. To provide help,wrap the person in a woolen blanket or apply coats or wet towels. A CO_2 type fire extinguisher may be used with caution (away from patient's head). The safety shower may be used only if very close by.

B. CHEMICALS - leave the vicinity at once, turning out all flames if possible. Use the CO_2 type extinguisher to extinguish the fire and provide a safe exit from the lab.

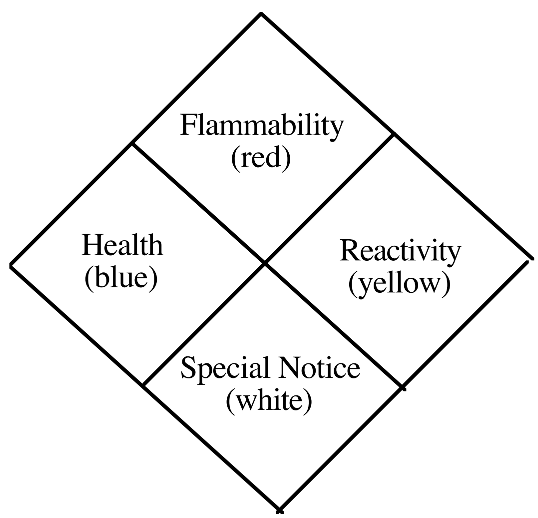
SHOCK - keep the patient quiet, lying down and comfortable. Keep them warm, and make sure that they have an adequate supply of fresh air. Reassure the patient until medical help is obtained.

INFORMATION ON LABELING CHEMICALS

All containers of hazardous chemicals must be labeled in so that the hazards are easy to identify. A number of methods are in use. Bottles obtained from the manufacturer will generally have at least some textual information and now some have pictographs as well. Textual warnings are: "Caution" --relatively low-level hazard; "Warning" --use with care; and "Danger" --use only after careful consideration of the hazards.

Containers prepared on campus will have labels indicating general hazards. The ones in common use at Williams are "Flammable," "Corrosive," "Poison," and "Cancer Hazard." Others you might encounter are "Oxidizer," "Radioactive," and "Water Sensitive." If a label is missing or damaged, please bring it to the attention of the instructor.

Some containers may have the diamond label shown below. This describes hazards as determined by the National Fire Protection Association. Be aware that the vast majority of chemicals have **not been** studied or rated by the NFPA. Therefore, the absence of such a label does not imply that the material is safe! Detailed descriptions of the meaning of the ratings can be found in the main stockroom. The blue, red, and yellow sections contain numerical ratings between 0 and 4. For present purposes, you should be aware that a "3" or "4" in any segment of the label or a notation in the white section is cause for concern --investigate further before you use the material.



WILLIAMS COLLEGE
CHEMISTRY DEPARTMENT EVACUATION PROCEDURES

In case of power failure:

1. Follow the procedures outlined by the instructor or research advisor.

2. The emergency lighting system will activate automatically but some areas may be dark.

3. Check the building to see if anyone needs help in getting out of restricted areas.

4. Turn off all computer equipment to avoid possible equipment damage from line surges when power is restored.

In case of fire or other emergency requiring evacuation:

1. Pull the alarm.

2. Evacuate the building.

Evacuation Procedures:

1. Stay as calm as possible.

2. In an orderly fashion leave by the closest safe exit. The emergency lighting system and emergency exit signs will guide you to these exits, and the diagrams on the accompanying sheets will show general evacuation routes from the labs and the classrooms.

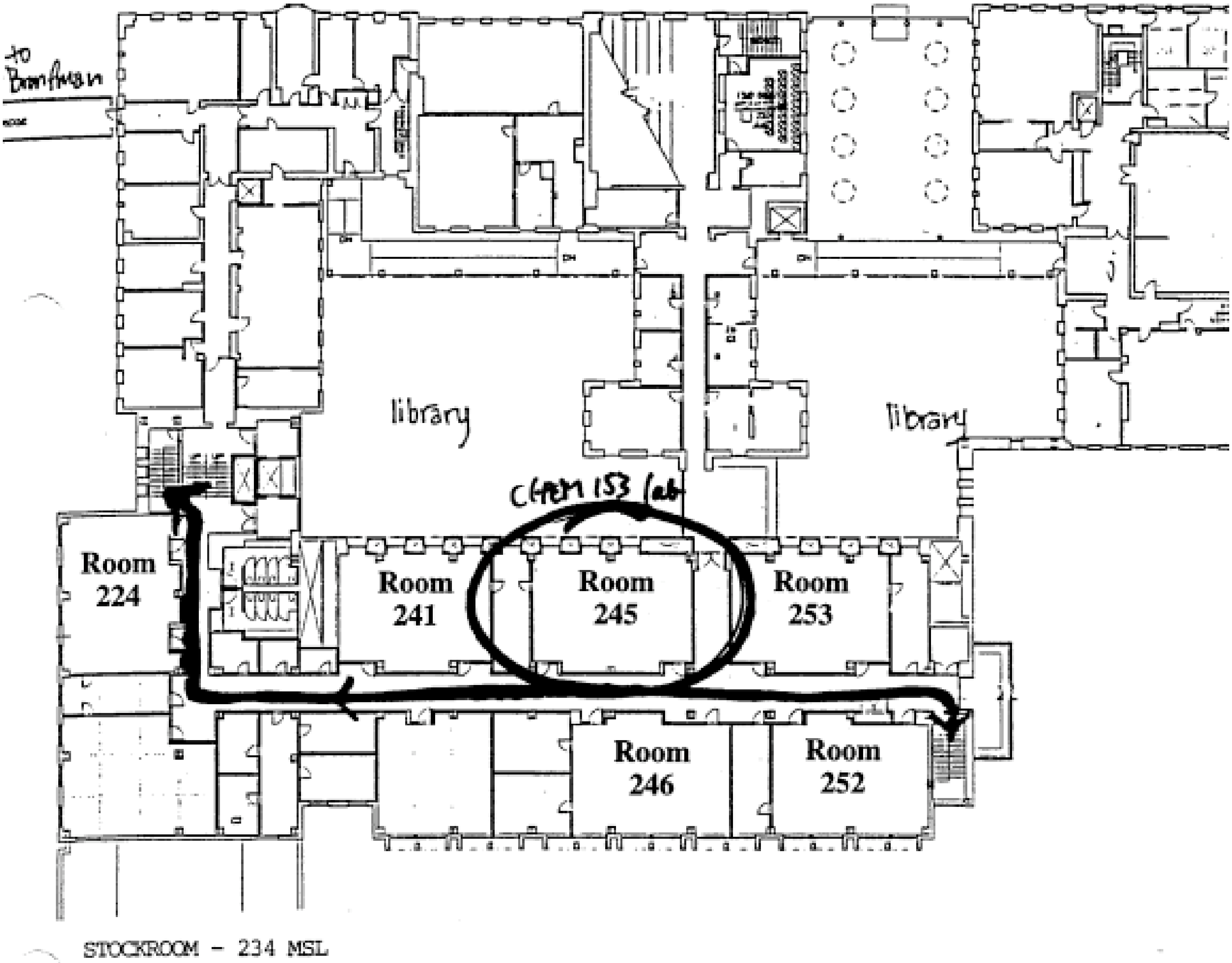
3. Nothing should interfere with the timely and safe evacuation of the building, however, depending upon the circumstances, it may be advisable to turn off equipment that could create an additional hazard.

4. While leaving, do not stop to search the building or argue with others who do not want to leave. Security Officers will take the responsibility for making sure the building is being evacuated.

5. In case of fire, feel any door for heat before opening. If it is hot, use an alternate route. If it is cool, open slowly. If there is smoke, close the door and use an alternate route.

6. Go to the middle of the Science Quadrangle, well away from the building so that all students and staff may be accounted for.

7. Do not re-enter the building until you are authorized to do so by a Security Officer.



MORLEY SCIENCE LABORATORIES
2nd Floor

LABORATORY REGULATIONS

1. Carry out all experiments and manipulations in accordance with instructions, laboratory regulations and accepted procedures to insure the health and safety of all persons working in the laboratory.
2. On withdrawal from a course at any time, the student must clean and check out all equipment within one week of his withdrawal. If this is not done, the Department will check out the locker, replacing all dirty and defective equipment at the student's expense. A charge of $50.00 will be made to the student's College account for this service.
3. To protect the eyes, all students and staff working in the laboratory must wear the safety goggles obtainable from the stock room. Contact lenses may be worn in the Chemistry labs, but the use of alternate glasses is suggested.
4. Do not conduct any unauthorized experiments.
5. Do not remove chemicals or apparatus from the laboratory for any reason at any time.
6. Work in the laboratory only during regularly scheduled laboratory periods except when special permission is granted by the instructor.
7. Never work alone in the laboratory.
8. Shoes must be worn in the laboratory at all times. Sandals and open-toe shoes do not provide adequate protection.
9. Hair must be restrained to keep it from accidental contact with flames and chemicals.
10. Smoking is not permitted in the Morley Science Laboratories.
11. Neither eating nor drinking are permitted in a laboratory.
12. Secure the approval of the Laboratory Coordinator for all absence excuses and requests for changes in laboratory periods.

LABORATORY PROCEDURES

1. Each student in the laboratory must be familiar with the location and use of the nearest shower, eye-wash fountain, fire blanket, first-aid kit, fire extinguisher, and fire exit.
2. Observe all of the following procedures in your laboratory work:

   a. Do not pour liquids in the waste crocks. Use crocks for solids only (matches, paper, etc.). Discard broken glassware in the specially marked containers.

   b. Do not put solids or paper in the sinks.

   c. When nonpoisonous acids or strong bases are poured into the sinks, wash them down with plenty of water. Deposit all organic solvents and all potentially harmful inorganic solutions and residues in the WASTE receptacles provided in the laboratory. Use minimal amounts of wash acetone.

   d. Sponge up promptly any acids or corrosive liquids spilled on the desks or floor. Use plenty of water to wash them off.

   e. Never heat a closed system, e.g., a stoppered flask.

f. Never heat organic solvents over an open flame. Use a steam bath or an electric hot plate with care. Do not pour or work with organic solvents when flames are in the vicinity. Avoid the storage of large quantities of flammable solvents in your laboratory. Use the stainless-steel safety containers.

g. Do not pour reagents above eye level.

h. Do not let chemicals contact your skin. Handle solids with a spatula or other appropriate device. Handle volatile organic liquids only when there is adequate ventilation, preferably in the fume hood.

i. Do not hold apparatus near face while mixing or heating reagents or observing reactions.

j. No open flames are permitted in the organic laboratory except by specific permission of the instructor. When permitted in any course, connect burner tubing to the gas outlet most distant from the apparatus to permit turning off gas with a minimum of danger in case of accident.

k. Never taste chemicals of any kind. Do not pipet by mouth.

l. When handling glassware, observe the following:

   (i) Fire-polish the ends of all glass tubing.

   (ii) When inserting glass tubing or thermometers into stoppers, be sure that the hole is large enough to accommodate the glass. Lubricate the tubing with water or glycerol. Hold the tubing in a towel and hold the stopper between thumb and forefinger, not in the palm of the hand. Grasp the tubing close to the stopper and rotate slightly while pressing.

   (iii) Do not attempt to push or pull glass tubing from stoppers or tubing which has become hardened. Cut the cork or rubber away from the glass.

   (iv) Do not force an oversized stopper into the mouth of a flask, bottle, or test tube.

   (v) Do not use glassware that is nicked or cracked.

m. Care should be exercised in marking glassware. The most satisfactory method is to write on ground-glass surfaces with ordinary pencil, but **not with ink or wax pencil**. Pencil marks on ground-glass surfaces may be removed by ordinary erasers. Wax pencils may be used on smooth-glass surfaces, but not on ground-glass surfaces since such marks are difficult to remove. Wax pencil marks will also melt at oven temperatures.

n. Do not waste distilled water. Use your wash bottle when one is provided.

o. Never use an ordinary wash bottle for organic solvents, e.g., acetone, alcohol. Red polyethylene wash bottles for this purpose are available at the stockroom. Indicate the contents clearly. Use minimal volumes of wash acetone.

p Side-shelf reagents are not to be taken to your desk. Take what you need in a container if necessary. Do not return unused reagents to the reagent bottle. Return reagents to proper place on the shelf. Do not use droppers to withdraw reagents from stock bottles except when stock bottles are so equipped.

q. At the end of each laboratory period wash your desk off with liberal quantities of water, using a sponge, and remove excess with a rubber squeegee. Wash your hands thoroughly before leaving the laboratory.

r. Put all your apparatus away. Be sure gas, water and lights are shut off where you have been working.

s. Lock your locker.

GENERAL LABORATORY INSTRUCTIONS

1. Attendance

   a. Attendance is expected at your assigned laboratory period. No unexcused absences or unauthorized section changes are permitted. Obviously, laboratory work at unregulated periods would require additional staff for supervision and overtax laboratory space. No make-up of laboratory work missed because of an unexcused absence is permitted, and a grade of zero will be recorded for such missed work. You may seek permission from the lab instructor to make up laboratory work missed for a reason beyond your control (e.g., illness confines you to the infirmary, representation of the College in extracurricular events takes you away from Williamstown). You are expected to complete the experiment for a given afternoon before leaving for a scheduled athletic practice or home game.

   b. If your absence can be anticipated, you are expected to arrange to make up the work **in advance**, if possible. Every effort should be made to make up the work within the week of the absence, to reduce the additional time involved in the extra preparation of reagents and special apparatus.

   c. No experimental work involving chemicals is to be performed outside of the regularly scheduled laboratory period. Operations such as the drying and cooling of samples, however, may be performed during the morning hours in preparation for the afternoon's laboratory work.

   d. **Satisfactory completion of laboratory work is required to pass the course.**

2. Planning Laboratory Work

   Before coming to the lab, each student is expected to think through the work to be done in the laboratory on a given afternoon. Before lab, write a sentence or two summarizing the purpose of the lab in your lab notebook. If you do not have your notebook when you come to lab, you will have to go back and get it before beginning work.

3. Notebook

   The first few pages of the notebook are used for a Table of Contents. Please update the table of contents after each experiment. The following pages are used for your data and the initial analysis for each experiment.

   All experimental data and observations must be entered, at the time they are taken, in non-water soluble ink (pencil and felt-tip pen smudge and become illegible and are unacceptable), directly into the notebook. Loose pieces of paper used to record data are not permitted. Do not erase data or tear pages out of the notebook. Do not use white-out to delete anything written in the notebook. If an analysis is discarded, indicate this by drawing a single line through the information. Begin a new page for each experiment, with date and title on it. Summarize the purpose of the experiment in a sentence or two. Record all your data with units. Label tables and table columns. A laboratory notebook is an official document in any research work. Emphasis should be on keeping it up to date, legible and well organized. Any chemist should be able to read your notebook easily. Write your notes as if your neighbor was to use your notes to write his or her report. Your notebook will be checked after each lab period.

   Following the recorded data, write out the experimental results and calculations in a form which indicates clearly how you determined the final results. See sample pages which follow for details.

4. Reports

   For each experiment, students will submit a written lab report or simplified worksheet. This may be a preprinted form, or an essay which summarizes the procedure used, the results and calculation, and a discussion of the results. This discussion should include estimates of sources of error, with comments on the effect these errors would have had on the final results. There may also be questions listed at the end of the description of the experiment in the lab manual. Follow these guiding questions closely.

5. Honor Code

   All reports involve numerical calculations. Where this work derives from experimental results, the Williams College Honor Code requires that students use their own data for such calculations. While consultation with other students is expected, since students will work in groups, the written report must be in your own words.

6. Calculators

   We recommend that you bring a small electronic calculator for use in mathematical manipulations during the laboratory. However, one must not assume that the answer flashed up by the calculator is correct--this will only be true if the correct information was correctly fed into the calculator. Double check all calculations both mathematically and using common sense.

show units!

Standardization of 0.1 M HCl with NaOH

I. $M = \frac{31.49\,ml \times 0.1123\,M}{35.42\,ml}$

$M = 0.0998\,M$

II. $M = \frac{31.60\,ml \times 0.1123\,M}{35.59\,ml}$

$M = 0.1002\,M$

III. $M = \frac{31.80\,ml \times 0.1123\,M}{35.72\,ml}$

M = ~~0.09997~~
0.1000 M

Standardization of 0.10M HCl

October 3, 2003

NaOH = 0.1123M

	I	II	III
Final reading:	41.22 ml	35.60 ml	36.01 ml
Initial reading:	6.80 ml	0.01 ml	0.29 ml
ml HCl	35.42 ml	35.59 ml	35.72 ml
Final reading:	32.11 ml	31.70 ml	32.10 ml
Initial reading:	0.62 ml	0.10 ml	0.30 ml
ml NaOH	31.49 ml	31.60 ml	31.80 ml

General formula:

$$M\,HCl = \frac{ml\ NaOH \times M\ NaOH}{ml\ HCl}$$

Results:

I	II	III
0.0998M	0.1002 M	0.1000 M

Average: 0.1000 M

Average deviation: 0.0001_3

ACCURACY AND PRECISION OF EXPERIMENTAL DATA

Accuracy means the closeness of approach of the average measured result to the true or accepted value of the quantity that is being measured.

Precision is the closeness of approach of a number of replicate results to the average value of these results in a series of measurements. Poor precision is associated with a wide scatter of the individual determinations about the average value.

Consider the following data taken by two students in determining the molarity, M, of the same solution:

	Student A		Student B	
	Concentration (M) (four titrations)		Concentration (M)	
1)	0.1985		0.1961	
2)	0.1979		0.2008	
3)	0.1990		0.1960	
4)	0.1987		0.1984	
	Average	Std. Dev.	Average	Std. Dev.
	0.1985	±0.0004	0.1978	±0.002

Student A would report the result as (0.1985 ± 0.0004) M; Student B would report (0.198 ± 0.002) M. Note that the standard deviation only contains one significant figure and that the average is rounded to the same decimal. Additional figures are within the margin of error of the experiment and not significant. Although the standard deviation gives an indication of the precision of the data, the precision is often expressed as a percentage of the average.

Relative Precision (%)

= (standard deviation / average) × 100%

Student A	**Student B**
$\frac{0.0004M}{0.1985M} \times 100\% =$ **0.2%**	$\frac{0.002M}{0.198M} \times 100\% =$ **1%**

If the true value of the molarity was 0.1990M, then the accuracy of the results may be expressed in either absolute or relative terms.

	Student A	**Student B**
Absolute accuracy = true value - average value	0.1990M - 0.1985M = **0.0005M**	0.1990M - 0.198M = **0.001M**
Relative accuracy (%) = $\frac{\text{true value - average value}}{\text{true value}} \times 100\%$	$\frac{(0.1990 - 0.1985)M}{0.1990M} \times 100\% =$ **0.25%**	$\frac{(0.1990 - 0.198)M}{0.1990M} \times 100\% =$ **0.5%**

Note that the scatter of Student B's data about the average value is much greater (i.e., poorer precision) than in the case of Student A. Note also that Student B's average (0.1978M) is farther from the true value (0.1990M) than is Student A's average value (0.1985M). Student A's result is considered to be both the more precise and the more accurate.

The attainment of a good degree of precision gives confidence in the consistency of the measurements but does not of itself prove that the average result is of high accuracy because constant errors inherent in a given technique affect all measurements. If one follows carefully a good procedure, however, there is a strong probability that precise measurements will also be accurate.

Precision in percentage or relative accuracy in percentage is more useful than the average deviation or the absolute accuracy as illustrated by the following determinations of the iron content in two different substances.

	Iron(III) oxide Fe_2O_3	**Hemoglobin** Fe_4Hb
Percentage iron by weight (true value)	69.94%Fe	0.33%Fe
Student's average determination with average deviation	69.89 ± 0.03%Fe	0.31 ± 0.03%Fe
Precision	$\frac{0.03}{69.89} \times 100\% = 0.04\%$	$\frac{0.03}{0.31} \times 100\% = 10\%$
Absolute accuracy	69.94 - 69.89 = 0.05	0.33 - 0.31 = 0.02
Relative accuracy	$\frac{0.05}{69.94} \times 100\% = 0.07\%$	$\frac{0.02}{0.33} \times 100\% = 6\%$

The average deviation is the same (0.03%Fe) in both cases, but whereas this represents good precision (0.04%) in the iron(III) oxide determination, it represents very poor precision (10%) in the hemoglobin determination. A similar comparison can be made between the absolute and relative accuracies.

How to use this information

Estimating the experimental uncertainty in a final result based on the uncertainties in the steps of the experiment is called "propagation of errors." "Error," as used here, does not refer to mistakes. Rather it describes the fact that repetition of an experiment, even by the same person, is likely to give different results because the measurements involved are neither infinitely accurate nor infinitely precise. "Error," or "measurement uncertainty," is thus what allows us to judge whether two results are truly different, or "agree within the limits of experimental error" (a common phrase in lab reports and scientific papers).

A simple and useful method for calculating the final uncertainty is to calculate the maximum error which would be obtained if the errors in all the measured quantities had their maximum values and were in such directions that all affected the final result in the same direction. It is unlikely that the errors will combine in this way, as there is usually some compensation of errors, but it is useful to know the maximum value an error could have in an unfavorable case.

Consider the determination of a value of u, which is obtained by adding measurements x and y:

$$u = x + y$$

In terms of errors in the quantities, u, x and y, we have

$$\Delta u = \Delta x + \Delta y$$

Thus, if the error in measuring x is Δx and the error in measuring y is Δy, the maximum error in u is $\Delta x + \Delta y$.

A particularly relevant example of the accumulation of errors can be found in weighing by difference, as practiced in Experiment 1. The balance has an inherent error of about 0.0002 g.

Weight of bottle with sample	27.1982 ± 0.0002 g.
Weight of empty bottle	27.0675 ± 0.0002 g.
Weight of sample	0.1307 ± 0.0004 g.

Although the ± 0.0002 g. is a negligible error (0.00006%) in the larger weights, the accumulated ± 0.0004 g. represents a 0.3% error in the weight of the sample.

In summary: The maximum error in a sum or difference is equal to the sum of the absolute values of the maximum errors in the measured quantities.

Propagation of error is more complicated if the calculations involved in finding the result include multiplication and division. In this case, the error in each factor should be converted to a percentage, and the percentages added to get a maximum uncertainty. Continuing the example above, let us assume that we are going to divide the sample weight by sample volume. If the volume is 100 ± 1 mL, the uncertainty in this measurement is 1.0%, and the total uncertainty in the calculation is 1.3%.

Now let us consider just what "uncertainty" means. In the study of statistics, the variability of a repeated measurement often follows a Gaussian distribution, or "bell-shaped curve," shown in Figure 1. The y-axis represents the probability of obtaining a certain value. For the weighing example above, the greatest probability is that if the weighing is repeated, the value will again be 0.1307 g. However, there is a certain probability that it could be anywhere between 0.1303 and 0.1311 g. Therefore any repeat value within those limits can be said to "agree within experimental errors."

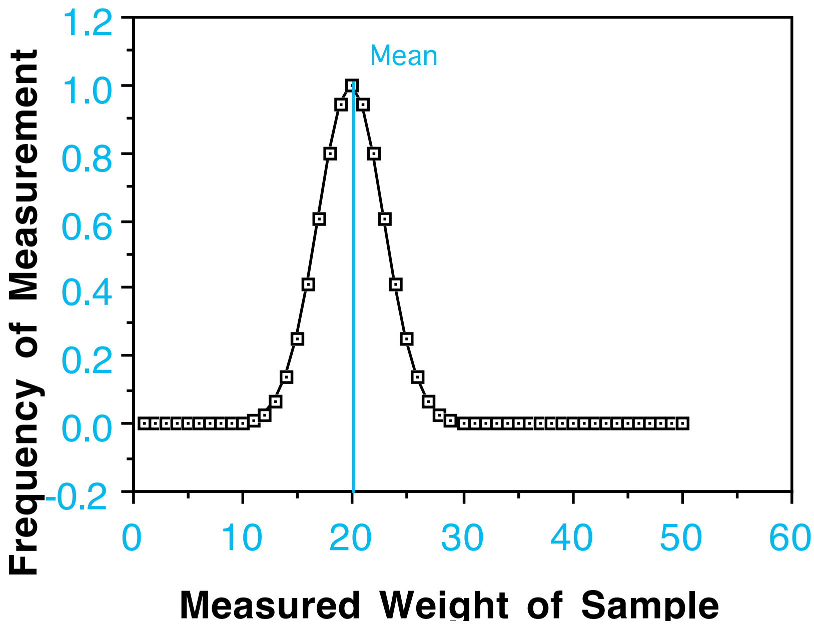


Fig. 1. Gaussian Distribution of Errors

Now let us assume that two experimenters have done the same experiment and we are comparing their results to see if they agree. One has measured the weight of the sample as 0.1307 $\pm$ 0.0004 g, and the other has measured it to be 0.1310 $\pm$ 0.0004 g. We plot both results on a graph similar to that in Fig. 1 and note that although the values are not the same, there is very significant overlap between the error distributions. We would say that there is some agreement, if not complete agreement, between the results. In contrast, if someone measured this sample and obtained a weight of 0.1320 $\pm$ 0.0004 g, there would be essentially no overlap between the two experiments, and we would say that they disagree with each other.

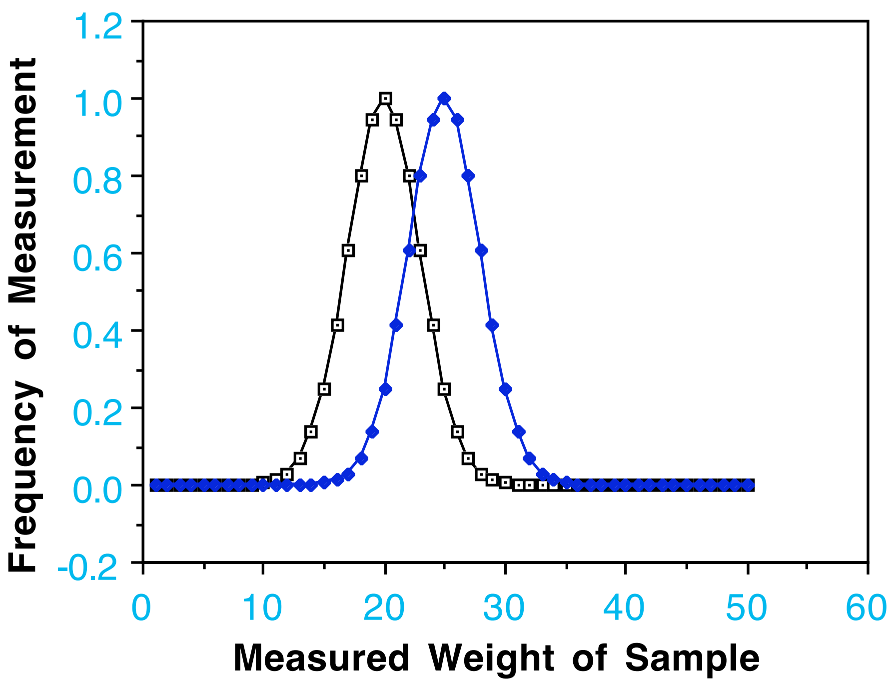


Fig. 2. Comparison of Two Gaussian Distributions

A more sophisticated way of propagating errors recognizes the potential for compensating errors in repeat results. Instead of adding the individual errors, either the absolute values or the percentages, it uses the formula

$$(\Delta u)^2 = (\Delta x)^2 + (\Delta y)^2$$

In the example above, this would give a final error of 1.04%, rather than 1.3%. However, for most of the work in introductory chemistry this level of precision is not needed.

Using terminology with which you may be familiar, we can write the mean or average as:

$$\text{Average (mean)} = \mathbf{\langle x \rangle} = \frac{x_1 + x_2 + x_3 + x_i + + x_n}{n}$$

<u>Standard Deviation</u> (σ)
The mathematical treatment of random errors gives the Gaussian distribution curve a theoretical basis and introduces this useful quantity to express the reliability of a set of results. This quantity, the standard deviation, is defined thus:

$$\sigma = \left\{ \frac{\sum_{i=1}^{n} (x_i - \langle x \rangle)^2}{n-1} \right\}^{1/2}$$

This is a function you may have on your calculator and which is available on most computer spreadsheets such as Excel. Standard deviation is rather meaningless for very small samples (such as 2 to 4 or 5 points) but works well for larger samples. Data may be reported as: (mean ± st. dev.) unit

SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES

It is customary in scientific work to write any number as a number between 1 and 10, with a decimal point, and to indicate the magnitude of the number by an exponential. It is then understood that there is some uncertainty in the most right-hand digit, plus or minus 1. It is generally held that if one or more of the right-hand digits are zeroes, the only certain way to know the number of significant figures is to use scientific notation. Thus in the examples below, 12000 could represent 2, 3, 4 or 5 significant figures. The scientific notations, on the other hand, are unambiguous. For example,

Number	**Should be Written as**	**Number of Significant Figures**	**Indicates a quantity in the range**
0.000001972	1.972×10^{-6}	4	1.971×10^{-6} to 1.973×10^{-6}
186,175.3	1.861753×10^{5}	7	1.861752×10^{5} to 1.861754×10^{5}
12000	1.2×10^{4}	2	1.1×10^{4} to 1.3×10^{4}
	1.2000×10^{4}	5	1.1999×10^{4} to 1.2001×10^{4}

A calculated result can be no more accurate than the data used to calculate the result. In the following example, a student weighed an amount of pure AgCl and wants to know how much Cl^- is contained in this AgCl.

Atomic weight Cl	35.453 g/mole (or amu)
Atomic weight Ag	107.868 g/mole
Formula weight AgCl	143.321 g/mole

If the AgCl, when weighed on a rough balance, was found to weigh 1.25 g, the calculation would be done correctly as follows:

$$\frac{35.453 \text{ g/mole}}{143.321 \text{ g/mole}} \times 1.25 \text{ g} = 3.09 \times 10^{-1} \text{ g Cl}$$

where the answer is limited to only three significant figures by the three-figure weight of AgCl, regardless of the very precise atomic weights.

If the AgCl, when weighed on a more precise balance, was found to weigh 1.2487 g, the calculation would be done correctly as follows:

$$\frac{35.453 \text{ g/mole}}{143.321 \text{ g/mole}} \times 1.2487 \text{ g} = 3.0888 \times 10^{-1} \text{ g Cl}$$

Remember that use of an electronic calculator, with a nine or ten digit display, in no way means your data are significant to nine or ten digits. The number of significant digits in your answer is determined by the precision of your experimental observations.

If you perform several trials of the same experiment, the precision of your calculated average result can not exceed the standard deviation of the data set. For example, the data 1.23 g, 1.35 g, 1.42 g, and 1.17g averages to (1.3 ± 0.1) g regardless of the three significant figures of the original data.

PREPARATION OF GRAPHS

In many experiments, calculation of the results requires graphing the data. Here are a few general principles for constructing an acceptable graph:

1. Number the graph (Figure 1, Figure 2, etc) and give it a title. Refer to the figure number when discussing the graph in the text of a report.

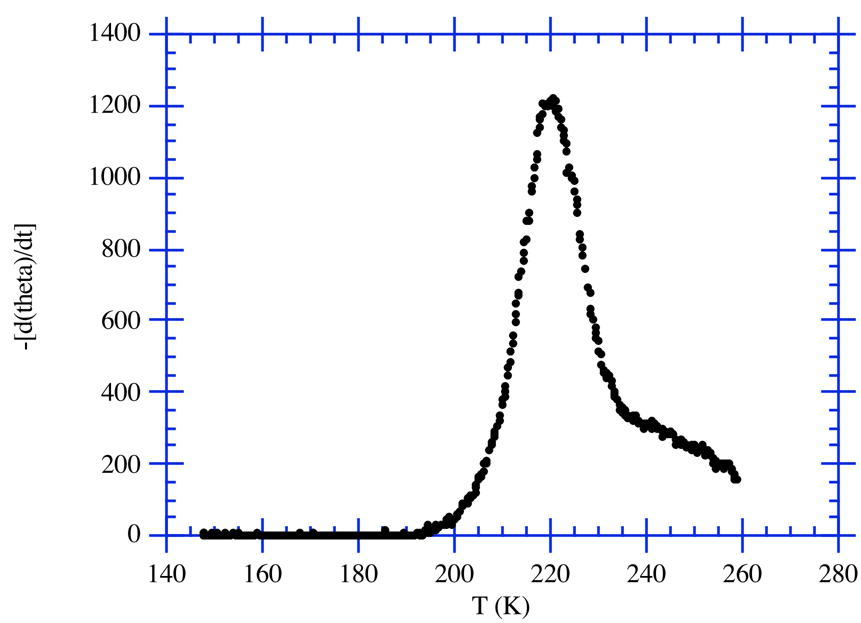
2. Label the axes and add units.

3. Choose the limits of the axes so that the data cover most of the available area. Pick tick mark label spacings that make it easy to interpolate (calculate values in between measured data points). If needed, choose a numerical multiplier to make the tick mark labels easier to read.

4. Use of the computer is not required. A hand-drawn graph is perfectly acceptable, provided it conforms to the previous suggestions. (See example below.) If doing a graph by hand, use a ruler to draw the line that best fits the points. If you want to determine the slope of the line (not always required), use large line segments.

5. Microsoft Excel by default adds a large amount of distracting decorations (graph junk) and chooses axes ranges, tick marks, etc. very poorly. If you use Excel, do not accept the default settings, but modify the graph carefully according to the principles outlined above. Alternatively, learn to use a scientific graphing program instead, such as Kaleidagraph.

Figure 1. Rate of Evaporation of β-NAT versus Temperature



A GUIDE FOR WRITING CHEMISTRY LABORATORY REPORTS

A good scientific report is clear, concise, and complete. You should strive to organize and express your thoughts carefully, avoid unnecessary words and phrases, and include enough information to explain clearly (to a chemist who has not done the lab) what was done, why it was done, how it was done, and what it means in the most concise fashion possible. A lab report is not an English paper.

Each experiment's grade depends not only on the precision and accuracy of the results, but also on the quality, content, and neatness of the report. The writing should use a good literary style and should follow the outline described. Typed or word-processed reports are preferable but not required. However, reports written in pencil are not acceptable. Be sure to proofread your report before submitting it. Try to avoid printing multiple copies of your report. You may correct minor typographical errors in pen.

The following format is similar to that used in scientific articles and should be used for your report.

I. **Title page**: Include your name, your partner's name (if any), a title for the report, the date you performed the experiment, the date you submit the report, your lab instructor's name, and the class name (e.g. Chem 155).

II. **Abstract** (max. 5 sentences): a statement about the purpose of the experiment and how it was performed and a brief summary of your experimental results (including numerical values and standard deviations when appropriate). Basically, the abstract summarizes the entire report with just the highlights. You might find it easiest to write this after the rest of the report. This section does duplicate statements that appear in the body of the report.

III. **Introduction** The introduction presents the background information for the experiment and places your paper in context. It is supposed to get the reader interested. To emphasize the significance of your experiment you can start with a "big" statement, which you subsequently narrow down to the specific question answered with your experiment. Do not start the introduction with the phrase: "The purpose of the experiment was to…"

IV. "**Materials and Methods**" or "**Experimental Procedure**": Describe what you did and what equipment and chemicals you used. If the procedures were exactly as presented in the laboratory manual, simply cite the page number(s) and then provide a brief summary of the essence of the methods followed. Do describe in detail any deviations from the prescribed procedures in this section.

The Results and Discussion sections will be the heart of your report and should comprise the bulk of the narrative. These may be separate sections or be combined if this facilitates writing the report in the most lucid and compact form possible.

V. **Results**: Describe your results and significant observations. Use chemical equations, rather than sentences such as "I mixed HCl and silver nitrate to make silver chloride". Both chemical and mathematical equations should be numbered. Try to present all of your data in clearly labeled and numbered figures (e.g. graphs) and tables; refer to these throughout the remainder of the report. Preface each table and figure with a succinct descriptive sentence. A graph must include clearly labeled axes with units, estimates of uncertainties (with error bars on the graph), and a title. The title "Plot of Y vs. X" does not convey any information. A title such as "Spectrophotometric determination of the pseudo first-order rate constant for the acid-catalyzed bromination of acetone" makes a graph much easier to read. Tables, like graphs, should include a meaningful title and perhaps a caption. If numerical results stem from more than one trial, give standard deviations (precision). If a literature value is available, calculate the percentage error (accuracy).

VI. **Analysis**: If you perform a multi-step analysis of your data, present each step in an easy to follow, step-by-step form. Start with your original data, use words to introduce new symbols and their value (mass of sample: $m_s = 2.315$ g), and formulas for each step of the analysis (molecular weight of sample: $M_s = m_s/n_{NaOH} = 112.5$ g/mol). See the sample worksheet below.

VII. **<u>Discussion</u>**: This section should contain a thorough analysis of the significance of your results and data. Comment on sources of error, and analyze accuracy and precision when appropriate. Address any questions raised in the laboratory manual in this section.

VIII. **<u>References</u>**: You should *explicitly* reference the laboratory manual, results of other students, any students or tutors with whom you consulted, and any chemical literature that you use in preparing your report. Complete book references include the author(s), title, page, publisher, city, and year. Complete journal references include the authors(s), journal name, volume, page, and year. See the references on the next page for examples of style. You do not have to cite any information that you learned in class.

Example Analysis using a spreadsheet (Exp 1)

mass KHP	amount KHP	Volume Titrant	concentration NaOH
	$n_{KHP}=m_{KHP}/M_{KHP}$		$c_{NaOH}=n_{NaOH}/V_{NaOH}$
m_{KHP} [g]	n_{KHP} [mol]	V(NaOH) [L]	c_{NaOH} [mol/L]
0.2534	0.001241	0.01213	0.1023
0.2211	0.001083	0.01070	0.1011
0.2944	0.001442	0.01397	0.1032
0.2412	0.001181	0.01179	0.1002

Mol Weight KHP
M_{KHP} [g/mol] 204.224

Note: $n_{KHP} = n_{NaOH}$

Avg. Conc. c_{NaOH} [mol/L]: 0.1017

Stand. Dev. Δc_{NaOH} [mol/L]: 0.0013

Final Result: $c_{NaOH}=(0.102 \pm 0.001)$ M

<u>Some additional comments and suggestions</u>:

1. Number *each* page.
2. Set each equation apart from the text and number it.
3. Number each table and figure.
4. Write in complete sentences. Break up your writing with paragraphs.
5. Use simple present or past tense; be consistent throughout your report. The active voice is generally preferable over the passive voice because the active voice is stronger and more direct, requires fewer words, and conveys accountability of the experimenter for the results and interpretation. Personal pronouns, "I" or a slightly less personal "we", are perfectly acceptable.

   Examples: Passive voice--"The temperature was measured to be 135°C."
   Active voice --"The temperature was 135°C."
   Active and personal--"We (or I) measured the temperature as 135°C."

6. <u>Spelling and grammatical errors detract significantly from the quality of a report</u>. Please proofread before submitting the report. Remember that spell-checking programs do not pick up all errors!

7. According to strict rules of grammar, you should avoid splitting infinitives: "to effectively measure" should be "to measure effectively." (This is a case of controversy as the English language does evolve with time. In fact, as of August 1995, the Oxford English Dictionary accepts split infinitives if used sparingly. You might still want to avoid split infinitives, however, since many people do not accept split infinitives.) One prime example of a split infinitive many of you will recognize: "to boldly go where no man has gone before."

8. You should eliminate unnecessary words: "The procedure was used in order to determine...." could be "The procedure was used to determine..." or even "The procedure determined...."

9. Avoid colloquial expressions and jargon: "The Cary 219" should be "The Cary 219 spectrophotometer."

10. "Absorption" is a general word. "Absorbance" refers to interaction with light. "Adsorption" refers to something adhering to a surface.

11. "Data" and "spectra," like strata, phenomena and media, are a plural words. "The data are given in the table". "Datum" and "spectrum" are the singular forms.

12. "Affect" is a verb and generally "effect" is a noun. One way to remember this is that in alphabetical order, the action has to come before the result (verb before noun).
    As a noun "effect" means "result." "Effect" can also be a verb, meaning "to bring about", "to accomplish," but this use is less common.

13. Two independent sentences joined by a conjunction such as "and" are separated by a comma. For example: "The mixture boiled for 15 minutes, and the solution turned purple." On the other hand, there is no comma in a single sentence when you are joining two verbs with a single subject. For example: "The mixture boiled for 15 minutes and turned purple." ("The mixture boiled and turned.")

14. Word-processing, graphing, and spreadsheet computer programs can make data analysis and presentation easier (and oftentimes much more time-consuming). Handwritten reports are acceptable if they are written *legibly* in ink. If you prepare your report on a word processor, one-inch margins, double spaced, 12-point Times make for easiest reading and most efficient use of paper.

15. All numbers should include **units,** the correct number of significant figures, and, where appropriate, estimates of the error.

16. Write your report so that a scientist could understand it without reading the laboratory manual. Instead of "The peak for the dilute sample occurred at 532." use "The wavelength of maximum absorbance for $1.0x10^{-4}$M rhodamine 6G dye in methanol is 532 nm."

17. You should be aware of several books (in the Chemistry Library) that are useful references for report writing:

    Janet S. Dodd, *The ACS Style Guide, A Manual for Authors and Editors* (American Chemical Society, Washington, DC, 1986).

    William Strunk, Jr. and E. B. White, *The Elements of Style*, 3rd Edition, (Macmillan, New York, 1979).

    Robert Schoenfeld, *The Chemist's English,* (VCH Verlagsgesellschaft, Weinheim, 1985).