Chemistry Experiments for High School *at Home*

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Welcome

W

How Important Are Chemistry Experiments?

A laboratory practicum incorporating a series of quantitative experiments is an essential component of any high school or college chemistry course. It is one thing to read about precipitations; it is another thing to see the precipitates form with your own eyes. Again, it is one thing to talk about the dramatic change in solution pH near the equivalence point of a titration; it is another to see how quickly the pH changes and to see the change in indicator color that occurs at the same time.

In addition to seeing the reactions first hand, laboratory experience provides students with practice using standard laboratory apparatus and methods. Modern chemistry is a discipline born in the laboratory, and the test tubes, graduated cylinders, and Bunsen burners used in a chemistry lab are familiar to nearly everyone who has completed a formal education. We remember an occasion when our head of school nearly lost his cool upon his discovery that some juniors in the Rhetoric class he was teaching did not know what a test tube was. The topic at hand was *in vitro* fertilization, and our head of school had used the phrase "test-tube baby," only to find that several students did not know what he meant. He raced down to the lab, grabbed a few test tubes, and stormed back to his classroom to inform the students of what their science education had apparently failed to inform them. These days, the experience gained in a chemistry lab can make a difference in a person's ability simply to follow an article in a newspaper!

Finally, there is nothing like laboratory practice to give students a feel for how the stoichiometric calculations learned in the classroom relate to the predictions and results of an actual experiment. Experienced teachers all know that when a student encounters a subject in several different ways and through various means, the learning outcomes are far superior to those that result when a student encounters a subject in only one way or through a limited number of means. Accordingly, students *learn* chemistry at a deeper level and *remember* chemical principles longer if they experience the subject through both the classroom and the laboratory.

The 19 experiments in this volume expose students to the practical aspects associated with the broad array of topics that occur in a first-year chemistry course. We encourage you to incorporate as many of these experiments as possible into your own students' experience of the subject.

Chemistry Texts

This manual has been designed to accompany these chemistry texts written by John D. Mays:

- Published by Novare Science & Math:

  General Chemistry
  Chemistry for Accelerated Students

- Published by Centripetal Press:

  Principles of Chemistry
  Accelerated Chemistry

At the beginning of each experiment in this book are references to content in these texts pertaining to the experiment. Exceptions are Experiments 13 and 14, which address topics covered only in the accelerated texts.

Introduction Part 1 Costs and Materials

I·1

Performing a sequence of legitimate, quantitative experiments for a course in chemistry cannot be done without significant expenses for apparatus and chemicals. In this section, we describe why this is so, what your options are, what you are getting for your money, and options for controlling costs. We also present complete details about the items needed to perform the experiments in this book. In Parts 2, 3, and 4 of the Introduction, we treat topics of the utmost importance for those who would conduct chemistry experiments outside of a formal chemistry laboratory—topics such as safety, storage, and disposal. *Please read the entire introduction carefully before proceeding with any purchases or experiments.*

Experiments Versus Demonstrations

A quick internet search for "home chemistry experiments" will turn up scores of sites purporting to describe "experiments" that can be done at home with common materials. Many of these activities are very interesting; some are quite astonishing. However, what one inevitably finds is that these activities are *not* the kinds of experiments students need to accompany a high school course in chemistry. In fact, a better term for these so-called experiments is *demonstrations*. There are some key differences between experiments and demonstrations.

A demonstration can be performed without much in the way of quantitative analysis. One prepares a few chemicals, mixes them together under certain conditions, and then watches the amazing result. Afterward, the demonstrator might lead the viewer through the chemical reaction that occurred, using the chemical equation to show how the reactants were transformed into the products. Such demonstrations do not get very technical. The only real technical content is the chemical equation. Stoichiometry and quantitative analysis are almost never involved.

By contrast, experiments supporting the formal study of chemistry are *quantitative*—they involve measurements, predictions, and more measurements. Specific quantities or concentrations of reactants must be prepared before the reaction. After the reaction, careful measurements of the reaction products must be made in order to compare the results to the stoichiometric predictions. Making measurements of volumes, masses, and temperatures requires apparatus—graduated cylinders, burets, mass balances, thermometers and a host of odds and ends. And for the measurements to be useful in the study of chemistry, the instruments used to make the measurements must be reasonably accurate and fairly precise.

This is a book of experiments, not demonstrations. A book about chemistry demonstrations isn't really needed—you can easily find plenty of them online. If you are not up for the costs and complexities of quantitative experiments, you should focus on the informal demonstrations instead.

This book has been designed for those seeking quantitative experiments to support a formal study of chemistry, who desire a full spectrum of experiments at the lowest possible cost. Moreover, the experiments were designed with two additional assumptions:

1. Lab apparatus such as Bunsen burners, vacuum systems, and a wide variety of glassware are not available.
2. Those performing the experiments are a single small student team at a school, or a single student or group of students at home working under the supervision of parents or a tutor.

The first of these assumptions affects the apparatus we have specified; we have attempted to use the narrowest possible assortment to minimize cost. The second assumption directly affects the quantities of chemicals purchased. We have specified the smallest quantities available so that costs are minimized and disposal of leftover chemicals is as simple as possible. Schools please note: If you have more than one student group working, or if you can order chemicals in larger quantities now to lower long-term costs over several years of your program, you should order larger quantities of chemicals than those specified in the charts on the following pages. A good supplier of larger quantities of chemicals is Flinn Scientific, at flinnsci.com.

If you intend to perform the quantitative experiments that should accompany the formal study of high-school level chemistry, you must procure a basic assortment of quantitative chemistry apparatus and quite a few chemicals. Moreover, you must use personal protective items such as gloves and goggles and provide for proper storage and disposal of all the compounds purchased for or produced by the reactions you study. This requires an investment of several hundred dollars. For schools, this investment is not much of a problem because the cost can be spread out over the tuition payments of many students and the apparatus can be used year after year. But for an individual home school family, the cost can be a much larger issue. There is no way around this except to dispense with real experiments and stick to fun demonstrations. These are readily available online, so again, this book is not designed to support those who decide to go that route.

Planning and Managing Costs

Supplies Kits

The cost and materials descriptions below were written for those procuring all their own apparatus and supplies. Since the first printing of this book, Novare Science & Math has teamed up with Home Science Tools (homesciencetools.com) to make kits available containing the supplies needed. As of January, 2019, kits are available for the Economy Core Experiments for both our chemistry courses (see below). These kits are available at the Home Science Tools website. Look for Novare under the Homeschool Curriculum & Kits tab.

Which Experiments Apply to Which Students

To assist with the cost discussion below, note the following:

- The full slate of 19 experiments in this book applies only to students using *Chemistry for Accelerated Students* (CAS) or *Accelerated Chemistry* (AC) at a school with a physical building.
- For students using *General Chemistry* (GC) or *Principles of Chemistry* (PC) at a school with a physical building, Experiments 13 and 14 do not apply, leaving 17 possible experiments.
- For students performing the experiments in a home environment, Experiment 18 does not apply (as explained in the Chemical Notes section of the Introduction Part 2). This means there are 18 possible experiments for students using CAS or AC and 16 possible experiments for students using GC or PC.

Costs vs. Experiments

Obviously, the costs to perform the experiments depend on which experiments are performed and the number of students involved. In the analysis below, we have assumed a single experimental team, which could be any of the following:

- A small classroom of 3–5 students working in a single team

- A home school coop with 3–5 students working in a single team
- A single student studying at home as part of an online course
- A single student studying at home in a home school environment

Chemical quantities and costs discussed below assume one of these "single-team" scenarios. As previously mentioned, at schools with more students than this the instructor should source chemicals in larger quantities than the "single-serving" sizes listed in our chemical tables. This increases initial costs but reduces costs over time and reduces the amount of time the instructor must spend ordering supplies each year.

For many families in which a single student is performing the experiments, costs are a major factor. This situation also typically applies to individual home school students and to students taking chemistry as part of an online course. For those whose primary consideration is holding down costs, we have designated an "Economy Core" of 8 or 6 experiments. These Economy Core experiments are as follows:

- For students studying in the CAS text, Experiments 2, 4, 9, 11, 12, 13, 14, and 15.
- For students studying in the GC text, Experiments 2, 4, 9, 11, 12, and 15.

Again, kits are available for these experiments at the Home Science Tools website.

Cost Categories

For a realistic assessment of the total cost, those planning the experiments should expect costs in each of the following expense categories:

- *Common Items*: The Common Items are listed in one of the tables below. We assume these items are already available in the home or can be purchased at a local store at minimal expense. Costs for Common Items are not included in the cost figures tabulated below.
- *Personal Protective Gear*: This gear includes the goggles, nitrile gloves, and laboratory apron that should be worn by every person present at every experiment. There are many sources, but items from sciencecompany.com are as follows:

Item	Catalog Number	Price
goggles	NC-11005	$3.95
nitrile gloves	NC-7026	$12.95 (pack of 100)
laboratory apron	NC-4780 (medium/junior) NC-4215 (large/adult)	$7.95 $9.50

  Additionally, we recommend that a face shield be worn by each person present when concentrated acids are being handled. You will find these at homedepot.com for $13.97. Finally, you need to have one pair of gloves on hand for handling hot items. Laboratory-grade heat-resistant gloves are quite expensive (around $100), but a good alternative is the long-cuffed gloves sold for barbecuing. These "BBQ and fireplace gloves" can be purchased at homedepot.com for $20.97.
- *Apparatus*: This category includes all the laboratory equipment needed. Students studying at home may wish to substitute readily available items from the home where possible to hold down costs. The cost figures tabulated below do not include shipping. Shipping costs may be minimized by ordering as much apparatus as possible at one time from each single supplier.
- *Plastic Bottles*: For preparing the solutions (see Introduction Part 3) and collecting chemical waste, a number of plastic bottles with plastic lids (both medium-sized and small) are required. How many you need depends on which experiments you perform and whether you plan to reuse bottles by discarding leftover chemicals after each experiment. For the

many small quantities required, you can use the dropper bottles listed in the apparatus list and clean them out after the experiment. Another possibility is to purchase case quantities from a company such as sciencecompany.com. (Search under "bottle" and go to the fourth page of the list to see the empty plastic bottles.) One way to reduce cost for the larger bottles needed is to use sports drink bottles that have been thoroughly cleaned and rinsed with distilled water. Note that no bottles used for chemical storage should be reused for any other purpose. Once you are finished with a compound, dispose of the compound properly, rinse the bottle, and recycle it. Other than the dropper bottles, costs for plastic storage bottles are not included in the cost summaries below.

- *Chemicals*: This category includes all the specialty chemicals that must be purchased from online suppliers and a few that may be purchased at drug or grocery stores. Shipping costs may be minimized by ordering as many items as possible at one time from each single supplier.
- *Work Area, Storage, and Cleanup*: As described below, these requirements may require purchase of a fire extinguisher, protective mat for the work surface, locking storage cabinets, plastic wash tubs, and other items. Specific costs for these items are not included in the cost figures below.

Cost Summary

The following table summarizes costs for apparatus and chemicals:

Student Group	Apparatus	Chemicals	Total Cost
Physical school with 1 lab team (3–5 students) using CAS or AC and performing all 19 experiments	\$410.80 (+23.88 if propane burner is needed for Experiment 3)	\$464.09	\$874.89
Physical school with 1 lab team (3–5 students) using GC or PC and performing 17 experiments (skipping 13 and 14)	\$410.80 (+23.88 if propane burner is needed for Experiment 3)	\$456.23	\$867.03
Single home school student performing all experiments except Experiment 18	\$374.65 (+23.88 if propane burner is needed for Experiment 3)	\$404.79	\$779.44
One school lab team or single home school student performing only the Economy Core experiments	\$320.86	CAS or AC (8 Exps.): \$92.60 GC or PC (6 Exps.): \$84.74	CAS or AC: \$413.46 GC or PC: \$405.60

The costs shown in the table above are based on the need to purchase essentially all of the items of apparatus listed in the tables below. However, the tables indicate some substitutions of common items found in the home that may be made. Using these substitutions where possible reduces the apparatus expense somewhat. The costs summarized above and detailed in the tables below are obviously subject to variation or change, but we have researched pricing and availability thoroughly so that schools and families would be equipped and prepared to make decisions about the experiments they choose to conduct.

Holding Down Costs

For home school families, there are a few ways the expense of the experiments can be minimized. The first is to participate in a home school coop where families can pool funds together. A second possibility is to take the long view with regard to your own family. If the family includes two or three children, then all the apparatus and some of the chemicals can be reused as younger children enter their high school years. Some chemicals will have to be reordered, either

General Items Needed Throughout the Experiments						
Item	Source	Model	Cost	Quan.	Notes	Acceptable Substitutes
alcohol burner	sciencecompany.com	NC-3787	5.95	1	In the absence of a natural gas Bunsen burner, this is the best substitute for general purpose heating. Experiment 3 will need to use a natural gas or propane stove or burner.	None.
balance	homesciencetools.com	BS-DB0200	49.95	1	200 g capacity, 0.01 g resolution. If you can afford a 0.001 g scale, get one. If not, this is the best deal on a 0.01 g scale.	None.
beaker, 50 mL	sciencecompany.com	NC-5584	3.20	2	Lab beakers are needed for heating. Heating items in regular jars or glass can cause the glass to crack.	Pyrex measuring cup.
beaker, 100 mL	sciencecompany.com	NC-7865	3.75	1	Lab beakers are needed for heating. Heating items in regular jars or glass can cause the glass to crack.	Pyrex measuring cup.
beaker, 250 mL	sciencecompany.com	NC-5583	4.50	4	Lab beakers are needed for heating. Heating items in regular jars or glass can cause the glass to crack.	Pyrex glass.
beaker, 400 mL	sciencecompany.com	NC-7866	4.95	1	Lab beakers are needed for heating. Heating items in regular jars or glass can cause the glass to crack.	Pyrex glass.
buret, 25 mL	sciencecompany.com	NC-9825	31.95	1	Purchasing 2 will expedite Experiment 11.	None.
buret clamp	amazon.com		8.00	1	Schools may wish to purchase the American Educational double buret clamp instead for $15.61.	None.
clamp, 3-finger, with ring stand clamp	amazon.com	Clamp Retort	9.00	1		None.
dropper, glass	sciencecompany.com	NC-0363-PK	2.35	1 pk	Pack contains 4 glass droppers.	Eye dropper.
dropper bottle	sciencecompany.com	NC-0343	1.95	10		Small jars or bottles with non-metallic screw-on lids.
Erlenmeyer flask, 125 mL	sciencecompany.com	NC-9166	3.95	3	For school classrooms, 6 flasks per student group are recommended.	None.
filter funnel, glass, 50 mm	sciencecompany.com	NC-0472	3.75	1	If possible, purchase 2 to expedite Experiments 8 and 11.	None.
filter paper, 9 cm	sciencecompany.com	NC-12142	6.95	1 pk		Coffee filters.
funnel support ring, 2 inch iron ring	onlinesciencemall.com		6.25	1	Search under “cast iron support ring”	None.

Introduction Part 2
Safety, Storage, and Disposal

I·2

Storage

It is important to plan out and arrange for your storage requirements prior to ordering chemicals. Otherwise, chemicals could be placed in inappropriate locations where there is the danger of fire or of harm to unknowing children or pets. For the chemicals used in the experiments in this book, the most important aspects of proper storage are the following:

- Chemicals are secured from children, pets, or anyone else who could come to harm by improper use or handling of the chemicals.
- Solvents are separated from sources of flame such as hot water heaters, sparking equipment, cook stoves, people smoking, and the like.
- Nitrate compounds, which are not flammable but which accelerate the burning of other compounds (because they are strong oxidizers), are separated from organic materials such as paper, fabrics, compost, wood, and charcoal.
- Acids and bases are separated from each other and from all metallic materials.
- Liquids (which include solvents and some of the acids) are contained so that any spillage from a leaking container does not come in contact with people, pets, or property that could be harmed.

Locking storage cabinets are ideal. However, a more modest storage plan may simply entail several plastic storage tubs stored in a locking storeroom. The table below summarizes these guidelines:

Chemical	Ideal Storage	Acceptable Storage
organic solvents (acetic anhydride, acetone, ethanol, hexane, toluene)	Locked flammables cabinet, away from sources of flame, in a ventilated, climate-controlled space	Away from sources of flame, in a ventilated, climate-controlled space; secured from children and pets
nitrates	Locked chemicals cabinet, away from organic materials, in a climate-controlled space	Away from organic materials, in a climate-controlled space; secured from children and pets
acids (HCl, HNO_3, H_2SO_4, acetic acid, benzoic acid, lauric acid, salicylic acid)	Separated from bases in a locked, non-metallic cabinet, in a ventilated, climate-controlled space	Separated from bases in a plastic or wooden tub or cabinet, in a climate-controlled space; secured from children and pets
bases ($NaOH$)	Separated from acids in a locked, non-metallic cabinet, in a ventilated, climate-controlled space	Separated from acids in a plastic or wooden tub or cabinet, in a climate-controlled space; secured from children and pets
other compounds	Locked chemicals cabinet in a climate-controlled space	Climate-controlled space; secured from children and pets

Waste Disposal and Clean Up

Most of the experiments in this book involve specific steps that must be taken so that waste is disposed of properly. In many cases, you can't just pour things down the drain. Prior to performing an experiment, be sure to read the waste disposal section at the end and have the materials ready that you will need for clean up and disposal.

Note the following important factors that apply to waste disposal:

1. If your sanitary sewer feeds into a private septic system, pouring *any* chemicals down the drain should be avoided. Even small amounts of some chemicals can disrupt the proper functioning of a septic system.
2. Never dispose of anything in the storm sewer, that is, by pouring it in the street, creeks, streams, or anywhere else rain water is channeled.
3. In many communities, the following practices are acceptable methods of waste disposal for small waste generators such as homes and small schools:
    - pouring small amounts of *certain* cations and anions[1] down the drain.
    - discarding of dried compounds in the trash.
    - diluting and neutralizing acids and bases, followed by pouring the resulting salt and water down the drain.

    We describe how these methods should be applied, in a fashion that is acceptable in most locations, at the end of each individual experiment. However, note that heavy metals, solvents, and other environmentally sensitive chemicals may never be discarded in the trash or the sanitary sewer.
4. Even though the procedures we describe are accepted in many locations, yours may not be one of them. You should contact your local officials to find out about regulations that apply in your own community. Start with contacting the Solid Waste and Wastewater Treatment departments in your city or county.
5. Some wastes must be disposed of at a local city or county hazardous waste collection facility. For homes and families, these facilities usually collect waste without charging any fee. For schools, they may charge a fee or they may require you to arranging for a private contractor to collect your chemical waste. Either way, schools will be in much better shape and may save money by making sure all your wastes are clearly labeled with contents, including species and concentration.
6. Obtain two plastic containers, of size 0.5 gal to 1 gal each, with wide-mouth, tight-fitting plastic lids. Label these as "Solid Hazardous Waste" and "Liquid hazardous Waste." Keep these handy for disposal of wastes throughout the course of study. After the experiments have been completed, take these containers to a hazardous waste collection facility for disposal. Maintain a list of all chemicals added to each container, including quantity and concentration.

Work Area

To maintain a safe work area for your experiments, here are some guidelines you should follow:

1. Make sure you have adequate ventilation.
2. Protect your work surface. You can purchase a plastic mat for the purpose from a craft store. Examples from hobbylobby.com are the 18" × 24" self-healing rotary mat for $34.99 and the

1 These terms refer to species dissolved in water. When a chloride salt or sulfate or nitrate compound dissolves in water, the compound comes apart (*dissociates*) to form positive cations and negative anions in the solution. For example, when salt (sodium chloride) dissolves in water, the NaCl crystal dissociates and becomes individual sodium (Na^+) and chlorine (Cl^-) ions in the water. These are just individual atoms, but they have a charge (shown by the + and – signs), so they are called ions.

17” × 23” rotary cutting mat for $24.99.

3. Keep curtains, loose papers, stored materials, and other such items away from your work area. You will be using an alcohol burner often and do not want the risk of surrounding material catching fire.
4. Make sure you have a fire extinguisher and phone in your work area.

Safety Procedures

It is very important that everyone involved in the chemistry experiments learn the following safety procedures and follow them conscientiously:

1. The experiments in this book involve toxic substances, flames, fragile glass, and concentrated acids and bases. Accordingly, students should always work under the supervision of an adult.
2. Everyone in the vicinity of the chemistry work area should wear appropriate protective goggles, nitrile gloves, and a laboratory apron when working with chemicals or flames. Wear a face shield when handling concentrated acids.
3. Make your arrangements for cleanup, treatment, storage, and disposal of waste before the experiment begins.
4. Keep the Safety Data Sheet (SDS)—formerly known as the Material Safety Data Sheet (MSDS)—for every chemical you acquire. The SDS is supplied with the chemical when it is purchased. Read the SDS for every chemical you use, and take note of information about toxicity, vapors, and other concerns that require special precautions.
5. When handling hot substances or apparatus, use tongs or wear heat-resistant gloves.
6. Never mix chemicals together randomly just to see what will happen. History is full of people who did this, only to discover that the result was poisonous fumes, an explosion, or some other disaster.
7. Follow the instructions for the experiments closely and do not take short cuts.
8. Be very careful and alert when you are heating items with the alcohol burner so that you do not accidently knock the burner over. A toppled alcohol burner can spill alcohol all over your work surface and instantly set it on fire. One of your authors has seen this happen.
9. Use great care when handling glassware. As we always say, there are three ways to break something—improper procedures, silliness, or carelessness—and all are bad in a lab!
10. Make sure you have a phone in your work area in case you ever need to call for help.
11. Always follow written procedures, and don’t take short cuts. Do not revise procedures to suit yourself without consulting with a responsible and knowledgeable person who knows about the kind of work you are attempting to perform.
12. Never taste substances used in chemistry experiments and never taste any substance resulting from a chemistry experiment.
13. Do not eat or drink on your chemistry work area. When it comes to the possibility of accidently ingesting a poisonous substance, take no chances.
14. Never use chemical apparatus for holding food or drink. It may look cool to drink water from a beaker, but in beakers hydrochloric acid and water look exactly alike. Reserve the chemistry apparatus for chemistry experiments and nothing else.
15. Always keep long hair tied back out of the way, remove jewelry, and don’t wear loose, blow-

Introduction Part 3
Preparation of Solutions and Glass Tubing

I·3

Preparing Stock Solutions

To perform the experiments in this manual, preparation of several stock solutions is required. For example, 6.0 *M* and 1.0 *M* HCl (hydrochloric acid) are used in several experiments, so you should plan to mix quantities of these that can be stored in plastic bottles for use throughout the course. The first experiment requiring one of these HCl solutions is Experiment 4.

In other experiments, small quantities of solutions of soluble ionic compounds are required. Some of these are only used once and can be prepared at the time of the experiment. Others are required more than once and should be prepared and stored for later use. Such solutions are first called for in Experiment 3.

The table below (continued on the next page) summarizes the solutions that need to be prepared for the experiments in this book.

Experiment	Solutions	Concentration	Quantity
3	LiCl, NaCl, $MgCl_2$, KCl, $CaCl_2$, $SrCl_2$, $CuCl_2$, $ZnCl_2$	0.5 *M*	5 mL ea
4	HCl	6.0 *M*	15 mL
5	HCl	6.0 *M*	90 mL
5	$Ca(NO_3)_2$, $CuSO_4$, $Mg(NO_3)_2$, $Fe(NO_3)_3$, $FeSO_4$, $SnCl_4$, $Zn(NO_3)_2$, $AgNO_3$	0.2 *M*	5 mL ea
6	$MgCl_2$	0.2 *M*	5 mL
6	$AgNO_3$	0.1 *M*	5 mL
8	$FeSO_4$	0.16 *M*	60 mL
8	$KMnO_4$	0.05 *M*	75 mL
8	$AgNO_3$	0.1 *M*	25 mL
8	Na_2CO_3	0.05 *M*	15 mL
8	H_2SO_4	3.0 *M*	30 mL
9	HCl	6.0 *M*	10 mL
9	acetic acid, CH_3COOH	1.0 *M*	30 mL
10	NaCl, NaI, Na_2SO_4, Na_2CO_3, $Ba(NO_3)_2$, $AgNO_3$, $Pb(NO_3)_2$, $Cu(NO_3)_2$	0.1 *M*	5 mL ea
10	HNO_3 (This solution is listed here for completeness, but does not need to be prepared. The item on the chemicals list is 25 mL of 1.0 *M* solution.)	1.0 *M*	25 mL
11	NaOH	0.2 *M*	150 mL
12	HCl	0.1 *M*	100 mL
12	NaOH	0.2 *M*	100 mL
13	NaOH	1.0 *M*	100 mL
13	HCl	0.5 *M*	200 mL
13	HCl	1.0 *M*	100 mL

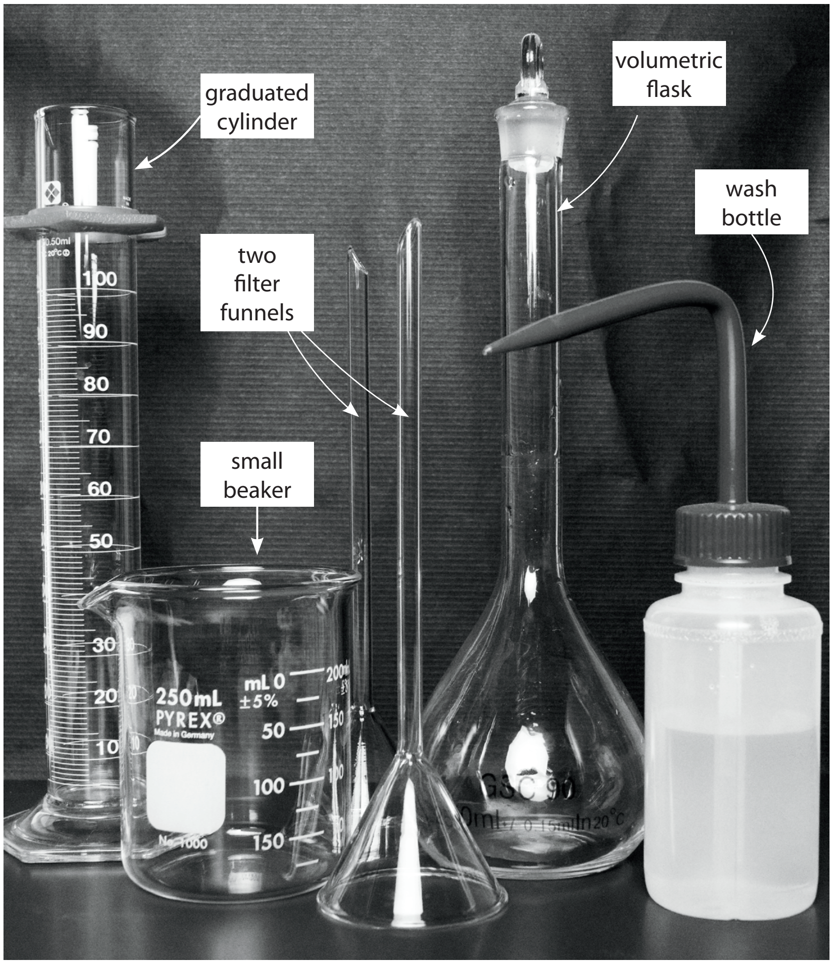

Figure I.1. Common items needed for preparing stock solutions.

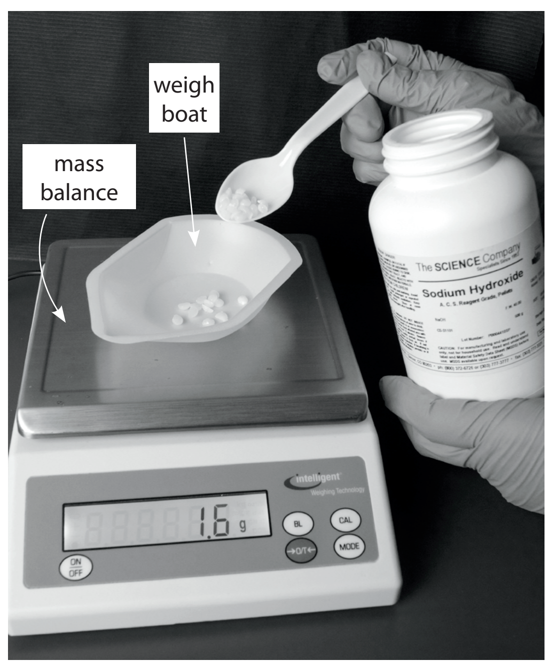

Figure I.2. Measuring out an amount of solid using a mass balance, plastic spoon, and weigh boat.

may then be cleaned up (while still wearing eye protection and nitrile gloves) and washed down the drain or placed in the trash.

10. In the event of a large spill of very concentrated acid, such as an entire bottle of 12 *M* acid, the baking soda may not be adequate for complete neutralization. Keep a jug of ammonia handy for neutralizing such a spill.

We now go through several examples of solution preparation. We use some of the required solutions from the lists above for the examples.

Example 1: Prepare 75 mL of 0.1 *M* oxalic acid, $H_2C_2O_4$

The table on page 26 indicates that a quantity of 75 mL of this solution is needed for Experiment 15. This solution will be prepared in a volumetric flask. However, the recommended apparatus includes only 50 mL and 250 mL volumetric flasks. Preparing two batches is not a good idea, since their actual concentrations will be slightly different. Instead, simply prepare more than you need. For the case of this example, we assume that we are preparing 250 mL of the solution, to be stored in a plastic bottle large enough to hold this amount.

Molarity concentrations (*M*) are always measured in moles per liter of solution. So begin by converting the required volume to liters:

$$250\text{ mL}\cdot\frac{1\text{ L}}{1000\text{ L}}=0.25\text{ L}$$

Then calculate how many moles of a substance are required to make 0.25 L of solution at a concentration of 0.1 *M*, which is 0.1 moles/liter.

$$0.25\text{ L}\cdot\frac{0.1\text{ mol}}{\text{L}}=0.025\text{ mol}$$

Next, calculate the molar mass of $H_2C_2O_4$, which is 90.04 g/mol. Next, determine the mass of $H_2C_2O_4$ for the required number of moles:

$$0.025\text{ mol}\cdot\frac{90.04\text{ g}}{\text{mol}}=2.25\text{ g}$$

Using a filter funnel, add distilled water to the 250-mL volumetric flask until it is about 25% full. Place a weigh boat on a mass balance and zero the balance. Using a plastic spoon, measure out about 2.25 g of $H_2C_2O_4$, and record the actual mass precisely. Using the funnel, add the $H_2C_2O_4$ to the volumetric flask, and gently wash it down the funnel with distilled water from a wash bottle. Swirl the flask until the oxalic acid has completely dissolved. Then fill the flask with distilled water so the bottom of the water meniscus is at the 250-mL mark. (The fill mark on a volumetric flask is a faint white line encircling the neck of the flask, and located near the base of the neck.) Stopper the flask and invert a few times to mix the contents, as described in the text. Finally, transfer the contents of the flask to a labeled, plastic storage bottle. The empty flask can now be rinsed out in the sink with water and rinsed a final time with distilled water.

Label the solution with the molarity you calculate using the mass of $H_2C_2O_4$ you actually measured. For example, if your mass measurement of $H_2C_2O_4$ was 2.31 g, then your solution molarity is calculated as follows:

Experiment 1
Measuring Physical Properties

1

Text Connections
- *General Chemistry* and *Principles of Chemistry*, Sections 2.2.3, 5.2.6, 5.3.11
- *Chemistry for Accelerated Students* and *Accelerated Chemistry*, Sections 3.1.1, 3.2.6, 3.3.12

Objective

To measure the physical properties of solids and liquids and use these measurements to confirm the identity of the compounds using standard reference data. Specifically, the properties studied are solubility, density, melting point, and boiling point.

New Lab Skills Focus for Experiment 1

1. Laboratory safety practices
2. Use of melting point apparatus
3. Use of boiling point apparatus
4. General familiarization with laboratory apparatus

Apparatus

alcohol burner
balance
beaker, 250 mL (2)
boiling chips
capillary tubes (5)
clamp, 3-finger, with ring stand clamp
dropper
glass stirring rod
glass tubing, 6 mm, with right-angle bend
graduated cylinder, 10 mL (4)
latex tubing, 3/16-inch ID
plastic spoons
ring stand and 3” iron burner ring
rubber bands, small
test tube, 25 mm × 150 mm
test tube, small (12)
test tube rack
test tube stopper, #000 (12)
thermometer
two-hole stopper, No. 4
watch glass (1 or 2)
wire gauze

Apparatus Notes

See the Introduction Part 3 for resources on cutting, bending, and fire polishing glass tubing.

Chemicals

solvents:	distilled water ethyl alcohol hexane	solutes:	acetone lauric acid naphthalene toluene

Safety

Always follow the general safety practices described in the Introduction. In particular, the following safety precautions should be taken during this experiment:

1. Wear nitrile gloves whenever handling any substances.
2. Wear appropriate laboratory eye protection at all times.
3. Wear a laboratory apron to protect your clothing.
4. Acetone, hexane, toluene, and ethyl alcohol are highly flammable; naphthalene is moderately flammable. Be sure to keep these substances away from the burner flame at all times.

Background

Often the properties of a substance allow us to determine the identity of the substance based upon physical or chemical examination. For instance, suppose you examine a metallic substance and find it has a silvery, shiny appearance like many metals. You also note that this metal is lightweight, durable, malleable, and ductile. Suppose also that you determine that this metal conducts heat and electricity well. These physical characteristics narrow the range of possibilities for the identity of the substance. Upon further examination, you discover that this metal is insoluble in water, has a density of 2.70 g/mL, and has a melting point of 660°C. Thankfully, scientists have compiled data relating to physical properties of elements and compounds and this information is readily available to us. If you refer to one of these references, you would be able to say with confidence that your substance is aluminum.

In this experiment, you examine the physical properties of four substances. Two of these substances are liquids—acetone and toluene—and two are solids—lauric acid and naphthalene. The properties you examine are solubility, density, melting point, and boiling point.

Procedure

Part 1: Solubility

You will add each of the four solutes to three different solvents—ethyl alcohol, hexane, and water—to determine their solubilities. If the substance dissolves completely, the substance is soluble (*s*), if the substance does not dissolve (remains solid or produces cloudiness) it is insoluble (*i*). A substance may also be sparingly soluble (*sp*)

Prepare a data table in your lab journal for recording solubility data. You have three different solvents and four different solutes. Your table should allow you to record the solubility of each solute in each of the solvents.

1. Obtain three clean, dry small test tubes. Add about 2 mL of distilled water to the first tube, add about 2 mL of hexane to the second tube, and about 2 mL ethyl alcohol to the third tube.
2. Add a small scoop of lauric acid to the solvents in each test tube. It is not necessary to measure the solute or solvent.
3. Stopper the top of each tube and shake for 5–10 seconds.
4. Record the solubility of this substance in your data table using the abbreviations *s*—soluble, *i*—insoluble, and *sp*—sparingly soluble.
5. Repeat this procedure for the remaining three substances. For liquid substances, use a clean dropper to add 4–5 drops into each solvent.

Part 2: Density

Prepare a data table in your lab journal for recording the data needed to calculate the density of each of the two solid substances you are working with, lauric acid and naphthalene. These data include the mass, initial volume, final volume, and net volume for each solid.

To determine the density of the solid substances:

1. Weigh about 1.5 g of one of the solids to the nearest 0.01 g and record the mass.
2. Obtain a clean, dry 10-mL graduated cylinder and add about 5 mL of the solvent in which this solid was insoluble. Record the volume to the nearest 0.1 mL.
3. Add the solid to the graduated cylinder, being careful to ensure that all the sample goes in the solvent and not on the sides of the cylinder. Record the new volume. The difference in volume readings equals the volume of the solid.

4. Calculate the density.
5. Repeat the same procedure for the other solid.

Prepare a data table in your lab journal for recording the data needed to calculate the density of each of the two liquid substances you are working with, acetone and toluene. These data include the volume, initial mass of cylinder, final mass of cylinder, and net mass of liquid for each liquid.

To determine the density of liquid substances:

1. Obtain a clean, dry 10-mL graduated cylinder and weigh it to the nearest 0.01 g. Record the mass.
2. Drop about 5 mL of acetone into the graduated cylinder. Record the volume to the nearest 0.1 mL. Weigh the cylinder and record the new mass. The difference in mass equals the mass of the liquid.
3. Calculate the density.
4. Using a different graduated cylinder, repeat the same procedure for the other liquid.
5. Save the two liquid samples for the boiling point determination in Part 4.

Part 3: Melting point of solid substances

Familiarize yourself with the melting point apparatus shown in Figure 1.1 before proceeding. Prepare a data table in your lab journal for recording melting point data. You must record the melting point range determined in each of two trials for the two solid substances.

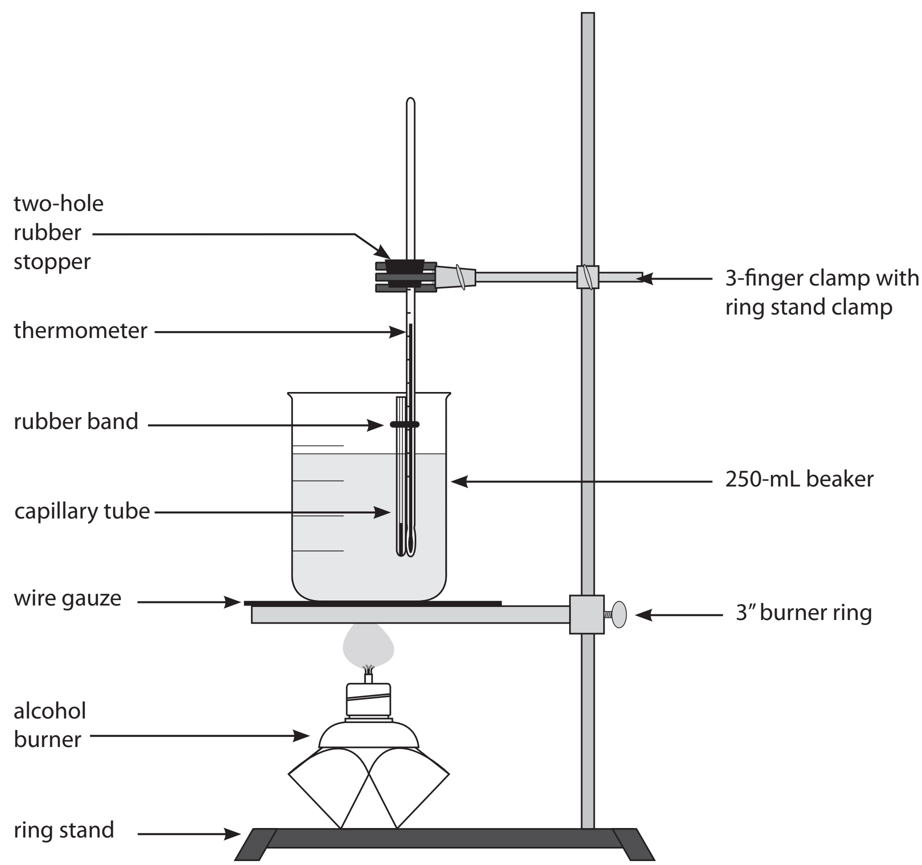

Figure 1.1. Melting point apparatus.

1. Pulverize a small sample of lauric acid in a watch glass.
2. Fill approximately 5 mm of your sample into the open end of the glass capillary tube by tapping the open end on the sample in the watch glass.
3. Gently tap the closed end of the capillary tube on the surface of your work bench until all the sample has reached the bottom (closed end) of the tube. Alternatively, the tube can be dropped through a "glass rod" to compact the sample.
4. Fit the thermometer into the rubber stopper and clamp it to the ring stand. While adjusting the thermometer, compare Figure 1.1 with Figure 1.2 and position the thermometer so it fits properly into the large test tube for Part 4.[1]
5. Secure the capillary tube to the thermometer using a rubber band as shown in Figure 1.1.
6. Place the thermometer with capillary tube into the beaker of water. Make sure the entire sample in the capillary tube is covered by the water and the open end of the tube is above the water.
7. Ignite the alcohol burner. Occasionally stir the water using a stirring rod.
8. Record the temperature when the sample begins to melt. Also record the temperature when the entire sample has melted. These two temperature measurements indicate the melting-point range.

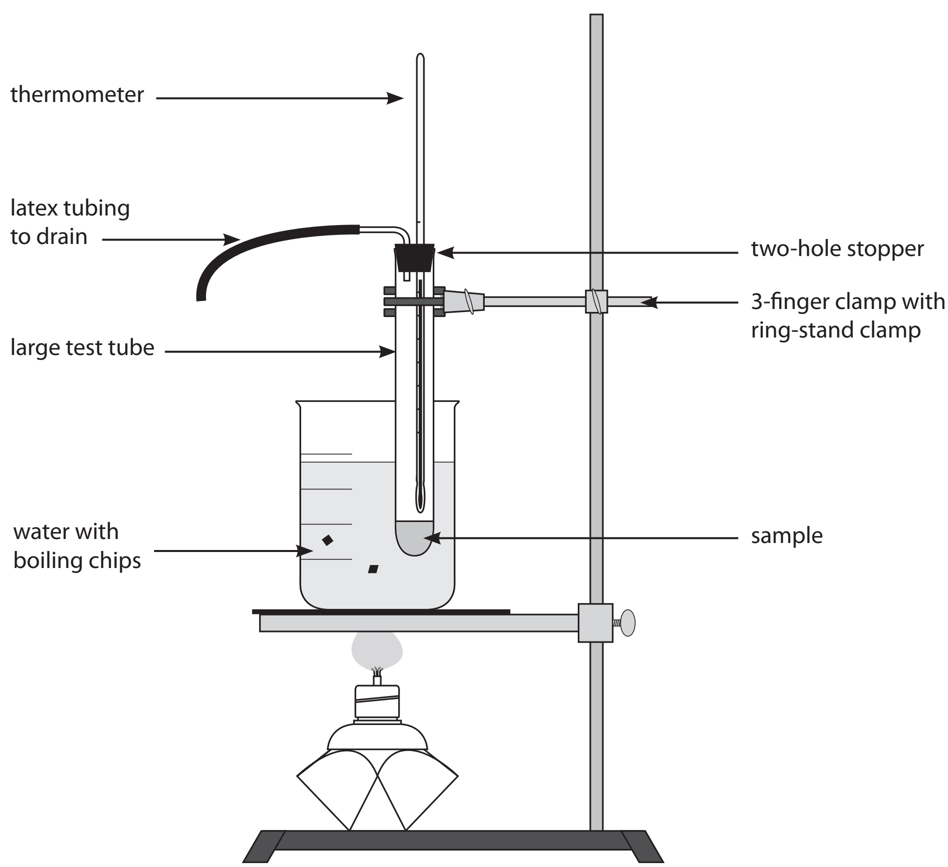

Figure 1.2. Boiling point apparatus.

1 Be careful doing this; it is easy to break the thermometer and cut your hand. We recommend wearing a leather glove on the hand holding the stopper. Also, if the thermometer is a tight fit, you may wish to lubricate the thermometer with liquid soap prior to inserting it in the stopper. After the thermometer is properly positioned, rinse the excess soap off before proceeding.

9. Repeat this procedure to confirm the melting-point range for the same substance. Continue to repeat until temperature ranges differ by 1°C or less.
10. Repeat the same procedure for the other solid.

Part 4: Boiling point of liquid substances

Familiarize yourself with the boiling point apparatus shown in Figure 1.2 before proceeding. Prepare a data table in your lab journal for recording boiling point data. You must record the boiling point determined in each of two trials for the two liquid substances.

1. Add about 3 mL of acetone from the sample used to calculate density (Part 2) into a clean, dry, large test tube.
2. Insert a two-hole rubber stopper into the test tube. Insert the thermometer making sure the bulb of the thermometer rests about 1 cm above the sample. Also insert a right-angle-bend glass tube connected to latex tubing. The latex tubing should be long enough to reach the sink or a waste beaker.
3. Add two small boiling chips to the water in the beaker. (These help the water boil more evenly, reducing the risk of splashing.)
4. Position the test tube in the water, making sure the sample is submerged. Clamp the tube to the ring stand.
5. Ignite the alcohol burner and watch for changes in the temperature.
6. The temperature will be constant once the sample boiling point is reached. Record the temperature.
7. Repeat this procedure to confirm the sample boiling point. Continue to repeat until temperature differs by 1°C or less.
8. Repeat steps 1–7 for the other liquid.

Substance	Density (g/mL)	Melting point (°C)	Boiling point (°C)	Solubility in water	Solubility in cyclohexane	Solubility in ethyl alcohol
acetone	0.79	–95	56	*s*	*s*	*s*
benzoic acid	1.27	122	249	*i*	*i*	*s*
bromoform	2.89	8	125	*i*	*s*	*s*
cadmium nitrate · $4H_2O$	2.46	59	132	*s*	*i*	*s*
cyclohexane	0.78	6.5	81.4	*i*	*s*	*s*
diphenylamine	1.16	53	302	*i*	*s*	*s*
ether, ethyl propyl	1.37	–79	64	*s*	*s*	*s*
hexane	0.66	–94	69	*i*	*s*	*s*
isopropyl alcohol	0.79	–98	83	*s*	*i*	*s*
lauric acid	0.88	43	225	*i*	*s*	*s*
methyl alcohol	0.79	–98	65	*s*	*i*	*s*
naphthalene	1.15	80	218	*i*	*s*	*sp*
phenyl benzoate	1.23	71	314	*i*	*s*	*s*
stearic acid	0.85	70	291	*i*	*s*	*sp*
toluene	0.87	–95	111	*i*	*s*	*s*

Table 1.1. Physical properties of pure substances.

Cleanup and Waste Disposal

Reminders

1. Check with local solid waste and/or wastewater treatment officials to confirm that the methods described here are acceptable.
2. Only flush chemicals down the drain if they go to a sanitary sewer and wastewater treatment facility.
3. Never dispose of chemicals into a septic system or in the storm sewer.
4. Wear goggles, nitrile gloves, and apron while cleaning up.

Cleanup and Disposal

Collect bulk quantities of leftover solids and liquids in separate containers.

Small amounts of ethyl alcohol and acetone may be left to evaporate, away from sources of flame, and secured from children and pets.

The alcohol and acetone are biodegradable. Separate these, along with their aqueous solutions, from the other items. Dilute these separately in water. Dispose of them separately by pouring down the drain with excess water at a maximum rate of 100 grams per day for each substance.

Excess uncontaminated hexane, naphthalene, and toluene should be returned to their containers and kept for future experiments or taken to a hazardous waste collection facility.

Pour the other waste mixtures into a plastic waste container with a tight-fitting plastic lid labeled Liquid Hazardous Waste. Save this for later disposal at the hazardous waste collection facility. Keep a log of species, approximate quantities, and concentrations that have been added to this container.

Lauric acid is a natural fatty acid and may be disposed of in the trash.

Clean your apparatus with soap and water. Perform a final rinse with distilled water to prevent mineral deposits from forming on the glassware during drying.

Analysis

Compare your data to the information in Table 1.1 for each of the four substances you tested. To begin your analysis, calculate the percent difference[2] for your four substances for density, melting point, and/or boiling point. Record these values in your lab journal. In your discussion, refer to these values to help establish the accuracy in your measurements.

2 See the Introduction Part 4 for an explanation of this term and the calculation involved.

Experiment 1: Identification of Substances by Physical Properties
Short Form Report Sheet

Your Name	

Your instructor or supervisor will determine whether you will write a complete lab report for this experiment or use the following short form report sheet.

Part 1: Solubility

(Show your data table here.)

Part 2: Density

(Show your data table here.)

Part 3: Melting point of solids
(Show your data table here.)

Part 4: Boiling point of liquids
(Show your data table here.)

Your Name	

Questions

1. Is bromoform a solid or liquid at room temperature?

2. Which solvent did you use to measure the density of naphthalene? Explain your choice.

3. If air bubbles were trapped in a sample of naphthalene during your volume measurement to calculate density, what error would result and how would that effect your density calculation?

4. A liquid was found to be insoluble in cyclohexane and had a density of 0.79 g/mL. List the possible identities of this substance. What experiment could be performed to confirm the identity?

5. Osmium is the densest element known. Use the internet to research the physical properties of osmium. List the properties and their associated values. Specify your source.

Experiment 3
Flame Tests and Metal Cation Identification

3

Text Connections
- *General Chemistry* and *Principles of Chemistry,* Sections 3.1.1, 3.1.2, 3.3.3
- *Chemistry for Accelerated Students* and *Accelerated Chemistry*, Sections 1.1.1, 1.1.2, 1.3.3

Objective

To relate the emission spectra of specific metal cations to their chemical identities.

New Lab Skills Focus for Experiment 3

Flame tests

Apparatus

cotton swabs
natural gas stove, propane burner, or alcohol burner
test tube, small (8)
test tube rack

Apparatus Notes

For best results, use the flame from a natural gas stove, portable propane burner, or Bunsen burner for the tests in this experiment. Natural gas and propane both produce a clear blue flame that makes it easy to see the colors produced during the tests. If necessary, the alcohol burner can be used and will also work, but poorly. Alcohol produces a bright yellow flame that can make the colors hard to distinguish—particularly when the color produced during the test is the same as the alcohol flame. Butane lighters also produce a yellow flame, and are not recommended for this experiment for the same reason.

Chemicals

0.5 *M* solutions of $CaCl_2$, $CuCl_2$ (or $CuCl_2 \cdot 2H_2O$), KCl, LiCl, $MgCl_2$, NaCl, $SrCl_2$, $ZnCl_2$

Chemical Notes

Prepare the solutions in small quantities, using a 10-mL graduated cylinder as described in the Introduction Part 3 (see Example 2). The precision of the solution molarities is not critical. Solutions may be transferred directly to test tubes for the experiment as they are prepared. Note that some of the chemicals listed for this experiment in the tables in the Introduction Part 1 are hydrates. For assistance preparing these solutions, refer to Introduction Part 3, Example 5.

Safety

Always follow the general safety practices described in the Introduction. In particular, the following safety precautions should be taken during this experiment:

1. Wear nitrile gloves whenever handling any substances.
2. Wear appropriate laboratory eye protection at all times.
3. Wear a laboratory apron to protect your clothing.