Designing, Building and Using a Home Laboratory

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Part 1: Introduction (Revised 30 March 2011)

In today's world with its terrorism, seemingly rampant drug use and other scary goings on it is certainly not unusual for the idea of building and using a home laboratory to be looked upon, by some, as an activity that must be very suspicious. There will be a never-ending stream of unwarranted remarks from friends and neighbors if you tell them you have a home laboratory. Usually, you'll hear some smart-alecky person ask, "So, you makin' meth?" On the other hand, if you tell someone that you have a workshop in your home, they'll either be very interested and want to talk about their own workshop and what projects you're working on, or they'll be so intimidated by your presumed skills that they'll quickly change the subject. A workshop <u>is</u> a laboratory; a laboratory <u>is</u> a workshop.

My personal travel into life with a home laboratory started when I was 12. Many of my customers at our science store in Parkville know my story well. I received an aquarium and a chemistry set for Christmas. As I like say, aquariums and chemistry have been inextricably linked, in my life, ever since. That link started in 1959 for me; I'd would have liked it to have started earlier, and I now tell our customers that 9 years old for a child, girl or boy, is the nearly perfect age to build and start using a home science laboratory. My father was a cabinet maker, and I never wanted for really nice work spaces with custom built desks and shelving. My first serious laboratory was in our home on Russell Road in Kansas City, It was in the basement, against a wall. My dad's cabinet workshop was on the other side of the basement. If I needed a test tube rack I simply crossed over to his side of the basement and working with a band saw, drill press, glue, clamps and table sander built what I needed. Even though my dad took little interest in what I did in my lab, he was always concerned about my safety, and was ready to assist me when his particular skills were needed.

In our science store we see families with interests in science, and we definitely see families in which the parents want to support their children's interest in science. We don't always recommend a home laboratory, but we are quick to recognize an ongoing theme when a family as made a few visits. In those cases we will often recommend a home laboratory as a way for the family to have a shared interest and as a way for the young scientists to understand that they can do real science at home.

Of course, we often see baby boomers like my wife and me, who either once had a chemistry set, or a modest home lab, but long since had "out grown" these earlier interests. Many say, "Wow, I wish there had been a store like yours when I was growing up." I think there are very few endeavors in life more interesting and exciting than science…any science. I became a scientist, a chemist, because of my early interest and encouragement. Today I am a chemist as well as an ichthyologist, and my family opened our science store just so there is not another generation that will grow up in Kansas City someday wishing there had been a store like H.M.S. Beagle when they were growing up.

A year or two before we opened the H.M.S. Beagle in Parkville I had designed and built chemistry sets that were housed in large, hardwood cases complete with brass hardware and secret compartments. No two sets were alike; the first one was built as a Christmas gift for a nephew in Hickory, North Carolina. It weighted in at 80 pounds and came complete with over 85 different chemicals. It also had a CD-ROM of the 1936 edition of the A.C. Gilbert *Chemistry for Boys* which accompanied their largest and most complete chemistry sets at the time. That manual is still to be found, in Adobe Acrobat PDF format, on a CD-ROM in the chemistry sets we sell at the Beagle (and, we often have actual, intact copies for sale at the Beagle). These sets were constructed of oak or walnut and had contrasting, rare, hardwood inlay accents. Most were built as double cases that were hinged along one long side and opened like a book. The last set I built before opening the Beagle was a triptych (one large case with two smaller ones that closed over it from each side). It was constructed of Osage orange wood and red heartwood. That last kit was sold to Brookside Toy and Science in Kansas City who then resold it. In November 2006 I met the man who bought the set; he told me that he displays it as a piece or art and never uses it! That was never my intention. A laboratory, whether it is nothing more than a shoe box with some modest pieces of equipment, a full-blown chemistry set in a hand-crafted case, or an entire room set up with work benches, cabinets, sinks and more; it is supposed to be used! So, with this introduction, embark with me on a shared adventure to design, build and use your home laboratory.

Part 2: Location, Location, Location (Revised 30 March 2011)

Just like in real estate where your lab is located is as important as what goes into it. Since the Beagle has been open I have heard nearly everything. “We’ve converted her walk-in closet to a lab space where she can work with her microscope and slides.” “The boys bring the chemistry set into the kitchen and we work with it on the counter.” “I finally got permission from my parents to clear a space in our basement where I have set up a work bench near a sink and where I have access to both electricity and a natural gas connection.”

Probably 90% of beginners will use the kitchen as their home laboratory, at least for a while. The obvious advantages to a kitchen location are access to both hot and cold running water, a sink for cleaning, rinsing and disposing, and ready access to glasses and jars and spoons for measuring and mixing. The problem with the kitchen will eventually become obvious. For one thing one can’t simply leave experiments sitting around and sometime the curious uninitiated (e.g. siblings) may accidentally disturb a critical experiment. Sooner or later, the kitchen has to be abandoned and a more suitable location will be needed.

I often talk to kids who have set up their chemistry set in their bedrooms; some in their bedroom closets. It is my sincere belief that a bedroom/closet in a far worse location than the home’s kitchen. The possibility of spills, fires and obnoxious, hard-to-remove smells is too great. If this is the only choice, then by all means stick with the kitchen location.

I recommend a garage or basement for locating a home laboratory. My first lab started off in a corner of a large basement. My father’s cabinet shop took up most of the basement space (which was really a basement garage), but with a suitable table, close access to running water (there was an extra faucet next to the ones that fed the clothes washer) and a floor drain (down which finished experiments were sent) I was set for my first couple of years.

The Ideal Home Laboratory Space The ideal space for a very usable home laboratory would be roughly 8′ x 12′ in one corner of a garage or basement. Instead of an assemblage of odd tables and shelves I recommend installing prefabricated upper and lower cabinets like those one can purchase from Lowe’s or Home Depot. The base cabinet would have a deep, utility sink with hot and cold water. There would be plenty of electrical outlets and if natural gas was unavailable there should be a propane tank like the ones used for home grills. If natural gas is available one should install a suitable gas valve with a hose barb for attaching flexible tubing. The gas (natural or propane) is used for Bunsen burner(s) and/or for a small hand torch, which when coupled with compressed oxygen could be used for glass blowing. One or two large metal, storage cabinets purchased from an office supply will work well for the storage of chemicals. If the metal cabinets can be locked this is even better. Between the counter top and the bottom of the upper cabinets a single shelf that runs nearly the length of the cabinet should be installed. This self should be no more than 8" deep (front to back) and should be well supported with metal angle brackets screwed into the wall studs. This shelf is for storing most of the liquid chemicals used in the lab. Under the sink one can store most of the large bottles of liquid chemicals. If possible the lab should be separated from rest of the garage or basement and if possible should have a lockable door. Finally, there should be an easily accessible fire extinguisher inside the lab and another outside the lab. I prefer CO2 extinguishers, but dry powder types will also work well even though if ever used one will have to clean up a lot of white powder.

Part 3. The work Space (Revised 30 March 2011)

The work space should, if at all possible, be a sturdy table with a top made of a durable surface. Such a surface can be as simple as 5/8" (or thicker) plywood that has been finished with a good quality industrial paint (preferably and “oil based” paint), that readily resists water. The best paint for a lab top is a two-part epoxy (e.g. Tnemec brand, North Kansas City, MO); this will help the surface not only resist water and most dilute acids and alkalis, but also many of the common solvents such as alcohols and ketones (e.g. acetone). If it can be afforded, a very good lab bench surface is one of the many composite surfaces (e.g. Corion). These are better than a laminate surface such as Formica since they can actually be sanded with fine sandpaper if they become badly stained or scratched. White is the best surface color since it makes it easier to see spilled chemicals as well as the colors of solution in flasks and beakers. The surface must be perfectly flat and level; spilled liquids should not run off the surface.

The top should measure at least 24" deep (front to back) and no more than 30"; Making it too deep means that one must reach a long distance across the surface to retrieve items near the back. The length can be any measurement that makes best use of the space available. A five- to six-foot top length should be considered a minimum length. Much shorter and one will find that there is not enough room to spread out projects and experiments. The top’s surface area is in addition to the area taken up by the sink (if you have or can install one).

If a sink is installed it should be near one end of the top and not in the center where it can get in the way of the needed work space. Glassware and other equipment that needs to be cleaned in the sink can be placed in the sink until such time that it can be cleaned. In addition, the wall immediately behind or beside the sink should be used for mounting a drying rack of some type (plastic is best with coated metal being next best; wooden racks are the least desirable). Otherwise, one will need to set aside space on the work top for draining and drying cleaned equipment.

Part 4: Working with Hazardous Materials (Revised 30 March 2011)

No matter what kind of workshop (laboratory) space or setup one has, it will be difficult to avoid working with hazardous materials at some point. My first exposure to hazardous materials (if one ignores the ever present cigarettes my father smoked) in a workshop were the various paints, varnishes, lacquers, shellacs, and their thinners (VM&P naphtha, mineral spirits, acetone, lacquer thinner, xylol and denatured alcohol) my father used. One could always tell from the odors when my dad was finishing a cabinet or a piece of furniture in the basement or garage.

Many of these same hazardous materials are found in nearly every garage and these are in addition to containers of gasoline, charcoal starter fluid and various other petroleum products. Most of us know and understand the hazards of highly flammable liquids. However, just because we think we know the hazards I will insert appropriate warnings and safety tips in the text of this document, and I will compile a series of appendices at the end one can refer to for more information. New appendices will be inserted from time to time and may not necessarily correlate, at the time of their insertion, to any given text in the body of this document until the entire document is completed.

Typical hazardous materials fall into a few recognizable types:

Poisons
Flammable Gases
Flammable Liquids
Flammable Solids
Corrosive Liquids
Corrosive Solids
Explosives

In addition there are some unusual hazardous materials with which many may not be familiar. The include:

Water Reactive
Air Reactive

While not familiar to everyone there are really quite a few that one will encounter in an active pursuit of science in the home. Typical water reactive substances, as every high school chemistry student well knows, are sodium metal and potassium metal. These are bother certainly air reactive but not so much as to instantly inflame or explode upon short-term exposure to the air. Rubidium metal and cesium metal are both so reactive in air that they will easily inflame on contact with air. On contact with water these last two elements are highly explosive.

Most laboratory chemicals have label indications of what hazards are associated. The BenchMark chemicals sold by H.M.S. Beagle use a convention of color warnings on their labels to indicate special handling and storage requirements. Ever since the January of 2011 the BenchMark chemicals’ labels include a quick-response (QR) code that can be scanned with a smart phone onto which has been loaded a, usually free, code scanner/ reader. These QR codes, when scanned, link directly to the appropriate MSDS sheet. Here is an example of just one such QR code, shown in actual size as it is printed on the chemical's label:

Try it out; just hold your smart phone up to the screen and scan the code.

Additionally, material data safety sheets (MSDSs) are available from chemical manufacturers, free of charge, that detail nearly everything one will need to know about every chemical. The CD-ROMs sold by H.M.S. Beagle in their chemistry sets have selected MSDSs, usually in Adobe PDF format. When searching the Internet simply use the following search terms, "msds sugar." Instead of "sugar", you can insert the name of the chemical in which you're interested. Finally, as the Beagle's library of MSDSs increases on-line one can simply go to http://www.hms-beagle.com/beagle_msds.html to see the currently available documents.

Appendix A: Laboratory and Industrial Acids and Bases

The liquid acids and bases used in laboratories and industry are usually of different strengths and purities and are typically sold in different size containers. The strength, purity and container sizes reflect the needs of the users of these different chemicals. The following information is meant to be a guide, but is by no means exhaustive and may be incomplete.

Acetic Acid (Ethanoic Acid), CH_3COOH: This acid is usually offered as a "glacial" acid, so named because it freezes at 16.7°C which is a little below room temperature. The glacial acetic acid that conforms to the reagent chemical specifications of the American Chemical Society (ACS) is a minimum of 99.7% pure and has a specific gravity (sp.gr.) of 1.050. The glacial acid was formerly sold in 1 pound and 5 pound bottles; the latter was about 5 pints. The "5 pint" bottle is still used today by most manufacturers, but the nominal size is now 2.5 liters.

In place of the 1 pound bottle, most manufacturers now offer 500 mL bottles. The bottle capcolor most often seen on the 2.5 L bottles is brown. Another commonly sold concentration of the acid is 36% and this is usually made to meet prevailing pharmaceutical (drug) specifications. However, this concentration of acetic acid is commonly used to make photographic developer stop bath solutions.

Ammonium Hydroxide, NH_4OH: This liquid base is an aqueous (water) solution of ammonia. The usual concentration is 28.0% to 30% ammonia (NH3). This is equivalent to about 52% NH4OH. This chemical is sold in this strength in an ACS reagent grade and an industrial grade usually referred to as Stronger Ammonia Water. The reagent grade material has a sp.gr. of 0.900 and is sold in 500 mL and 2.5 L sizes. Formerly the larger size was a 4 pound bottle. The bottle cap color most often seen on the 2.5 L bottles is green.
Hydriodic Acid, HI: This is one of the most expensive of the mineral acids. Its typical strength, when sold as an ACS reagent, is 47% minimum and it has a sp.gr. of 1.500. It is sold in 100 mL, 500 mL and 2.5 L bottles.

Hydrobromic Acid, HBr: Hydrobromic acid, like hydriodic acid has few industrial uses. It is usually sold as a 47.0% to 49.0% ACS reagent in 100 mL, 500 mL and 2.5 L bottles. It has a sp.gr of 1.500.

Hydrochloric Acid, HCl: This is the least expensive of the hydrohalide acids, and it is one of the most useful industrial acids being used in cleaning masonry and as a pH adjuster in swimming pools. The industrial form is usually known as muriatic acid.

For laboratory use this acid is sold as a 36.5% to 38.0% ACS reagent with a sp.gr. of 1.180. The typical sizes are 500 mL and 2.5 L. Formerly, the larger size was sold as a 6 pound bottle and the cap color is blue. The acid of industry, muriatic acid, is often a pale yellow to yellow color (due to impurities like iron) and has a concentration of 32% and a density of 20° Baume, which equals a sp.gr. of 1.160. Muriatic acid is most often sold in quarts and gallons and 15 gallon carboys. Both concentrations of this acid fume in moist air.

Hydrofluoric Acid, HF: Because of its reactivity towards glass, this acid is sold in poly containers. Before the regular use of plastic containers HF was sold in wax bottles. The laboratory, ACS reagent, grade acid is 48.0% to 51.0% and has a sp.gr. of 1.160. It is sold in 500 mL and 4 L containers.

There are two acids of industry. One has a nominal concentration of 52% and the other of 70%. All three concentrations fume in moist air. These two concentrations are also sold in 500 mL and 4 L containers.

Nitric Acid, HNO^3: Both the industrial acid and the laboratory, ASC reagent grade, acids are sold as 68.0% to 70.0% and have a sp.gr. of 1.408. The reagent grade acid is sold in 500 mL and 2.5 L bottles with red colored caps. Formerly, the larger size was a 7 pound bottle. The industrial or technical grade acid is usually sold in stainless steel carboys that resemble beer kegs. This acid fumes in moist air.

Nitric Acid, Fuming, HNO_3: This is a more concentrated form of nitric acid having a minimum strength of 90.0% and a sp.gr. of 1.500. Unlike 70% nitric acid, this acid is usually reddish in color due to free nitrogen oxides. Like the name suggests its fumes strongly when opened to the air.

Perchloric Acid, $HClO_4$: Perchloric acid is sold in three, ACS reagent, strengths for laboratory use. The typical strength is 69.0% to 72.0% with a sp.gr. of 1.660. There are two weaker strengths of 60.0% to 62.0% with a sp.gr. of 1.540 and of 48.0% to 50.0% with a sp.gr. of 1.400. The usual sizes of this acid for laboratory use are 500 mL and 2.5 L.

A technical grade acid for industrial use is sold with a concentration of 68.0% to 72.0% and is usually sold in sizes of greater than 50 liters.

Phosphoric Acid, H_3PO_4: This mineral acid has many uses in both the laboratory and industry. The usual strength is 85.0% minimum and it has a sp.gr. of 1.690. This acid does not fume in air. The typical laboratory sizes are 500 mL and 2.5 L.

Sulfuric Acid, H_2SO_4: Sulfuric acid is considered to be the most valuable and most useful of all chemicals after water. It is sold as both an ACS reagent grade acid with a concentration of 95.0% to 98.0% and a sp.gr. of 1.840, and an industrial grade acid with a concentration of 93% and a density of 66° Baume (sp.gr. = 1.835). The reagent acid is sold in 500 mL and 2.5 L bottles. Formerly, the larger size was a 9-pound, 5-pint bottle with a yellow cap. This acid does not fume in air and has no noticeable odor.

Sulfuric Acid, Fuming, $H_2SO_4 + xSO_3$: As the name suggests, this acid fumes in moist air due to the high concentration of sulfur trioxide dissolved in the acid. The ACS reagent acid has an assay of 18.0% to 24.0% SO_3. It is usually sold in 500 mL and 4 Kg sizes. Another concentration with 26.0% to 29.5% SO_3 is also available from some suppliers.

Appendix B: Cyanide disposal: Waste Cyanide Destruction by Potassium Permanganate

Potassium permanganate ($KMnO_4$) is a well known oxidizing agent and has been reported to react with cyanide ions in alkaline or neutral media according to the following equation:

$$2KMnO_4 + 31CN^- + H_2O = 2MnO_2 + CNO + 2OH^-$$

For each kilogram of cyanide to be oxidized requires 4.05 Kg of $KMnO_4$. To enhance the cyanide oxidation rate, a catalytic amount of a Cu (II) salt has been found to be very effective. While using only $KMnO_4$ as an oxidant cyanide levels did not drop much after 3-4 periods, but it came down to almost zero level after introduction of catalytic amount of copper (II) sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$.

To destroy the waste cyanide in the lab use the amount of oxidants required according to the equations shown below:

$$\text{Amount of } KMnO_4 \text{ (in grams)} = V \times [C] \times (4.05 \times 10^{-3})$$

(where [C] is the cyanide concentration in milligrams/liter (mg/L) and V is the volume in liters):

$$\text{Amount of } CuSO_4 \cdot 5H_2O \text{ (in grams)} = V \times [C] \times (2.5 \times 10^{-4})$$

For example, when we have treated 25L of 100 mg/L cyanide waste with 10g $KMnO_4$ and 0.6g $CuSO_4 \cdot 5H_20$, a cyanide probe shows more than 99% of the cyanide having disappeared in less than two hours. To ensure complete oxidation of cyanide and metal cyanide complexes, it is better to keep permanganate treated waste cyanide standing overnight prior to discharge it into the sewer.