

***MicroLAB* COMPUTER INTERFACING
IN THE CHEMISTRY LABORATORY:**

Compiled and Edited

by

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January 2005

PREFACE

The *MicroLAB* Teaching Curriculum

This CD contains sixty-four computer-based *MicroLab* experiments for general and advanced chemistry courses, including variations on some of them. In 1992, an initiative called **Computers in Chemistry Laboratory Instruction (CCLI)** was organized by Dr. John R. Amend, and a compilation of twenty-six experiments obtained, the copyright for which now resides with *MicroLAB*. Those participating in this original CCLI Initiative and the schools they were associated with at that time were: Dale Hammond, Brigham Young University, Hawaii; Mike Seymour, Hope College; John Amend, Montana State University; Susan Arena, Mount San Antonio College; Sophia Nussbaum, University of British Columbia; Steve Gammon, University of Idaho; Steve Zumdahl, University of Illinois at Urbana-Champaign; Ron Furstenau, U.S. Air Force Academy; and Joe Crook, Don King, and Jack Weyh, Western Washington University

Significant effort has been directed at assembling and revising the CCLI experiments and adapting them for use on the *MicroLAB* interface by Dale A. Hammond, PhD. Those experiments are simply referred to as “The CCLI Initiative” in a title block of the Experiment write up.

Additionally, many experiments have been assembled from the work of John Amend, Dale Hammond, and others, and adapted for use on the *MicroLAB*. Individual credit will be given in the title block to those involved in each experiment. The list of experiments is still growing, at this time. All of the experiments, in PDF format, including new ones as they are developed, will be available from **MicroLAB, Inc.** at PO Box 7358, Bozeman, MT 59771-7358, or at the web site information at microlabinfo.com, and different experiments will be posted on this website from time to time.

Individual experiments in Word, and WordPerfect formats of these experiments are available for purchase from *MicroLAB* at \$25 per experiment at the above addresses. Faculties are encouraged to use these resources to create experiments for use in their courses. Although these materials are copyrighted by MicroLab, permission is granted to a faculty who purchase the individual experiments to modify and use the experiments at their institutions.

In each experiment listing, there is an **Experiment** file, ready for printing, which guides the student through the experiment, and an **Instructor’s Resource** file, containing Learning objectives, Procedure Overviews, suggested Report sheets, suggested Questions/Problems sheets, a Tips and Traps section to alert the instructor to potential problems and helps, Sample Data, Sample *MicroLAB* screens (unfortunately, not in all of them at this time), completed Report sheets and Questions/Problems sheets, and Laboratory Preparation per student station.

Most of these experiments are of the “confirm the law or principle” format, but can be easily converted into the “guided inquiry” or the “pure inquiry” format, as discussed in the next section.

INTRODUCTION

The Scientific Method

Science is mankind's search for understanding of the universe that surrounds us. Science progresses through inquiry, which often involves the observation of as yet unexplained phenomenon, and the search to understand it. Although every scientific discipline follows somewhat different protocols, the generalized protocol is what is commonly called the **Scientific Method**, which consists of five generally accepted steps as follows:

1. Observation of some as yet unexplained phenomena
2. Searching the literature and conducting preliminary experiments to obtain additional information.
3. Formulating one or more hypotheses to explain the observation in terms of the literature of known information and the additional information gained through the preliminary experiments.
4. Devising experiments to test the hypotheses in terms of the known facts.
5. Accepting, rejecting or modifying the original hypotheses in light of the experiments undertaken.

This process is then refined by reviewing all of the known information, devising new hypotheses or refining the old hypotheses, developing new experiments, etc. The common concept that the scientist goes into the laboratory knowing what he or she is going to discover and just goes about confirming it is, of course, fallacious. A currently growing number of educators have come to the conclusion that science should be taught the way it is practiced, by inquiry. However, particularly in general chemistry, there is not sufficient time for students to discover all of the chemistry facts to be learned in that course by this method. Consequently, one usually settles on a mix of experiments consisting of some “confirm the law or principle” experiments (Type 1), a few “guided inquiry” experiments (Type 2), and only two or three “pure inquiry” experiments (Type 3). Each of these types will be discussed in turn for application in the general chemistry laboratory.

“Confirm the Law or Principle” Experiments (Type 1)

The basis of a “confirm the law or principle” experiment is to give the students careful directions on how to set up the equipment, how to conduct the experiment, and how to analyze the data. Because the beginning chemistry student lacks the chemical background and laboratory skill's necessary, initial experiments should be devoted to building this basic laboratory background and skills. For experiments that use the *MicroLAB* interface, these beginning skills may be developed by using the manual **Measurement, the Basic Science**, published by Hayden McNeil, where the student is introduced to computerized data collection, using various sensors such as temperature, pressure, pH, and colorimetry to collect data, using that data in making and interpreting graphs, etc. This manual takes students through the first two or three lab periods, at the preference of the instructor. An exercise that is particularly helpful to students in this early stage is **An Exercise in Organizing and Analyzing Experimental Data**, (Experiment 12.1 or 12.2 on this CD) which leads the students through the steps listed below to help them understand the use of graphing (either using the

MicroLAB spreadsheet or **EXCEL**) and mathematical modeling to better understand the relationships of experimental variables to each other:

- a. The roll of models in science.
- b. Using graphs to identify mathematical models.
- c. Regression analysis and the correlation coefficient.
- d. Predicting from the model.
- e. Linearizing non-linear data to determine the variable relationships
- f. Six directed non-linear examples involving power functions, inverse relationships, etc.
- g. Three completely independent examples.

One then begins to build chemical knowledge and laboratory confidence with additional “confirm the law or principle” experiments, interspersing a “guided inquiry” experiment here and there as they build confidence, and toward the end the semester, introduce one or two “pure inquiry” experiments. The second term can then build on this basis by introducing more “guided inquiry” and “pure inquiry” experiments.

Guided Inquiry and Pure Inquiry Experiments

The purpose of the guided inquiry experiments is to begin weaning the students away from the “cookbook” approach of the “confirm the law or principle” type experiments, and to begin guiding them toward thinking out the experiment for themselves in terms of (1) what are the variables involved, (2) which of these variables are dependent and which is the independent variable, (3) how can these variables be controlled so that the data is meaningful, (4) what experiments need to be designed to gather preliminary information upon which to formulate hypotheses, (5) how do I go about formulating hypotheses, (6) how do I devise experiments to test those hypotheses, (7) how do I analyze the data from those experiments, etc. This is nearly always a totally new experience for the students, and often is a shock to them. They need to be guided into that mode by providing sufficient information in the beginning that will help them begin to think through these questions. Consequently, “guided experiments” early on in the term should provide more help than those later on in the term. Additionally, since each instructor, as well as the backgrounds of the collection of students are unique to each classroom, it is best for each instructor to determine when directed inquiry should be introduced, and how much help is to be provided at each stage as the students progress

Figure 1 visualizes the process we are trying to get the students to master. The student is presented with a problem, for which he or she needs to obtain a solution. The students are given a preliminary experiment design, which in the beginning is more detailed, but as they progress, the detail is shifted more and more for them to work out. They carry out the initial experiment, acquire the data, then organize it and try to draw conclusions concerning whether they have solved the problem. If they adequately understand the problem, then they have arrived at their solution. If they do not yet adequately understand the problem, then they must discuss the problem with their partner and/or their instructor, seek additional resources to shed more light on it, redesign their experiments in light of their new information and repeat the process from experiment to acquire data to organize and draw conclusion and again determine if they adequately understand the problem. This is known as the Axiomatic-cum-pragmatic cycle, where axioms or postulates about the problem are made, the experiments are carried out, and the results correlated back to the beginning postulates for confirmation.

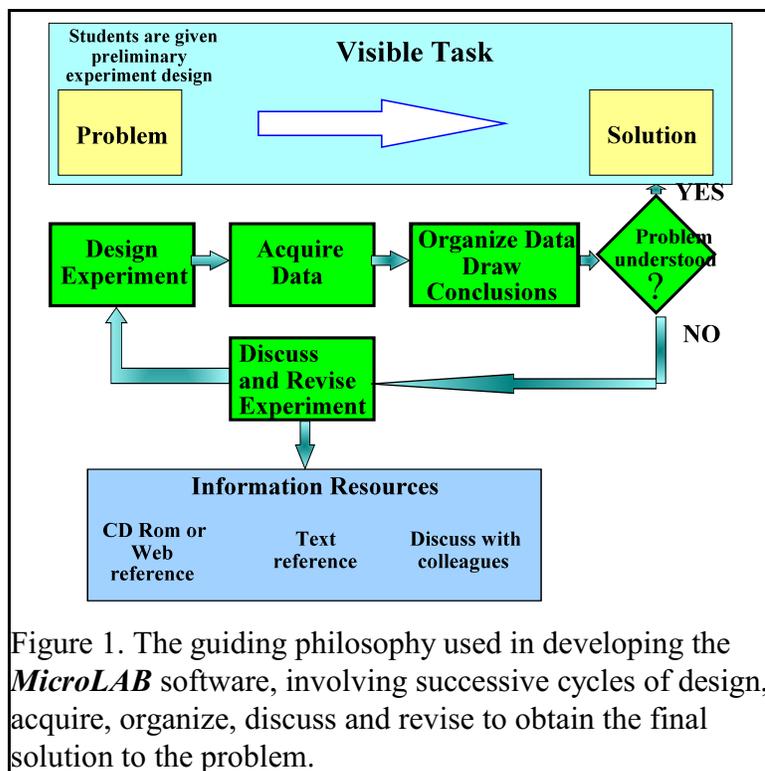


Figure 1. The guiding philosophy used in developing the *MicroLAB* software, involving successive cycles of design, acquire, organize, discuss and revise to obtain the final solution to the problem.

This is known as the Axiomatic-cum-pragmatic cycle, where axioms or postulates about the problem are made, the experiments are carried out, and the results correlated back to the beginning postulates for confirmation.

In light of the above discussion, one can see what is necessary for the “confirm the law or principle” type experiment to be converted to “guided inquiry” experiments simply by revising the Microsoft Word or WordPerfect version of the experiment that can be purchased from *MicroLAB*, as indicated above.

This transformation is accomplished by simply reducing the specific directions available in the student version of the experiment. Where the experiments provided here usually contain extensive instructions, as the semester progresses, the experiments selected can provide less and less extensive instruction until near the end of the semester, the experiments have evolved into “pure inquiry” where the students are given only the problem, and are required to complete all of the above listed steps on their own. Some students will readily adapt to this type of experiment, but others will struggle with it. They have not had any, or have had very few experiences in their past education where they have actually had to think something through for themselves. Be patient with these students, struggle with them, and they will eventually begin to get their brains in gear and produce. The best way I have found to do this is to use the Socratic method, i.e., I answer their questions with a series of questions designed to lead them through to the answer to the question they asked. This is frustrating to many of the students because they want answers, not more questions. However, I have found it pays off with great rewards in the end. I have had many student indicate on evaluations that I was the hardest teacher they ever had, then several years later I would get an email or letter from them thanking me for making them work hard and learn how to think because they were finding they were doing

better than many of their colleagues because they had learned to think for themselves and had mastered the basic material.

I have found the **MicroLAB** interface one of the best tools to help students of chemistry understand the laboratory aspect of chemistry. The main screens are easy to understand, the operation is intuitive, and the data analysis is fairly straight forward. The observation of the graph formation as the experiment proceeds is an eye opener for the students. One of the main problems experienced in lab is that the computer screens become smeared with finger prints from the discussions that go on between the students, and students and instructor and have to periodically be cleaned, a welcome chore. As in all computer programs, there is a learning curve, but the instructions and power points that come with the **MicroLAB** and the **Useful Tools** contained on this CD will quickly help your students become proficient in its use. If you have any problems while working with these experiments, please contact me at the information below, I will be more than happy to try to help you out.

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Purposes of The General Chemistry curriculum

The General Chemistry curriculum has two basic goals. First, we hope the students will develop an understanding of the basic principles that govern the behavior of molecules. These principles were discovered over many generations by people who encountered unexplained behavior in nature and who designed and conducted the experiments which ultimately led to understanding. Students encounter many of these principles in their text and in the lecture part of their course.

An understanding of the basic principles known today, however, is not enough. Because chemistry and all of the other sciences are a continually evolving body of knowledge, many of the concepts they learn in class will be modified or even proven incorrect during their lifetime. The second major goal of the general chemistry course involves helping students learn how to look for unexpected behavior in nature and how to design and conduct experiments to develop an understanding of the principles that govern this behavior.

We have some tools to help us in this search. One of the most powerful and modern of these is the computer. This handbook is also a tool to help you help the students understand chemistry. These experiments will show them how computers can be used to help design experiments, to collect experimental data inexpensively and accurately, and finally to organize the data to look for generalizations and basic principles.

As you will quickly find out, it won't matter whether or not your students have had any experience with computers. If you give them the proper introduction to computers, as is contained in these materials, and if they come to lab each week having read the assigned materials, and the experiments you have selected for them, they will be in great shape. We believe that this exposure to computers will not only help them understand chemistry better, but will help them when they use computers in other classes as well.

INTRODUCTION TO THE COMPUTER

Getting Started

To begin, look at your computer to determine what type of disk drives you have available. There are a wide variety of configurations, but the most common are (1) one 3 1/2" drive, (2) one 3 1/2", CD ROM and a zip drive, and (3) the latest configurations seem to be a CD ROM drive and USB ports for the use of removable USB solid state storage devices variously known as **keys, flash cards or scan disks**, etc. In addition, your computer will have a hard drive. If in doubt, ask your instructor. Your instructor will be able to specify what drive configuration you will actually use.

A program called **Microsoft Windows**, is the computer's secretary; it keeps track of where information and data are located on your disks and allows you to retrieve it when you want it. Although you will not directly encounter the inner details of these systems, they are very important. They allow the keyboard, monitor, and disk drives to operate together as a system. They also controls the use and execution of the **MicroLAB** interface program. The **MicroLAB** interface program uses these operating systems to manage the data it obtains.

Most of the computer commands that you'll need to know are selected through the **MicroLAB** interface software. You will be learning about these commands throughout the course. You will only be working directly with the computer's operating system to copy files, copy a disk, or to see what files are on your disks. Files are simply blocks of information with names, just like a file folder contains certain papers. To accomplish these tasks, you enter commands (instructions) through the keyboard which tell the operating system what you want to do.

You will need to know how to make a copy of a disk or to copy files. If you do not already know, your laboratory instructor will help you learn. The actual sequence of commands will vary depending upon the exact configuration of your computer. Ask your laboratory instructor if there is something you don't understand about using operating system used on the computers in your lab.

Using the Computer to Organize and Analyze Data

The computer is an ideal tool for quickly organizing and analyzing data. It accomplishes in a few seconds what takes much longer to do by hand. John Amend had the experience, while working with the early LabWorks program on 8088 computers, of the students complaining about how slow the computer was in printing out the graphs. His response to that complaint was to give them a sheet of graph paper and a pencil with instructions to make the graph by hand. He made his point very well with the students. Several commercial programs exist for manipulating and graphing data, e.g., Microsoft's EXCEL, Corel's Quatro Pro, as well as **MicroLAB**.

Graphing and Spreadsheet Exercises

A **Spreadsheet** is a two dimensional array of cells which allows calculations, graphing, and analyzing data obtained from your experiments. You can manually input data into the **Spreadsheet** for analysis or import data from a previously generated data file, such as would be acquired by collecting the data from an experiment into the computer. Manipulation of such data by graphing and mathematical analysis can significantly improve the understanding of the experiment.

Opening the *MicroLAB* program:

1. Double click on the MicroLAB icon on the desk top, or single click the icon in the task bar.
2. When the second window opens, click on the ***MicroLAB* Experiment** icon, then on **Open**.
3. To open a **Pre-Designed** experiment, double click on one of the **Template** tabs to open it, then double click on **Name.exp**, where **Name** refers to the particular experiment file to be opened or that particular experiment. You can also go to **File** and select **New** to obtain a blank ***MicroLAB*** screen to write your own program.
4. This will bring up the **Main Screen** of the ***MicroLAB* Experiment** software, ready for you to begin your experiments.

Measurement: *The Basic Science*, a manual for student use published by Hayden McNeil Publishing, a copy of which you can obtain from ***MicroLAB***, contains all of the information for your students to quickly come up to speed in the operation of the ***MicroLAB* Experiment** software. A partial table of contents of the manual is included herewith so you can seek answers to questions that may arise in familiarizing yourself with the ***MicroLAB* Experiment** software and assisting your students.

1. **Measurement: *The Basic Science***: Discusses measurement and the role of instruments and computers, and a brief introduction to the ***MicroLAB*** interface
2. **Getting Started I: The *MicroLAB* software, sensor calibration and programming**: discusses starting the ***MicroLAB*** software, the six views in the ***MicroLAB*** main screen, sensor inputs, sensor calibration, designing experiments, changing data presentation, measuring pH, light and pressure, and statistics.
3. **Getting Started II: Setting up experiments and collecting data**: discusses identifying the problem, designing and building experiments, testing the program, running experiments (boiling point of pentane, freezing point of glacial acetic acid and evaporation of a liquid), saving and exporting data, drawing information from graphs and saving template files.
4. **Getting Started III: Drawing information from graphs**: Discusses using graphs, slope and the linear (first order) curve fit, hand entered data, adding a first order curve fit line, significant figures on spreadsheets and graphs, predicting Y values for the slope-intercept equation, printing, and an example project on a pressure-operated depth gauge.
5. **Physical Properties of Matter: Identification of an organic compound**. A project for students to use the skills and techniques learned in the first four sections.
6. **Using the *MicroLAB* Colorimeter**: discusses basic principles of colorimetry, loading the colorimeter software, setting up the experiment, reading the blank, transmittance, log transmittance, absorbance, the molar absorptivity constant, determining the concentration of an unknown substance, and solution preparation.

Organization of the *MicroLAB* Interface Software.

The *MicroLAB* software package is a compilation of programs to accomplish a variety of tasks. It is opened by clicking on the *MicroLAB* icon, which will open a second window with the various program options, e.g., *MicroLAB*, *Colorimeter*, *Color Mixer*, *Half-life and Energy of Light Experiments*, as well as the options to choose pre-designed experiments from the tabs.

The Main Screen of the *MicroLAB* software consists of six **Views**, as seen in Figure 2. Moving from top left clockwise they are: 1. Data Sources/Variables view, where data sources, formulas and analysis results are listed; 2. Graphing view, 3. Digital Display view, where instantaneous readouts of the sensors are seen; 4. Spreadsheet view, where each data sampling set is stored for later reference; 5. Experiment Steps view, where the steps to run the experiment are listed; and finally, 6. Experiment Control view, where the experiment is started, stopped, repeated and which has two computer controllable switches activated by clicking on them.

With this introduction, and the material contained in the **Measurement: The Basic Science** manual, we are ready to begin an examination of the experiment listing. First will be the listing of the experiments, with procedural abstracts, in categories listed alphabetically by type of experiment, from the less to more complex experiments, with beginning page numbers for each experiment. This listing will then be followed by the student version of the experiment (the first page number), then followed by the Instructor's Resources for that experiment (the second page number).

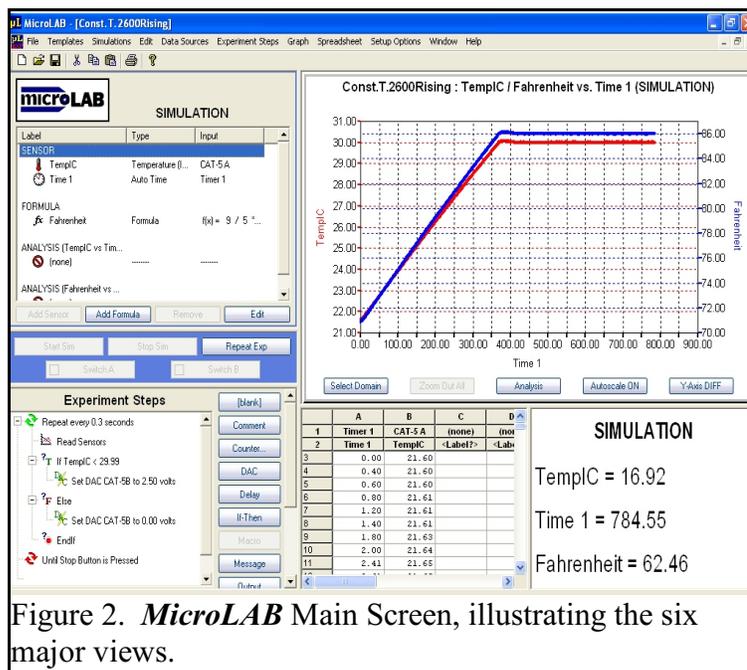


Figure 2. *MicroLAB* Main Screen, illustrating the six major views.

A Listing of the Experiments using the *MicroLAB* Interface as of January, 2005.

Of the sixty-four experiments contained on this CD, those that are annotated in bold type with a # at the beginning of the name are included in the book published by **Hayden McNeil Publishing**. Additional copies of this CD can be obtained from *MicroLAB*, and the individual experiments in Word or WordPerfect format can be purchased from *MicroLAB*, at address give previously in the Preface.

1. Calorimetry and Thermochemistry

- 1.1 Introduction to Calorimetry: Hot and cold water are mixed and the water masses and temperature changes are used to calculate the heat lost and heat gained. Ice is melted in water and the heat of fusion is calculated. A candle is burned under a metal cup containing a known mass of water, and the heat of combustion of the candle is calculated.
- 1.2 Hess's Law: Time/temperature program used with a styrofoam cup calorimeter. Δt values are determined graphically for Mg/HCl and MgO/HCl reactions. Hess's Law is used to determine the heat of combustion of Mg.
- 1.3 Enthalpy of Hydration: Qualitatively correlate the ΔH_{soln} of several compounds with their properties such as ionic charge, size, etc., quantitatively determine the enthalpy of solvation of MgSO_4 and $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, quantitatively determine the enthalpy of the water of hydration in $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, and calculate the Q_{soln} per g, the ΔH_{soln} per mole for MgSO_4 and $\Delta H_{\text{hydration}}$ for MgSO_4 to $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$.
- 1.4 **#Hot Packs, Cold Packs (9, 13)** The *MicroLAB* interface is used to measure temperature changes in a styrofoam cup calorimeter, ΔT values are determined graphically for the dissolution of four salts, ΔH_{soln} are calculated for each salt, ΔH_f are calculated for the ions in each of the four salts, ΔH_f values for the ions are used to find ΔH_{soln} for two additional salts, and a cold pack is designed using NH_4NO_3 , and a hot pack designed using MgSO_4 .
- 1.5 Determination of Enthalpy and Entropy of a reaction: **(Same as the * experiment in Electrochemistry)** A simple electrochemical cell $\text{Cu(s)}/\text{CuSO}_4(\text{aq}) // \text{Zn(s)}/\text{ZnSO}_4(\text{aq})$ is constructed in a Chem-Carrou-Cell™ or well plate and voltages are measured at different temperatures, a spreadsheet is used to plot a linear regression graph of voltage *versus* temperature, and the graph is used to calculate the enthalpy and entropy changes for the cell reaction, and the heat of reaction of zinc powder with 0.5 M CuSO_4 solution is determined calorimetrically.

2. Colorimetry

2.1 #Colorimetry: Quantitative Analysis with Light (Using Food Dyes) (25, 35)

The observed spectra of colored solutions is projected on the screen by an overhead projector and is matched with *MicroLAB* Spectrum Profiles of percent transmission and wavelength, The origin of color is observed using colored solutions and the visible results of color mixing is predicted, a set of five standard food dye solutions of known concentrations are made by dilution of a given standard, Beer's law is derived and used to determine the concentration of an unknown colored solution, and the concentration of chlorine in pool and tap water samples are colorimetrically determined.

2.2 Beer's Law using Crystal Violet: "Ideal" simulated data is manually entered into the *MicroLAB* spreadsheet and a series of plots using different functions operating on the percent transmittance readings are constructed in order to discover a linear relationship between the percent transmittance and concentration variables, a series of standard crystal violet solutions are prepared and analyzed using the *MicroLAB* colorimeter, A Beer's Law plot of these concentrations is constructed using the relationship discovered with the simulated data., and an unknown solution of crystal violet is analyzed in the colorimeter and the Beer's Law plot is used to determine its concentration.

2.3 Formation Constant of FeSCN by colorimetry (Same as the ** experiment in Complex Ion Formation): A set of standard solutions is prepared, the *MicroLAB* colorimeter is used to determine the absorbances of the five standard solutions and the molar absorptivity constant for FeSCN^{2+} , the *MicroLAB* spreadsheet is used to calculate the equilibrium concentrations of Fe^{3+} , HSCN, and H^+ from the equilibrium concentration of FeSCN^{2+} , and the value of K_f is calculated for the complex formation reaction from the collected data.

2.4 Spectrophotometric Determination of an Equilibrium Constant: Colorimetric measurements are made for the absorbance of four different solutions of a complex ion, $[\text{Fe}(\text{SCN})^{2+}]$ using the *MicroLAB* Interface and the equilibrium constant for the formation of the complex is determined.

3. Complex Ion Formation

3.1 Version 1: Determining the Coordination Number of Ni^{2+} and Cu^{2+} by enthalpy: Equimolar amounts of $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ or $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ and ethylenediamine are reacted and the heat of reaction is determined calorimetrically, the reaction mixture is then cooled down to the initial temperature, and a second equivalent of *en* is added. This process is repeated until the addition of the next equivalent of *en* fails to produce a significant temperature change. The small temperature increase observed when further replacement is not possible is due to the heat of dilution of ethylenediamine. By measuring the evolved heat, it is possible to determine the maximum number of ethylenediamine molecules that have chelated in each complex ion.

3.2 #Version 2: Do Ni and Cu react with ethylenediamine to form the bis- or tris chelate? (45, 51): A series of experiments is done with the $[\text{Ni}(\text{OH}_2)_6]^{2+}$ complex to determine the number of en molecules which will bind to Ni^{2+} . One mole of $[\text{Ni}(\text{OH}_2)_6]^{2+}$ is reacted with 1, 2, 3, and 4 moles en. A comparison of ΔH values is used to identify the maximum number of en ligands bonded to the Ni^{2+} ion.

A similar series of experiments is done with the $[\text{Cu}(\text{OH}_2)_6]^{2+}$ complex to determine the number of en molecules which will bind to Ni^{2+} . One mole of $[\text{Cu}(\text{OH}_2)_6]^{2+}$ is reacted with 1, 2, 3, and 4 moles en. A comparison of ΔH values is used to identify the maximum number of en ligands bonded to the Cu^{2+} ion.

- ** Formation Constant of FeSCN by colorimetry (**Same as 2.3**) Colorimetric measurements for the absorbance of four different solutions of a complex ion, $[\text{Fe}(\text{SCN})^{2+}]$, are made using the *MicroLAB* Interface, and the equilibrium constant for the formation of the complex is determined.

4. Electrochemistry

4.1 **#Electrochemistry & Nernst Equation (61, 67)** An electrochemical series is determined with respect to Sn. The half cells constructed are: Sn (s)/ SnCl_2 ; Nichrome/ FeSO_4 , $\text{Fe}(\text{NO}_3)_3$; Cu (s)/ $\text{Cu}(\text{NO}_3)_2$; and Zn (s)/ ZnSO_4 , the Nernst Equation is explored using different concentrations of copper sulfate solution and 1 M solution of zinc sulfate and a graph of voltage vs. $\log([\text{Cu}^{2+}])$ is plotted and used to determine concentration of an unknown copper solution.

- * Enthalpy and Entropy (Determines ΔG from E° .) (**Same as experiment 1.5**) A simple electrochemical cell $\text{Cu}(\text{s})/\text{CuSO}_4(\text{aq}) // \text{Zn}(\text{s})/\text{ZnSO}_4(\text{aq})$ is constructed in a Chem-Carrou-Cell™ or well plate, and voltages are measured at different temperatures, a spreadsheet is used to plot a linear regression graph of voltage *versus* temperature, and the graph is used to calculate the enthalpy and entropy changes for the cell reaction and the heat of reaction of zinc powder with 0.5 M CuSO_4 solution is determined calorimetrically.

5. Freezing Points

5.1 **#Freezing Point of Glacial Acetic Acid. (79, 85)** A temperature probe calibration at 0°C and 55°C , the experiment program and temperature probe are tested, the apparatus is assembled and the data collected for the cooling curve with super-cooling followed by spreadsheet treatment of data for glacial acetic acid.

5.2 Freezing Point of Phenyl Salicylate: A temperature probe calibration at 0°C and 55°C , the experiment program and temperature probe are tested, the apparatus is assembled and the data collected for the cooling curve with super-cooling followed by spreadsheet treatment of data for Phenyl Salicylate.

6. Gas Laws

6.1 Boyle's Law: The interface and syringe assembly are set up and calibrated, pressure/volume data pairs taken at three different central volume settings and the data analyzed and graphed, and questions answered.

6.2 Charles' Law: The interface and temperature probe assembly set up and calibrated, temperature/volume data pairs taken over wide temperature range and the data analyzed and graphed, and questions answered.

6.3 **#Combined Boyle's and Charles' Laws (93, 101)**: Accomplishes both experiments 15 and 16 in one lab period.

- 6.4 Dalton's Law: The objectives of this experiment are to introduce the concept of ideal gases, experimentally determine the relationship between pressure and amount of gas, using the **MicroLAB** interface system to collect and analyze the data, and experimentally determine how the addition of different gases affects Dalton's law, using the **MicroLAB** interface system to collect and analyze the data.
- 6.5 Gay-Lussacs Law: The interface and temperature probe assembly set up and calibrated, temperature/pressure data pairs taken over wide temperature range and the data analyzed and graphed, and questions answered.
- 6.6 Vapor Pressure of Water: The relationship between the temperature and vapor pressure of water is explored, the vapor pressure of H₂O is determined at a series of temperatures, and Log P/P_o is plotted against 1/T to give a straight line with a slope of $H_{\text{vap}} / 2.303 R$.

7. Independent Projects (Pure inquiry type experiments)

- 7.1 Introduction to Independent Projects
- 7.2 Project Experiments and Instructor Resources
- 7.2.1 Acid/base properties of antacids
 - 7.2.2 Acid/base properties of buffered aspirin
 - 7.2.3 Acid/base properties of common household products and food
 - 7.2.4 Thermometric determination of ammonia in household cleaner
 - 7.2.5 Phosphoric acid concentrations in colas
 - 7.2.6 Measuring caloric content of snack foods
 - 7.2.7 Molar enthalpies of acid/base reactions
 - 7.2.8 Enthalpies of solution
 - 7.2.9 Determination of a mixture of copper and cobalt by colorimetry
 - 7.2.10 Identity of group 1 carbonate samples
 - 7.2.11 Factors affecting freezing point depression in water
 - 7.2.12 Penetrating ability of beta and gamma radiation
 - 7.2.13 Colorimetric determination of phosphorous in plant food
 - 7.2.14 Quantitative determination of vitamin c in various fruits

8. Kinetics

- 8.1 Crystal Violet kinetics: The kinetics of the decomposition of crystal violet is studied using the **MicroLAB** colorimeter, the experimental data are plotted to determine the order of reaction in crystal violet and the reaction is studied at two different concentrations of hydroxide ion to determine the order of the reaction in hydroxide.
- 8.2 Crystal Violet kinetics with Activation Energy (E_a) calculation: The kinetics of the decomposition of crystal violet is studied using the **MicroLAB** colorimeter, the experimental data are plotted to determine the order of reaction in crystal violet, the reaction is studied at two different concentrations of hydroxide ion to determine the order of the reaction in hydroxide and the activation energy, E_a, is calculated for the reaction from supplied data)
- 8.3 Formaldehyde Clock Kinetics (An Open Inquiry Experiment): The equipment, burets for dispensing reagents, interface and computer are set up, the reagents are mixed appropriately, the kinetics measured using the **MicroLAB** colorimeter to explore the variation of rate with a change of concentration of formaldehyde.

- 8.4 Kinetic Studies of the Ferriox Complex: The kinetics of a series of reactions involving ferriox is studied using the **MicroLAB** colorimeter. Each student group will complete two of three possible reaction series, at two different concentrations and temperatures, the data will be pooled so that each student has a complete set for all three reactions, the order of the reaction for ferriox and three different non-ferriox reactants will be determined graphically, the rate constants for each series at each temperature will be determined and the activation energy will be estimated by comparing the rates at the different temperatures.
- 8.5 **#Kinetics of Catalyzed Decomposition of Hydrogen Peroxide (115, 127)**: (a modification of an ACS experiment.) This experiment introduces the concepts and units of pressure, catalysts and kinetics, experimentally uses pressure to monitor the kinetics of the catalytic decomposition of hydrogen peroxide, H₂O₂, using the **MicroLAB** interface system to collect and analyze the data and experimentally determines which catalyst is most effective.

9. Radioactivity

- 9.1 Some Properties of Nuclear Radiation, Cs-137 version: Reviews the operation of a Geiger-Mueller tube and the common types of radiation, students examine the statistics of radioactive decay, both for background counts and a radioactive source, measure the half life of an electron storage device and plot the natural logarithm to determine a linear relationship, measure the half life of Barium-137* and plot the natural logarithm to determine a linear relationship and learn how to add error bars on an EXCEL graph. (Only if EXCEL is being used to graph the experimental data.)
- 9.2 Some Properties of Nuclear Radiation, Th-232 version: Reviews the operation of a Geiger-Mueller tube and the common types of radiation, students examine the statistics of radioactive decay, both for background counts and a radioactive source, measure the half life of an electron storage device and plot the natural logarithm to determine a linear relationship, measure the half life of Thallium-208 and plot the natural logarithm to determine a linear relationship and learn how to add error bars on an EXCEL graph. (Only if EXCEL is being used to graph the experimental data.)

10 Spectroscopy

- 10.1 **#Spectroscopy: Quantitative Analysis with Light (135, 145)**: Hot solid and gaseous sources of light are viewed through a diffraction grating spectroscope and classified according to the type of spectrum they emit, band or line, a simple diffraction grating and the concept of wave interference are used to develop a relationship between the color and wavelength of light, light-emitting diodes are used to develop a relationship between the energy and color, frequency, and wavelength of light, a gaseous element is "finger printed" by its emission spectrum, an unknown element is identified using the program **Atomic Spectrum** by measurements made on a colored photograph of its emission spectrum, together with a mercury spectrum and some evidence is collected to support Bohr's planetary orbit model for electrons.

11. Titrations

- 11.1 Acid/Base Titration Curves: After calibration of the pH electrode with buffers of 4, 7, and 10 pH and determination of the flow rate for the automatic titration, a NaOH solution is standardized against HCl, a pH titration curve for acetic acid is obtained and its pK_a is determined, an unknown sample of Lysol is analyzed for its HCl content using the standardized NaOH and an unknown sample of Liquid Plumr is analyzed for its NaOH and NaOCl content using HCl of known molarity.

- 11.2 Analysis of Soda Ash: After calibration of the drop size and the pH electrode with buffers of 4, 7, and 10 pH, a hydrochloric acid solution is standardized against pure Na_2CO_3 and an unknown sample of soda ash is analyzed for its Na_2CO_3 content using the standardized HCl.
- 11.3 Analysis of a Solid Mixture: A solution of NaOH is prepared by diluting a stock solution, the NaOH solution is standardized with KHP by using an indicator for experience in classic indicator titrations and also using the *MicroLAB* interface for experience in potentiometric titrations and the percent KHP in an unknown solid mixture is determined both by indicator and potentiometric titration.
- 11.4 Characterization of Weak Acids: After calibration of drop size and the pH electrode with buffers of 4, 7, and 10 pH, a solution of NaOH is standardized with KHP, an unknown weak acid is titrated with the standardized base, the molar mass and dissociation constant for the acid are calculated and the identity of the unknown acid is determined from the molar mass and K_a values.
- 11.5 Indicators and Titration of HCl & HOAc: An introduction to pH as a means of determining the amount of an acid or base present, exploration of the change in acidity versus the volume of titrant added during a titration, the difference between a strong acid and a weak acid titration curve, the effect of a weak acid/strong base titration on the acidity of the equivalence point.
- 11.6 Introduction to Acids/Bases and Titration of HOAc: Students will explore the nature of acids and bases by observing the effect of buffers in the range of pH 2 to 11, on various indicator papers and solutions, acid reactions are then explored using the common acids HCl, H_2SO_4 , HNO_3 with substances such as marble chips, zinc, paper clips, aluminum, egg albumin and copper, the reactions of such common bases as NaOH, $\text{Ca}(\text{OH})_2$ and NH_4OH are then explored with these same substances and finally, a simple titration is performed using NaOH as the titrant and acetic acid as the analyte and utilizing the *MicroLAB* Interface to get a feel for a titration curve. .
- 11.7 **#Ka1 of Phosphoric Acid by Titration (187, 193)**: The dropping buret is calibrated for drop size and the pH electrode is calibrated with buffers of 4, 7, and 10 pH, four titrations of an 0.1 M solution of phosphoric acid of both equivalence regions are accomplished with standardized 0.1 M NaOH, the exact volume for the first equivalence point is determined for each titration and the K_{a1} value for each titration is determined from the pH at the half-equivalence point volume, and the average and standard deviation are obtained.
- 11.8 Determination of K_{a2} of Sulfuric Acid by Titration: Students will experience the titration of a diprotic acid with one strong and one weak dissociable hydrogen ion, learn proper technique in pipette and buret usage, determine the second dissociation constant for sulfuric acid from the titration curve and become familiar with Pauling's rules for oxyacid strength.
- 11.9 **#Titration of a Cola Product (175, 179)**: The pH electrode is calibrated with buffers of 4, 7, and 10 pH, the instructor will designate what type of titration, e.g., timed, drop count or buret volume by keyboard input, will be performed and refer the students to the **Useful Titration Operations** for the specific instructions, at least three titrations of a de-carbonated cola product are accomplished with standardized 0.01 M NaOH, the exact volume for the first equivalence point

is determined for each titration, the molarity value for each titration is determined from equivalence point volume, and the average and standard deviation are obtained.

11.10 Titration of an Acid Mixture: A solution containing both HCl and H_3PO_4 is titrated using standardized NaOH solution, the titration is followed using a pH electrode attached to the **MicroLAB** interface, volumes are read from the buret and manually entered to the spreadsheet from the keyboard, allowing four significant figure volume control in the experiment and the titration and first derivative curves are constructed and the two acid concentrations are determined from the equivalence points.

11.11 #**Titration Curve and Dissociation Constant for Acetic Acid (159, 163)**: The pH of solutions of HCl and $\text{HC}_2\text{H}_3\text{O}_2$ are calculated following addition of various amounts of NaOH and a titration curve is constructed using the **MicroLAB** Hand Enter data program, an acetic acid solution of unknown concentration is titrated with NaOH using the MicroLab Interface, the molarity of the acetic acid solution is determined and a K_a value for acetic acid is calculated at three points along the titration curve.

12 Mathematical Modeling on the Computer

12.1 Organizing and Analyzing Experimental Data (*MicroLAB* version): Discusses the roll of models in science, studies using graphs to identify mathematical models, regression analysis and the correlation coefficient, predicting from the mathematical model, and linearizing non-linear data to determine the variable relationships. Provides six directed Non-linear examples involving power functions, inverse relationships, etc. as guided exercises, and three completely independent examples.

12.2 Organizing and Analyzing Experimental Data (*EXCEL* version): All subsections the same except the examples are worked out for the EXCEL spreadsheet.

12.3 The Scientific Method Experiments: The objectives of these experiments are to introduce the student to the basic steps of the Scientific Method, give practical experience in the Scientific Method by solving a simple physical problem via this methodology, and provide experience in presenting the results of the investigation orally and in writing. Each group of two or three students will be given a sheet of instructions for one of the eight experiments to be done as they enter the lab, they will obtain the "perception of their problem" by carefully reading the instruction sheet, assemble the equipment as instructed. (Instructions are purposely somewhat vague in order to encourage their thought and analysis of the problem as they proceed.), carry out some preliminary experiments, as instructed on the experiment sheet, to obtain their "preliminary observations", graph their preliminary observations, do a linear regression on the data if linear, **OR**, evaluate what mathematical transformation could be done to the data to linearize the data and get a linear regression equation. (Suggestions for this are contained in the paper on "Organizing and Analyzing Experimental Data: The Role of Models in Science, experiment 12.1 using the **MicroLAB** spreadsheet, or 12.2 using EXCEL.), predict from the regression equation the dependent variable value for an as yet unobserved independent variable value, carry out the experiment, setting the independent variable and then measuring the dependent variable value to see if they measure what they predicted, repeating this several times at different independent variable settings, which will allow them to "validate" or reject their hypothesis. It is suggested that each group give a five (5) minute oral presentation to their laboratory section, and each student turn in an independent report on their project.

13 Qualitative Analysis on the Computer

13.1 Computerized Qualitative Analysis (This one does not use the *MicroLab*, but is a very good experiment.): Explores the reactive properties of seven cations, Ag^+ , Cr^{3+} , Mg^{2+} , Ni^{2+} , Pb^{2+} , Na^+ and Zn^{2+} with Cl^- , I^- , OH^- , SO_4^{2-} and NH_3 . Based on the reactive properties observed and instructor guidance, students construct a flow chart for the analysis of the seven cations, four anions and NH_3 , and analyze five types of anions: one cation, two cations, one compound, two compounds, any number of anions. Points obtained on sliding scale with difficulty of analysis.

14 Useful Tools

14.1 Creating and Drawing Information from EXCEL Graphs

14.2 Making Oral Presentations

14.3 Organizing the Research and it's Report

14.4 Programming the *MicroLAB*

14.5 Useful Titration Operations

14.6 Sample MicroLAB Programs