Lesson 4: Performing Experiments

Introduction

This document is Lesson 4 of the SEAChem2020 open source chemistry curriculum program for secular homeschoolers. This version was current as of 28 August 2017. To if there is a more current version of this document, visit www.SEAChem2020.org.

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We welcome any help you are willing to provide in supporting this project. Even if you're not a chemist or a professional educator, you can help in the following ways:

- **Let us know about minor fixes**. If you find anything from a factual to a stylistic error, or even a typo, let us know by using this form.
- **Let us know if you find big problems**. Does something need rewriting? Let us know by contacting us using this form.
- **Give us your resources**. If you've done one of these lessons and have put something cool together, email us at misterguch@chemfiesta.com so we can include it!
- **Volunteer**. Do you want to edit this curriculum? Do you have things to add? Would you like to write some of these lessons? Let us know!
- **Publicity**. Tell your friends about these resources. When the community grows, the project keeps growing!

Thank you for using this resource, and please consider helping out!

Lesson 4: Performing Experiments

Parent Reference

Objective: To teach students how to perform meaningful scientific experiments and analyze the data that's collected.

This lesson contains the following:

- Text: Performing Experiments
- Lesson glossary
- Practice sheet
- Activity: Building your own lab
- Assessment
- References for further study

Additional resources needed: The lab activity will require you to collect some lab equipment for later use in this course.

How to use this material:

This lesson is set up to be used in the following way. During the course of this lesson, your child should:

- Read the material in the text.
- Rewrite the material in their own words. (Optional but recommended).
- Complete the practice sheet.
- Write their own practice sheet for the material, complete with answer key. (Optional but recommended).
- Complete the activity.
- Write their own activity for the material, with suggestions on how to best to complete it. (Optional but recommended).
- Take the assessment to ensure they understand the material.
- Write their own assessment, along with solutions. (Optional but recommended).

These steps should be followed by a debrief, in which you and your child will discuss the material. Any suggestions you have to improve this lesson, as well as any materials your child writes during this lesson (text, practice, activity, assessment) should be sent to SEAChem2020 so that we may incorporate it into the curriculum.[1]

Practice Sheet:

This practice sheet is a mixture of both rote definition questions that universities will assume incoming students should have and open-ended problems that challenge your child to think creatively (which is what universities *really* want). When your child is finished with the practice sheet, we recommend that they spend a few minutes writing their own practice sheet. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any practice sheets to SEAChem2020 at misterguch@chemfiesta.com.

1 *Any submitted material added to the curriculum will be licensed under the same Creative Commons license as the rest of this material and will be free for others to use and adapt. Please make sure your name is included somewhere on the submitted resource(s) if you wish to receive credit for your work. All submitted resources may be edited for accuracy, formatting, and style.*

Activity:
The information about the activity is included within the activity itself.

Assessment:
The assessment in this lesson, as in all of the lessons, is meant to not only indicate whether your child has learned the material, but to push them to think even further than they have before. After all, assessments should be part of the learning process, too. When your child is finished with the assessment, we recommend that they spend a few minutes writing their own assessment. Teaching is the best way to learn something, and by teaching others your child can help to teach him/herself. Please submit any assessments to SEAChem2020 at misterguch@chemfiesta.com.

Lesson 4: Performing Experiments

It should be no surprise to you that chemistry requires experimentation to test hypotheses.[2] It's not enough for us to think really hard about what we think *should* happen under some set of circumstances because unusual and interesting things happen more frequently than we might expect. The world is interesting and complicated enough that even educated guesses are likely to tell us everything we need to know.

Depending on what we're studying, experiments can be either very easy or very difficult to perform. If you want to know what happens when you stick a fork into a power outlet, you simply need to stick a fork into a power outlet and observe the outcome.[3] On the other hand, if you want to find out how protons behave when you accelerate them to 99.997% of the speed of light, you'll have to build an enormous particle accelerator to get the job done.[4]

The Fermi National Accelerator Laboratory, Batavia, IL.[5]

In this lesson, we'll explore the process by which we can create meaningful, safe, scientific experiments. Let's examine the steps we'd normally go through when performing an experiment:

Step 1: Define the problem you're trying to solve

All experiments have some goal in mind. It's important to clearly articulate this goal before you get started so you know *exactly* what it is you're trying to do. Your goal should have the following characteristics:

- **It should be narrowly defined**: There's no single experiment that can answer the question "Is global warming occurring?" It's too complicated a problem and there are too many factors involved. If you're going to perform an experiment, you need to focus on a small enough piece of the problem that the experiment can actually address it.
- **It should be realistic**: Unless you've done a lot of work building up to it, you're not going to invent a spaceship that travels faster than light. Setting your sights too high will not be likely to result in useful results.
- **It should be testable**: The question "Is there a God?" is not testable using science. Nor can you use science to determine that your dog really likes you or that cheese is

2 *If this* is *a surprise, head back to Lesson 1 where we discuss this at length.*
3 *Don't perform this experiment. You will not like the outcome.*
4 *Fermilab website: http://fnal.gov/pub/science/particle-accelerators/accelerator-technology.html*
5 *By Fermilab, Reidar Hahn [Public domain], via Wikimedia Commons.*

the best food ever. Because these can't be tested, they aren't good subjects for an experiment.

Step 2: Writing a hypothesis

When you've isolated your problem, it's time to write a hypothesis in which you explore how one aspect of the phenomenon can be manipulated. Hypotheses generally come in the form of an "if [independent variable] then [dependent variable]" statement in which you state what you're going to manipulate in the experiment (the independent variable) and what you believe will result from this manipulation (the dependent variable).[6] For example, if you want to understand something about how ducks fly, you might write a hypothesis such as "if the feathers at the end of a duck's wing are removed, then the duck cannot fly." Note that this is a very simple hypothesis that addresses just a small part of the overall question about ducks flying, because answering the question in one experiment is unlikely.

Step 3: Devise an experiment

When you've determined your hypothesis, the next step is to write an experiment that will test it. Because all hypotheses are different, there's no general way in which an experiment can be written. However, there are a few guidelines that might help to make this easier:

- **Make sure you only change *one* variable**: Good experiments involve changing only one variable. The reason for this is simple: If you change more than one thing at a time, you'll never know which of the things you changed are responsible for the observed outcome. For example, let's say that our hypothesis is "If I add fertilizer to my lawn, then it will grow faster." If I write an experiment in which I add fertilizer to my lawn and also water it differently than before, it will be impossible to tell whether it is the watering or the fertilizing that caused my lawn to grow faster. Variables that are not changed during the course of an experiment are called **controls**.
- **Check to see if somebody's done an experiment like this before**: There's no reason to design a completely new experiment if somebody has already performed one just like it. A quote by Frank Westheimer sums this up nicely: "A month in the laboratory can save you an hour in the library." Don't spend a month reinventing the wheel when a little research will suffice!
- **Determine whether you have the right equipment and facilities**: There's no point in designing an elegant experiment if you don't have access to the needed equipment or if your lab space isn't adequate. If you don't have access to what you need, either improvise or test your hypothesis in a simpler way.
- **Make sure you have the time to correctly perform the experiment**: At some point, you'll have problems setting up your experiment or getting your experiment to work properly. If you set up an experiment such that under ideal circumstances you'll just *barely* have enough time to finish, the likely non-ideal circumstances will lead to an unfinished experiment. Remember Murphy's Law: "If something can go wrong, it will."[7]

6 *This should be familiar from Lesson 1.*
7 *Perhaps a more accurate version of this is Sod's Law, which states that "If something can go wrong, it will – at the worst possible time."*

- **Safety first!** If you have any doubts about your ability to perform a lab safely, don't do it! Lab safety is more important than everything else mentioned in this Lesson, because failure to be safe can result in injury or death! A separate document in this lesson will outline the basic safety procedures for performing experiments.

Step 4: Performing the experiment

Once you've gotten the prep work out of the way, performing the experiment should be fairly straightforward. *Should* being the operative word. In reality, experiments have the tendency to go awry. It's rare for something to behave as you anticipate, which can result in repeated experiments or inconsistent results. Be ready for this, and don't be too surprised if you have to redo an experiment.

Step 5: Analyzing your data

When you've finished your experiment, you'll have collected a variety of qualitative and quantitative data. Though we normally think of quantitative data as being better than qualitative data, in reality both forms of data can give us valuable insight as to what is going wrong. For example, imagine you perform an experiment where the expected quantitative data are found but one of the bits of qualitative data involves the entire experimental apparatus bursting into flames. Though we'd like to say that our hypothesis had been proved, it might be a good idea to try the experiment again to ensure that our data are truly as we expected.

When analyzing your data, you will find examples of experimental error. Far from being a disaster, experimental error is both normal and expected when you work in the lab. There's no such thing as perfection, so don't be upset if your data aren't perfect! You're not a bad scientist – you're just a normal person!

There are several main sources of experimental error:
- **You**: Nobody is perfect, and experiments are never carried out without error. If there are errors in your experiment, chances are excellent that you are the source of them.[8] Mistakes of this kind are referred to as **human error**.
- **Equipment**: Scientific tools are not flawless and, as a result, can give erroneous answers. It should be noted, however, that instrumentation error is much less common than human error.
- **Unknown sources**: If something went wrong and you're not sure what, it's probably an example of human error.

In addition to these sources of error, we also need to be aware of the different ways in which data can be incorrect. **Systematic error** are errors that take place in a repeatable fashion. For example, let's say that somebody has taped a penny to the bottom of the scale I'm using. Because pennies weigh 2.5 grams, I can expect the weight of everything I measure to be 2.5 grams heavier than the actual answer. Systematic error is frequently caused by a badly-calibrated measuring tool. **Random error**, on the other hand, represents errors that don't

8 *I cannot stress enough that human error is both normal and expected in all experiments. Human error is only a big deal when we fail to recognize it for what it is – doing this means that we'll make the same mistake over and over again.*

occur in any predictable fashion. Sometimes the answer is higher than expected and sometimes it's lower. Sources of random error are difficult to pin down and can be caused by nearly anything. The best solution to dealing with random error is to perform the experiment several times.

Step 6: Determining whether the hypothesis was correct

Once you've worked through the data, it's time to determine whether your hypothesis was correct or incorrect. This may seem like it would be the easiest part of the experiment, but it's sometimes the most difficult.

Imagine this: You've worked on a problem for a long time and come up with a hypothesis that you feel is correct. When you perform your experiment, you don't get the answer that you'd like. What do you do? If you're honest with yourself, you admit that you were wrong and come up with a new hypothesis. Unfortunately, many people aren't able to admit when they've made a mistake, which leads them to believe that their data have supported their hypothesis when they really haven't. This tendency to analyze data such that the expected result is erroneously confirmed is called **experimenter bias**.

How do we minimize experimenter bias?

*The best way to ensure that we've minimized our experimenter bias is to make sure that disinterested people agree with our analysis of our data. If I've spent a great deal of time and money in an experiment, I've got a very real stake in what happens. To a colleague, however, there's no such reason to falsely confirm a hypothesis. This analysis by outsiders of experimental data is called **peer-review**.*

This NIH reviewer is evaluating research proposals for funding.[9]

The main ideas in this lesson:

- To perform a meaningful experiment, you must define the problem you want to solve, write a hypothesis, devise an experiment, perform the experiment, analyze your data, and determine whether the hypothesis was correct.
- Experimental error is normal and expected in scientific inquiry.
- Safety is of paramount importance in the lab!

9 *By Center for Scientific Review [Public domain], via Wikimedia Commons.*

Lesson 4: Glossary

control: Some factor that is not changed over the course of an experiment. For example, if you were going to test how light affects a chemical reaction, you would want to keep the temperature steady so you could be sure that temperature didn't affect the outcome.

experimenter bias: The tendency a scientist has to confirm their hypothesis, regardless of the outcome of an experiment. Experimenter bias can be minimized by peer-review or by confirming the outcome in a different way.

human error: An experimental error caused by human actions. Most experimental errors are also human errors.

peer-review: When scientific results are reanalyzed by another scientist who is not involved in the experiment. Reputable scientific journals are always peer-reviewed.

random error: An unpredictable source of error. If you were to weigh an object in a moving car, the answer would be incorrect in some way that could not be repeated.

systematic error: An error that occurs in a predictable way. A thermometer that always gave a reading two degrees lower than the true reading would have a predictable, systematic error.

Safety Rules for Homeschoolers

During this chemistry course, you will be performing labs that involve various chemicals[10] and equipment setups. Though both the chemicals and equipment will be less involved than you might find in a classroom, there are still dangers that you need to be aware of when doing chemistry in your home. If you follow these rules and exercise common sense, you shouldn't have any problems.

Primary sources of concern:

Though, as we'll see below, there are specific rules that should be followed to safely work in a lab, the main dangers can be broken down into a few categories. When performing experiments, pay attention to ensure that the following don't become a problem:

- **Eye damage**: Your eyes are the most easily-damaged part of the body, as well as being a part of the body that is very difficult to fix once injured. To prevent eye damage, the single most effective step you can take is to wear safety goggles. Yes, I know that it may seem strange to wear safety goggles around the house, but it's much better to feel silly than it is to take a trip to the hospital.
- **Burns**: Whenever working with heat, there exists the possibility of burns. These burns can come from open flames, from touching hot objects, or from having hot items splashed on you. Pay attention to possible burn hazards when designing and performing labs.
- **Poisoning**: These lessons will occasionally involve toxic chemicals. From sodium hypochlorite (bleach) to isopropanol (rubbing alcohol), you'll be working with chemicals that can pose a hazard when consumed. Be careful to avoid situations where this might be a problem!
- **Fire**: In addition to harming you, fire can also harm your surroundings. Make sure that flammable materials are kept away from heat sources when doing experiments to ensure that your house remains in one piece.

This is not to say that there aren't other possible sources of danger when doing labs. This leads to the zeroth law of lab safety:

If you've got a gut feeling that something isn't safe, it's probably not safe.

This may not sound particularly scientific, but it turns out that your subconscious mind is careful when it comes to things that might be harmful. Even if you're following all of the safety guidelines outlined below, *never* do anything in the lab if you feel that something's not right.

At this point, you probably don't have a good feel for what's safe and what's dangerous when working in the lab. To help with this, follow the guidelines below when performing experiments in your homeschool lab.[11]

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10 *The term "chemical" is being used in this document to refer to the reagents you use in experiments and the products that are formed. As you're probably already aware, all substances are chemical in nature.*

11 *These rules have been specially-written with the homeschooler in mind. Though good general rules, they do not cover circumstances that you might run into when working in actual chemistry labs. Whenever you perform labs in new lab environments, make sure that you are well-versed in the safety rules for that location.*

1. **Wear goggles at all times when performing experiments.** Even if you think that the chemicals your working with cannot damage your eyes, the fragility of your eyes requires that you wear goggles. Goggles should be rated to protect you against chemical splashes.[12]
2. **Make sure anybody present when performing a lab wears goggles at all times.** It doesn't take long for eye damage to occur, so make sure the people near you are protected, even if they're only in the room a moment.
3. **Make sure everybody present when performing a lab wears goggles.** This is included yet again because it's the single most effective thing you can do to avoid accidents.
4. **Anybody not directly involved in performing the lab should be kept out of the lab area while the experiment is ongoing**. Particular care should be given to siblings and pets.
5. **Never start an experiment until you understand the potential safety issues and have worked out solutions for them**. The best way to react to an emergency is to have thought about it ahead of time.
6. **Perform your experiments in a dedicated lab area**. If you're performing your experiment in the kitchen, make sure that your lab is the only thing going on in that part of the kitchen until you have finished. Before starting your experiment, clear out everything that isn't needed for your lab so you have an uncluttered area in which to work. Similarly, if you perform your lab in the garage, make sure that you do it in an area that has been cleared of all non-lab items.
7. **Make sure you have the equipment and supplies you need before doing the lab**. If you need running water, make sure you have a source of water ready. If you need some particular bit of lab equipment, make sure it's present before starting. By having everything prepared ahead of time, you minimize distractions once the lab has started.
8. **Rubber gloves should *not* be used when performing experiments**. In most cases, the protection they give is minimal. When heating chemicals, they can melt to the skin causing serious burns.
9. **Have proper safety equipment nearby**. In a home lab, you should always have the following items handy: Fire extinguisher[13], fire alarm[14], portable eyewash[15], and baking soda[16]. Additional items may be required, depending on the lab.
10. **Know how to use all safety equipment**. In many cases, this will be intuitively obvious. In the case of the eyewash, practice using it before you actually need it.
11. **Food and chemicals must always be kept separate**. If you need to store the results from an experiment, store it away from food items. If you need to use a food item for an experiment, do not pour any of the excess back into the original container.
12. **Wear proper clothing**. Tie back long hair and wear clothes that are not loose-fitting. Closed-toe shoes should be worn.
13. **If a glass item is broken, clean the entire room in which you were performing the experiment**. Glass shards may travel farther than you think they will!
14. **Never reach across any source of flame**.

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12 *Swim goggles and everyday eyeglasses are not sufficient – make sure you get real chemical protective goggles that meet the ANSI Z87.1 standard.*

13 *Any fire extinguisher should be ABC rated. At this writing, they can be purchased for less than $20 on Amazon.*

14 *Fire alarms cost as little as $10 at big box stores or online. If you don't have at least one fire alarm on every floor of your home, this is an excellent chance to increase your home's overall fire safety.*

15 *Portable eyewashes can be obtained for less than $6 on Amazon, as of this writing.*

16 *Ordinary baking soda (sodium bicarbonate) can be purchased for less than $1/lb at grocery stores. Baking soda can be used to smother fires or neutralize acid burns.*

15. **Properly dispose of any chemical waste**. Most waste can be disposed of down the sink, but if exceptions are indicated, please follow the disposal instructions.
16. **When heating anything, make sure to take the proper precautions**. All flammable materials should be kept away from the source of heat, and any open flames should be limited to the stove top or outdoors.
17. **Hot items look the same as cold ones**. If you're not sure if something is cool enough to handle, splash some cold water on it. If it doesn't sizzle, then touch it for a brief second – if it doesn't feel hot, it's probably safe to handle.
18. **All containers that hold chemicals should be kept within easy arm's length when handling and kept below eye level**. Never look into a container that holds chemicals.
19. **Damaged equipment should be replaced promptly**.
20. **Electrical equipment should be kept away from water**.
21. **If a fire breaks out, or if another situation occurs that you believe you cannot handle, immediately call 911 and evacuate your home**.[17] Though you may think this is overreacting, it may save you from injury or death. If it turns out you were overreacting, rest assured that emergency services have been called out for far less than whatever necessitated your call.
22. **When performing experiments in multi-family buildings, make sure that the building owner and landlord have given their approval for experiments**.
23. **When you have finished working on your experiment, clean all equipment and your workspace**. If you have been using anything that is hazardous when touched or ingested, wash it twice.
24. **If something goes wrong, don't panic!** Running around in fear doesn't solve problems, so take a minute to collect yourself before acting if something goes wrong.[18]
25. **Use the buddy system!** Never perform labs without adult supervision.
26. **Not everything that goes wrong is a disaster**. It is completely normal to drop, spill, and break things during the course of a science experiment. Doing this doesn't make you unsafe or a bad scientist – they make you human.
27. **Remember, safety is *your* responsibility and yours alone!** No list of safety rules can adequately address all possible hazards, so use your best judgment if you're not sure what to do.

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17 *911 is the emergency number in the U.S. and Canada. In Europe dial 112, in Australia 000, in New Zealand 111; in other locations, make sure you determine the emergency number before starting any labs.*

18 *This assumes that the danger is not imminent, such as an explosion or serious injury. In this case, evacuate immediately and call for help.*

Lesson 4: Practice Sheet

1) Why do all experiments need controls?

2) My hand shakes whenever I try to move a chemical from one container to the other. Would any errors caused by this shaking be systematic errors or would they be random errors? Explain your answer.

3) In the field of global warming, some groups are said to have biased beliefs supporting global warming and others are said to be biased against global warming.

   - As a scientist, how can we be sure that we don't fall victim to experimenter bias when analyzing our data?

   - The scientific community has overwhelmingly come out in support of the idea that global warming is taking place. How can they be so sure that they're correct?

4) It was said in the safety rules that you and you alone are responsible for safety when performing a lab experiment. Do you believe this is reasonable, given that you are a student and this chemistry curriculum was written by people knowledgeable in laboratory practice? Explain your answer.

Lesson 4: Practice Sheet Answers

1) Why do all experiments need controls?
The control variables are any factor that is not changed over the course of an experiment. Only one variable during an experiment is not controlled so that we can be sure that any observed outcome is due to that variable and not something else.

2) My hand shakes whenever I try to move a chemical from one container to the other. Would any errors caused by this shaking be systematic errors or would they be random errors? Explain your answer.
This would be a random error, as my shaking hand will sometimes cause more of the chemical to be transferred than at other times. A systematic error would be an error that was reproducible, such as a balance that always weighs 0.1 grams heavy.

3) In the field of global warming, some groups are said to have biased beliefs supporting global warming and others are said to be biased against global warming.

- As a scientist, how can we be sure that we don't fall victim to experimenter bias when analyzing our data?
To be good scientists, we need to write our experiments such that any biases will be minimized. For example, if we believe that a medication will cure a disease, we must set the experiment up such that nobody involved knows who is getting a medication and who is getting a placebo. Additionally, understanding that experimenter bias is something to which every scientists is susceptible helps to keep us aware of these tendencies within ourselves.

- The scientific community has overwhelmingly come out in support of the idea that global warming is taking place. How can they be so sure that they're correct?
In science, we cannot be 100% sure of anything. However, there have been a huge number of studies about global warming performed in many different ways, and they definitively show that global warming is taking place. Generally speaking, gathering information using different methodology is a good indication that something is valid.

4) It was said in the safety rules that you and you alone are responsible for safety when performing a lab experiment. Do you believe this is reasonable, given that you are a student and this chemistry curriculum was written by people knowledgeable in laboratory practice? Explain your answer.
The reason that you are responsible for your own safety is that only you understand exactly what the conditions are in the location you're doing the experiment. Though general guidelines will be sufficient to give you a good understanding of safe lab practices, they cannot be extended to all possible lab situations in all possible locations. For you to remain safe, you must first understand the general lab rules that this lesson provides, and then study your own circumstances to understand what might pose a specific danger to you.

Lesson 4: Lab Activity

The lab activity for this lesson is going to be just that: An actual lab activity. Because we'll be performing labs while learning chemistry, it's important that we have the equipment we need. As a result, in this activity you'll be getting the materials you need to construct your lab.

I've provided two lists of items that you'll need. The first is the actual lab item, which can be purchased on Amazon, eBay, Walmart, or scientific supply companies. The second will be the home version of this equipment; while not the fancy scientific version, it will get the job done. In cases where one is preferable to the other, an asterisk will indicate the one that's recommended.

Scientific equipment	Price[19]	Cheaper version	Price	Purpose of equipment
beaker*	$2-$4	drinking glass	<$1	Storing chemicals, performing reactions, boiling chemicals[20]
evaporating dish	$6	coffee cup or cheap cooking pot*	<$1-$10	Boiling away the liquid from a chemical, heating solids.
Bunsen burner[21]* (propane tank also needed)	$24; $8 for 2 propane tanks	propane soldering torch[22]	$14	Heating chemicals to high temperatures. Note, do not heat flammable materials over open flames!
hot plate	$10	electric stove[23]	$0	Boiling solutions
graduated cylinder*	$5	measuring cup with mL gradations	$3	Measuring specific volumes of liquids. Graduated cylinder highly recommended.
pipettes*	100 for $6	eyedropper	$0	Placing small amounts of reagent. Because pipettes are much cheaper than eyedroppers, it is recommended you only use an eyedropper if you already have one readily available.
balance	$100	kitchen scale*	$12	Weighing chemical compounds. Ensure that it can measure to the nearest 0.1 gram and has a capacity of at least 100 grams.
forceps[24]	$5	tweezers*	$2	Grasping small items.
spatula or scoopula*	$5	straight spatula	$5	Used for removing small amounts of powder from a reagent bottle. Scoopula recommended.
thermometer	$6	digital meat thermometer*	$7	Measuring temperature. The meat thermometer should have gradations of 0.1 °C and cover the range from -10 °C to 110 °C. Digital meat thermometer highly recommended because it's both more durable and more precise.

19 *Prices in USD, effective 7/5/2017. Good sources of these supplies include Amazon, eBay, and local retailers.*
20 *Beakers are only heat-resistant for boiling water, drinking glasses should be replaced with coffee cups when heating.*
21 *If you purchase a Bunsen burner, you need to make sure you buy one that's designed to burn propane and not natural gas – propane tanks can be purchased at hardware stores. Though gas stoves use natural gas, do not under any circumstances try to reroute the gas into a Bunsen burner!*
22 *Gas stoves can also be used as a heat source at no cost.*
23 *Assuming you have an electric stove.*
24 *These are different than the "forceps" used by doctors, which look like scissors with grasping ends. Chemistry forceps are basically indistinguishable from the tweezers you use around your house.*

watch glasses*	$10 for 10	no good substitute	n/a	Performing reactions, covering solutions.
ring stand and wire gauze*	$12; $6 for 3	no inexpensive substitute	n/a	To heat containers over open flame.
glass stirring rods*	$5 for 10	plastic swizzle sticks	$6 for 50	To stir reaction mixtures.
fire extinguisher	$20	no good substitute	n/a	Putting out fires

Common chemicals we'll be using during this course:

During this course, you will be using several chemical compounds on a regular basis.[25] Though you don't need to obtain them now, you will, at some point, need to obtain the following:

Name	Compound	Hazards associated with compound
ammonia	ammonia (NH_3)/water (ammonium hydroxide)	irritant when inhaled, extremely dangerous when combined with bleach-containing solutions.
baking soda	sodium bicarbonate ($NaHCO_3$)	not considered hazardous
chalk	calcium carbonate ($CaCO_3$)	not considered hazardous
moisture absorber, ice melter	calcium chloride ($CaCl_2$)	irritates wet skin, gives off heat when dissolved
nail polish remover (acetone)	acetone (C_3H_6O)	extremely flammable, toxic
nail polish remover (ethyl acetate)	ethyl acetate ($C_4H_8O_2$)	flammable, toxic
rubbing alcohol (ethanol) Everclear, grain alcohol, vodka	diluted ethanol (C_2H_5OH)	ethanol used as rubbing alcohol is toxic if consumed – in other forms is an intoxicant; flammable; use of consumable forms of ethanol is age-restricted – check laws in your area before using.
rubbing alcohol (isopropanol)	diluted isopropanol (C_3H_7OH)	toxic if consumed, flammable
sugar	sucrose ($C_{12}H_{22}O_{11}$)	not considered hazardous
vinegar (white)	dilute acetic acid (CH_3COOH)	not considered dangerous, rinse from skin
washing soda	sodium carbonate (Na_2CO_3)	irritates wet skin, may cause irritation if ingested

25 *The warnings given for each chemical are those you'll be most likely to find and are not meant to be comprehensive of all possible dangers. As always,* you *are ultimately responsible for safety in your home!*

Lesson 4: Assessment

1) When performing scientific investigations, why is it important that problems be narrowly defined?

2) What does the expression "A month in the laboratory can save you an hour in the library" mean? Is it a good rule of thumb when performing scientific research?

3) What is the difference between systematic error and random error in an experiment? Which do you believe would be easier to correct, and why?

4) If a hypothesis has been shown to be incorrect, what do you believe the next step should be?

5) Why is it far more important to wear goggles than to follow any other safety rule?

6) Examine the area you have set aside as your lab area and identify three safety concerns that are not addressed in the safety rules from this lesson.

Lesson 4: Assessment Answers

1) When performing scientific investigations, why is it important that problems be narrowly defined?
Problems that are too broadly-defined cannot be effectively studied in a single experiment due to their complexity. Instead, problems need to be broken down into smaller parts that can each be carefully-controlled.

2) What does the expression "A month in the laboratory can save you an hour in the library" mean? Is it a good rule of thumb when performing scientific research?
This expression means that it doesn't make sense to redo work that others have already published elsewhere. It's a very good rule of thumb and can prevent a huge amount of redundant work from being performed.

3) What is the difference between systematic error and random error in an experiment? Which do you believe would be easier to correct, and why?
Systematic error is error that is predictably wrong, whereas random error gives erratically-wrong answers. Systematic error is usually more easily-corrected because the nature of the error often gives clues as to where it's coming from.

4) If a hypothesis has been shown to be incorrect, what do you believe the next step should be?
The next step is to find another way around the problem you want to solve. If you've done the experimental work to find that a hypothesis is false, you simply won't be able to use it to solve your problem.

5) Why is it far more important to wear goggles than to follow any other safety rule?
Most parts of the body heal easily when damaged. Eyes, on the other hand, can very easily be permanently damaged by chemicals or broken glass.

6) Examine the area you have set aside as your lab area and identify three safety concerns that are not addressed in the safety rules from this lesson.
These will depend on the lab area you are using. The following are examples of issues that may be present:
- **Garage: Flammable materials present (particularly shop rags, gasoline, other liquids), area is crowded with lawnmowers and other tools, need to time experiments around vehicles, dirty work conditions**
- **Kitchen: Flammable materials present (particularly rags and curtains), small working area, children or pets underfoot, working area too near food preparation area.**
- **Outside: Flammable materials present (grass, wood, deck), wind blowing experimental apparatus around, other weather-related issues.**

Lesson 4: References For Further Study

Writing a hypothesis:

- How to write a strong, testable hypothesis: https://www.sciencebuddies.org/blog/2010/02/a-strong-hypothesis.php

Confounding variables:

- Confounding variables are variables that falsely show a relationship between the independent variable and dependent variable in an experiment: https://explorable.com/confounding-variables

How Murphy's Law works:

- The history of Murphy's law and its influence on society: http://people.howstuffworks.com/murphys-law.htm

Types of experimental errors:

- Systematic and random errors can be broken down into subcategories. Learn them here: http://www.physics.nmsu.edu/research/lab110g/html/ERRORS.html

Experimenter bias:

- The story of Clever Hans, the horse who could (supposedly) solve math problems: https://www.damninteresting.com/clever-hans-the-math-horse/