Teacher's Supplement

Building a Rainbow: Supplementary Information

NEEDED MATERIALS:

Common (For an entire class):

methanol – 1 L (**Caution: highly volatile, highly flammable**)
lactic acid, 85 – 90% – 1 L (**Caution: weak acid, mildly corrosive**)
cupric sulfate pentahydrate, 250 g (not significantly toxic in solid form)
sodium hydroxide, 1 kg (**Caution: strong base, corrosive, reactive**)

Crimper
Wire stripper (or scissors)
Wire cutter (or scissors, but they will dull quick)
Electrical wire (1 roll of red, 1 roll of black), 20 – 22 gauge
Tape
1-L Waste bottle (or larger for larger classrooms or for more repeated experiments)
Labels (See *Waste Management* Section)
1 funnel which sits comfortably in the mouth of the waste bottle
1 electrolyte bottle, for about 30 mL × no. experiments, but 100 mL minimum.
Diamond scribe
ITO glass, 10 cm^2 × no. experiments, probably the minimum order is enough.
Black fine point Sharpie® pen, Blue extra fine point Sharpie® pen

Grouped (For several groups of experimenters)

Voltmeter (and corresponding 9V battery)
1 resistor package (5-pack) of each kind (10k, 22k, 33k, 47k)
2 22-18 gauge quick-disconnect packages (8 male, 8 female with crimp shrouds)
Copper mesh, about 1 ft^2 (1000 cm^2), mesh size not important.
Compressed air dust-off blower
2 Lecture squirt bottles (1 for methanol, 1 for deionized water)
Gloves (nitrile or vinyl)
Tissues, wipes, or paper towels

Individual (For each experiment)

Notepad and pen/pencil
Plastic Petri dish
100 mL beaker (2), one labeled (waste)

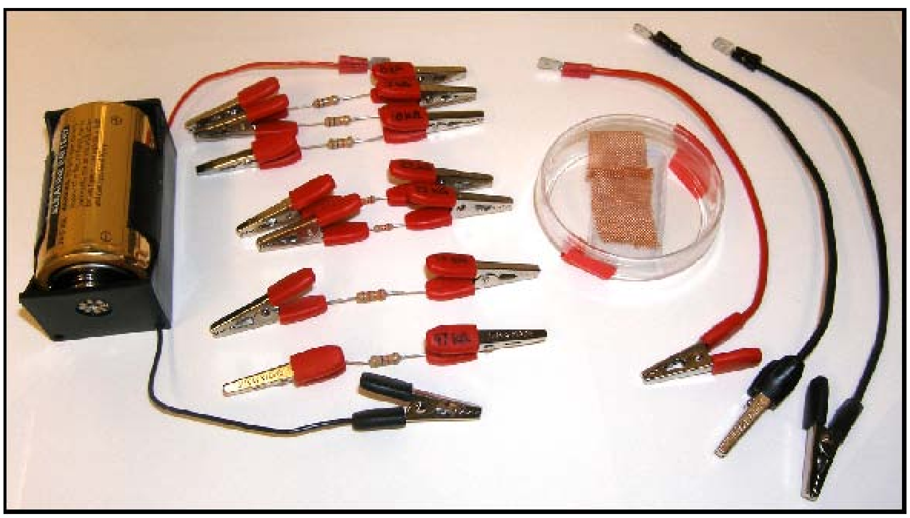
"D" battery
"D" battery casing with wire leads
4 1-3/8" mini-alligator clip packages (5 red and 5 black)
Blue fine point Sharpie® pen
Watch with second hand, or a timer.

PREPARATION:

ELECTRICAL:

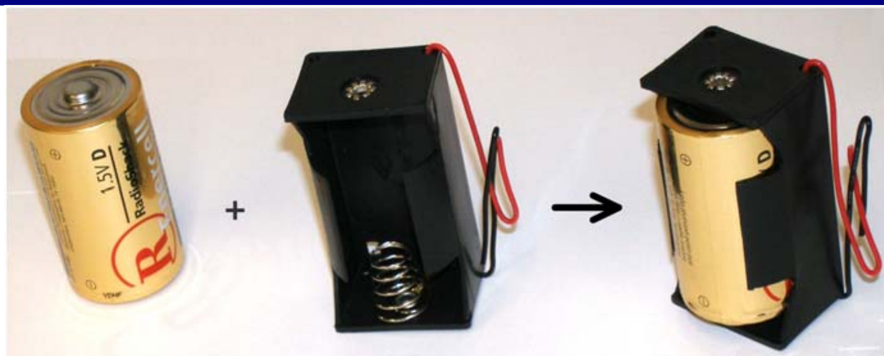
The electrical preparation can be performed once and for all, and if done well, should not have to be repeated from year to year. Thus, these methods refer mostly to the construction of the "kit". Other methods will then focus on the chemical preparation methods, which must be performed prior to the class as the chemicals can degrade over time. The electrical "kit" is shown below and the steps for how to build it follow.

The electrical "kit":

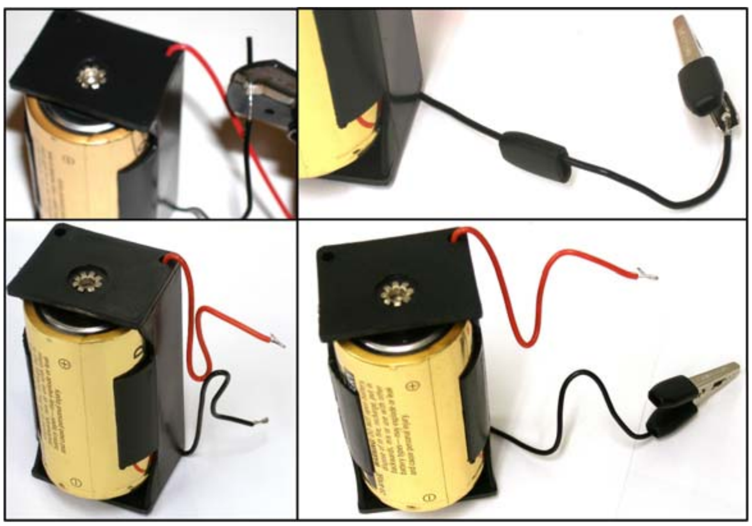


Each experiment is suitable for a student pair or possibly triplet. The details below are provided *per* experiment set-up. Each experiment is suitable for a student pair or possibly triplet. Duplicate as needed.

Teacher's Supplement



Step 1: Put a battery in its holder. The "D" size is best as it provides the most capacity.



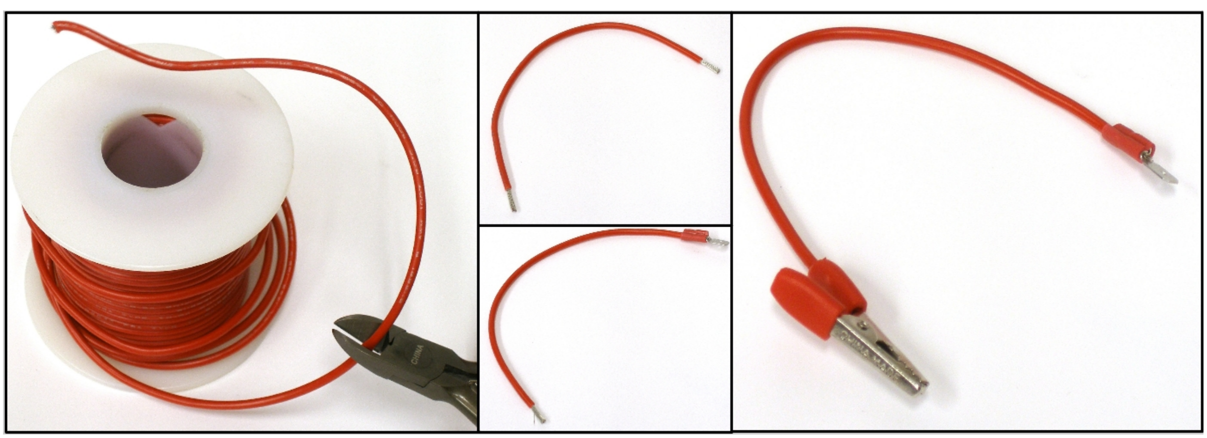
Step 2: Strip both wire ends about ½" back to expose wire (upper left) and fold it (lower left). Remove insulator from black alligator clip and wrap exposed negative wire around lead by twisting (upper right). Push insulator back over wire to compress wire around lead (lower right). **Note: ideally, this last step should be completed by soldering the connection before recovering the insulation, but if electrical contact is made, it's okay. Also, the folding is needed here because this wire is about 28-gauge and too thin to crimp. For other wire, the folding won't be needed.**

Step 3: On the red terminal wire, use a 22-18 gauge male quick disconnect (shown alongside in the left figure) and crimp (middle figure). The complete power supply assembly is shown (right figure).

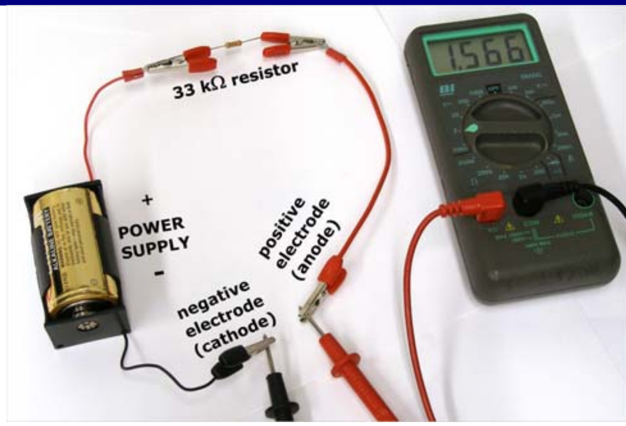
Step 4: Test contact. If the voltage reads negative, it's possible you connected your leads wrong. However, a fresh battery should read about 1.5 – 1.6 V. If it's anything less, use a brand new one. Remember to select DC voltage, not AC voltage (which looks like a wave, DC looks like a line on top of a broken line)

Teacher's Supplement

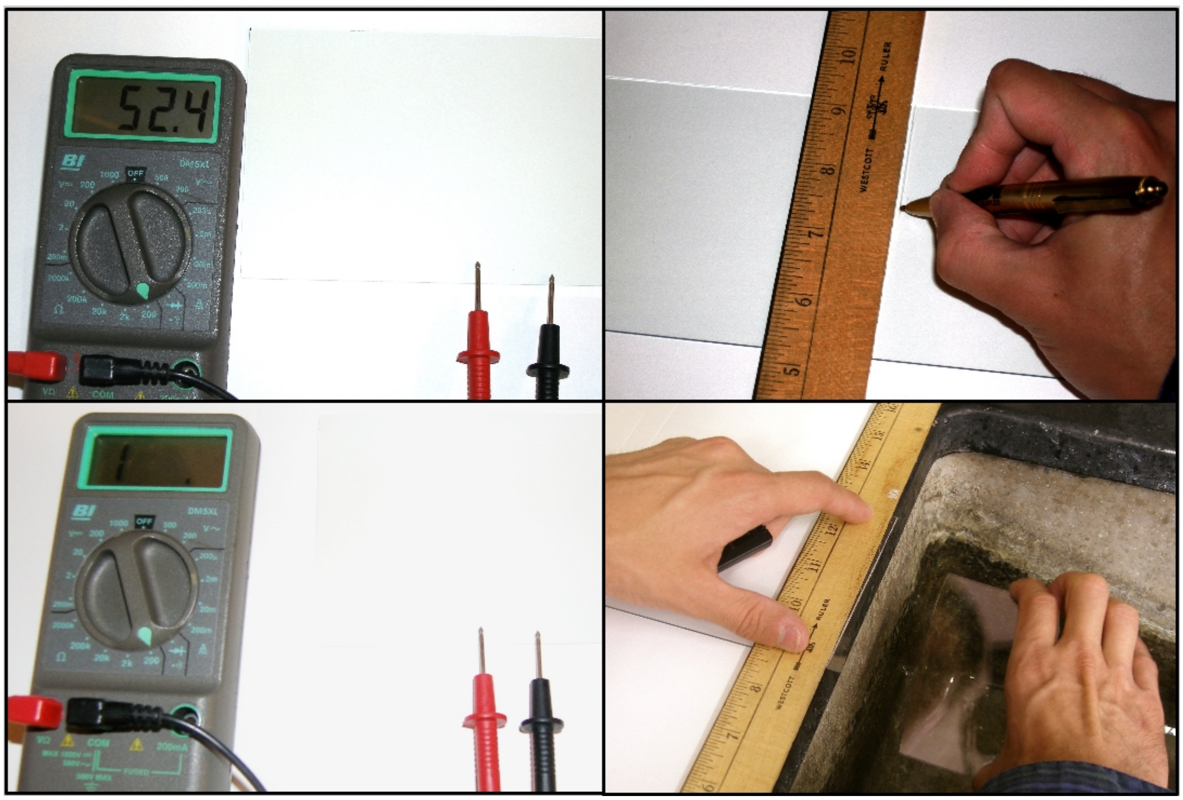
Step 5: Prepare a set of alligator-clipped resistors. It's best to keep the color-coding of red, but not crucial if you run low. Also, check the resistance with the voltmeter to make sure you have good contact at the alligator clips. For each experiment, make up the following set: (1) 47 kΩ, (1) 33 kΩ, (2) 22 kΩ, and (3) 10 kΩ. **Note: It would be wise to mark each prepared resistor with it's resistance on the alligator clip.**



Step 6: Create your positive electrode wire by cutting a piece of red electric wire (left), stripping off ¼" from each end (middle top), and crimping on a red male quick disconnect on one end (middle bottom) and attaching a red alligator clip to the other (right). Repeat this process twice using black wire and black gator clips. **Note: I would even "paint" the quick disconnect black with a Sharpie® pen.**



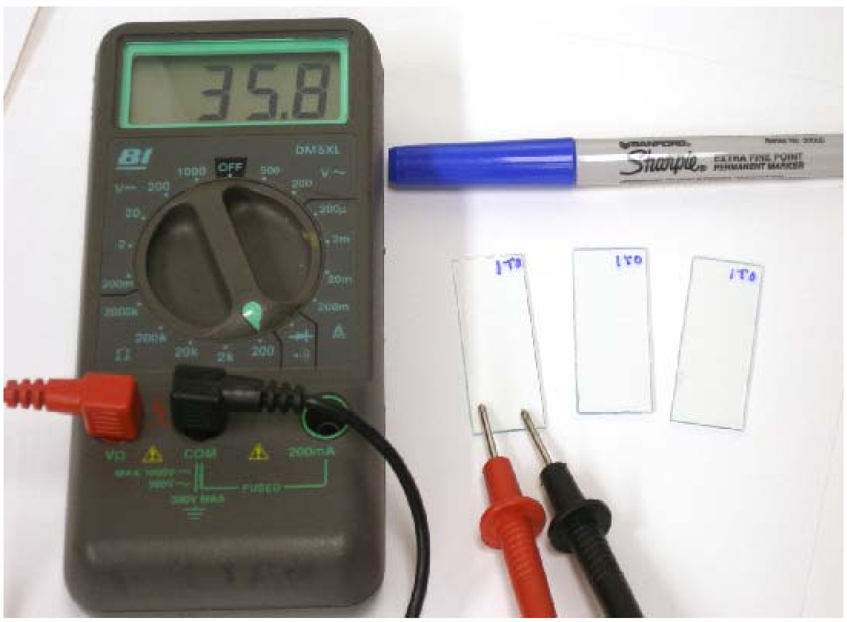
Step 7: Confirm electrical continuity by constructing a sample circuit using each resistor and testing across the negative (black) alligator clip and the positive (red) alligator clip and checking the voltage of the battery. **Note: This should be repeated just before experiments as well, to check for bad contacts.**



Step 8: Cut up ITO glass into individual pieces. First, check the resistance of each side to find the coating, only one side will give a meaningful resistance value in the tens of Ω range (upper left). The other side is just glass and has infinite

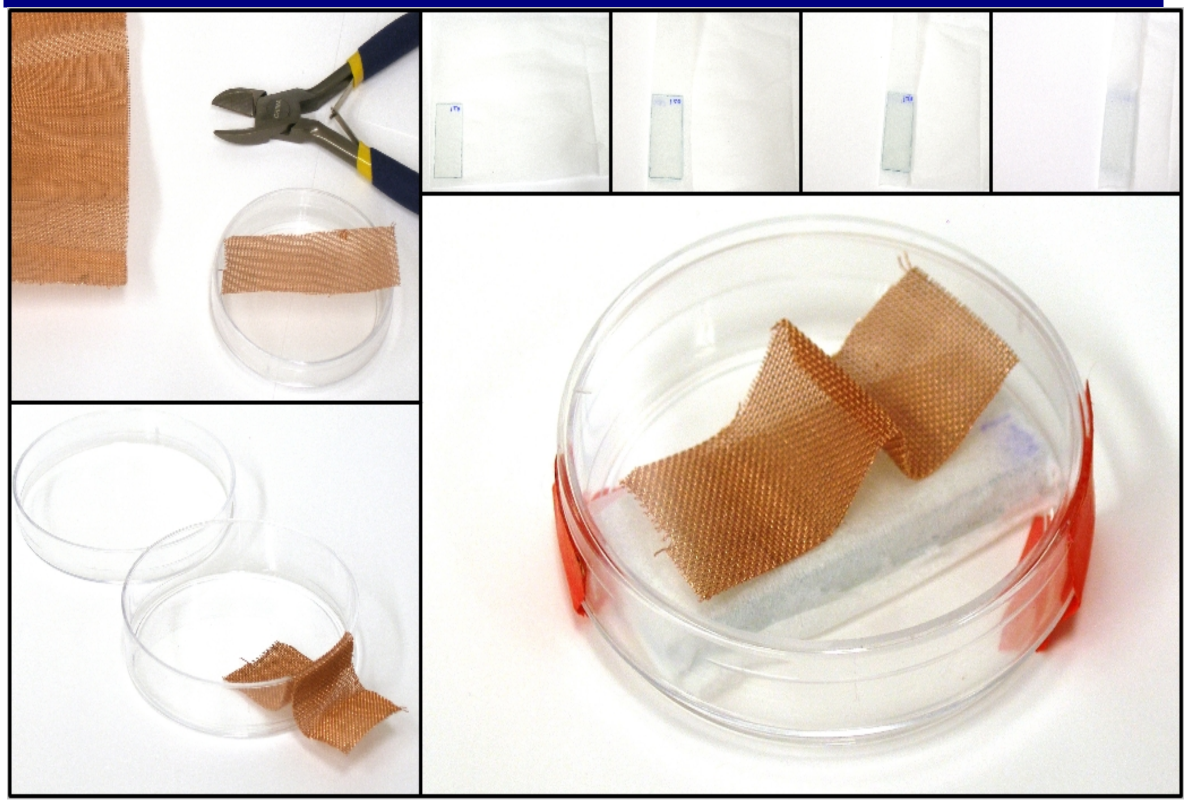
(effectively) resistance, and so place the ITO glass so that the coating is face down on paper to protect it (lower left). Use a straight-edge to help score the glass with a diamond scribe (upper right) and wash off glass microparticles in a sink. Finally, using the straight edge, apply pressure on one half over a table or sink edge and break the other half over it by bending down (lower right).

When finished, rinse all surfaces with water to remove particles.
Repeat breaking in halves until you have 3 small pieces, about 1 cm × 2 cm.



Step 9: **It is a good idea to mark which side is the conducting side of the glass (the ITO side) for later. Check it by looking for a meaningful resistance by a voltmeter (tens of ohms). This will be helpful later.**

Teacher's Supplement



At this time, the electrodes are complete and can be packaged. Take the 3 ITO electrodes (the "working electrodes") and wrap them in tissue paper by separating each piece from each other with a sequential fold in the tissue (upper right) until all are folding in and the package taped. The Petri dish, the copper mesh (the "counter electrode"), and the working electrodes can then be taped up for storage until needed (lower right).

The chemicals here last about 6 months or so before they start to decompose into solids (though can still be used in this state). These preparations should be performed in advance because they also consume valuable instruction time.

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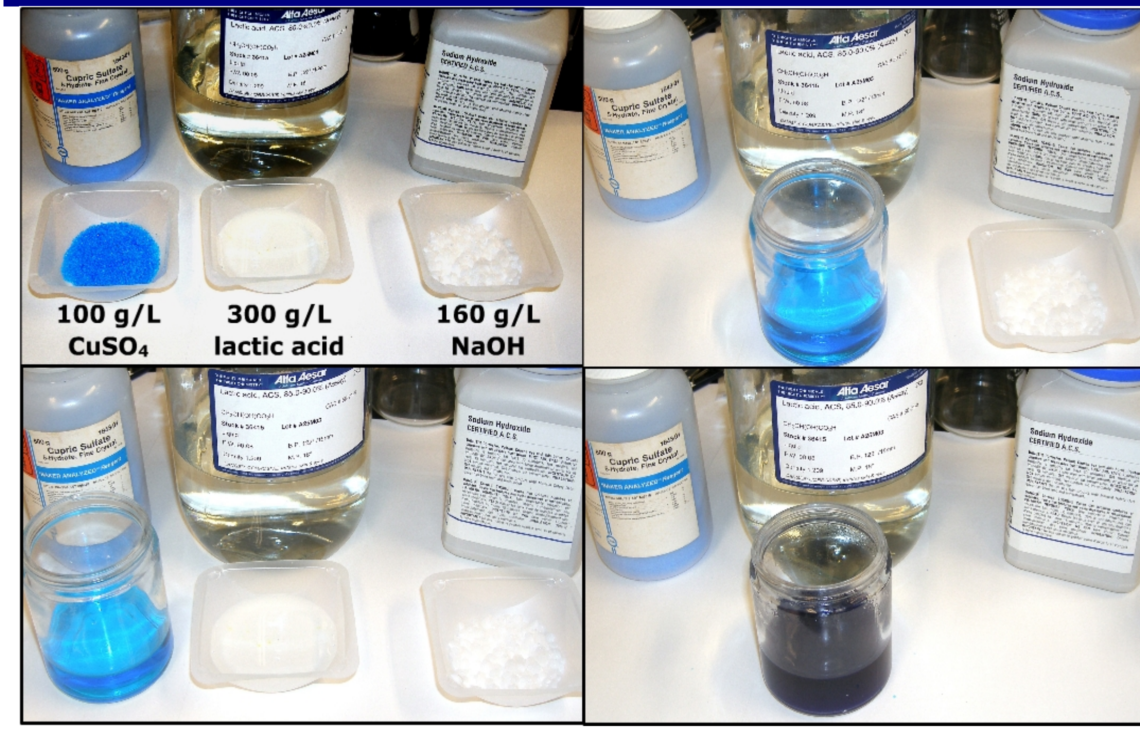


Step 1: Prepare the electrolyte by weighing out the chemicals (upper left). First add the copper sulfate (lower left) in about 30 – 40% of the intended volume of water, preferably deionized water. Then add the lactic acid and mix well (top right). Then, **little by little**, add the sodium hydroxide (lower right).

CAUTION: adding sodium hydroxide to the acidic solution will generate lots of heat. When the container gets hot to the touch, let it cool down a bit or put the jar in a bin with cool war circulating over it.

Step 2: **Using a funnel, transfer the solution into a bottle until use (left). Then top off to the desired volume with water (right). Close the bottle and stir contents well.**

With the electrolyte prepared, the next step involves preparing the labels needed for the electrolyte, the rinse bottle, and the waste jar. In the *Waste Management* section there is a page containing pre-made labels that can be taped onto bottles when printed.

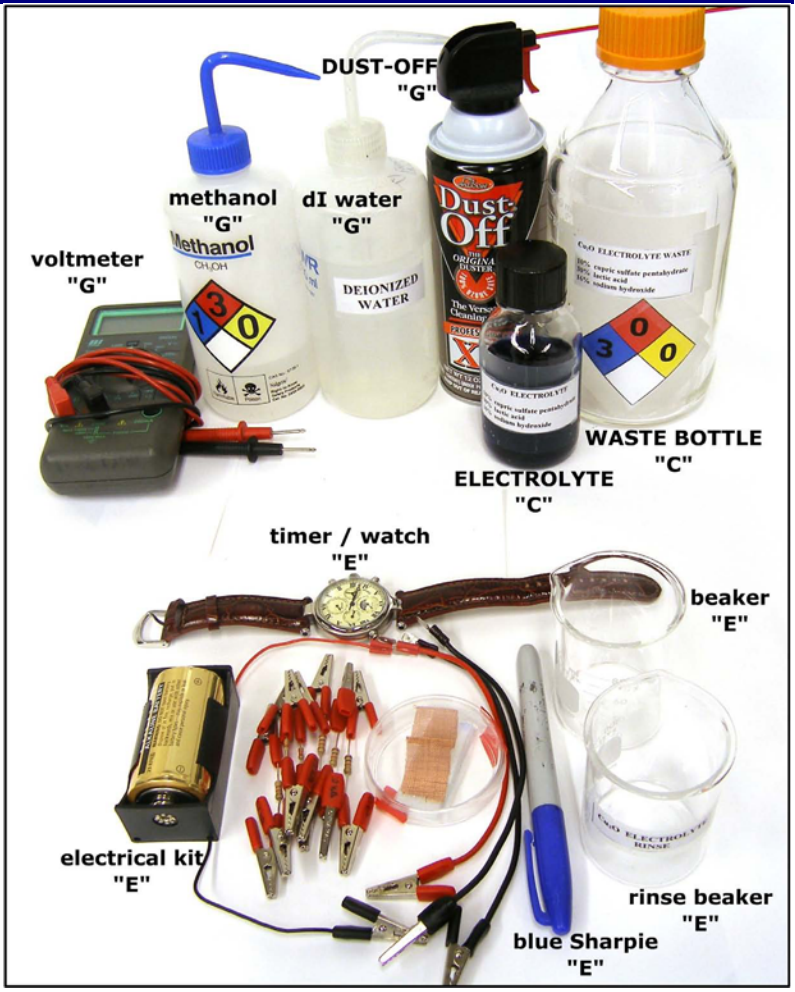
Teacher's Supplement

PREPARATION (continued): CHEMICAL (continued):

Step 3: **Place the HAZARD label and an electrolyte waste label on a large enough jar for long term accumulation of waste. Place a plain electrolyte label on the electrolyte bottle. Place a rinse label on each experiment kit's rinse beaker.**

LAST MINUTE CHECK: **After checking you have these items, practice the experiment following the student worksheet yourself a few items.**

Teacher's Supplement



Rainbow Building Kit: Note the items are labeled **"C"** for items that can be shared by a class, **"G"** for items that can be shared by groups of experiments close to each other, and **"E"** for items that are needed for each experiment group. Not shown are gloves and paper towels (**"G"** items), and paper and pad (**"E"** items).

	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE
Cu_2O ELECTROLYTE WASTE 10% cupric sulfate pentahydrate 30% lactic acid 16% sodium hydroxide	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE
Cu_2O ELECTROLYTE 10% cupric sulfate pentahydrate 30% lactic acid 16% sodium hydroxide	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE
Cu_2O ELECTROLYTE 10% cupric sulfate pentahydrate 30% lactic acid 16% sodium hydroxide	Cu_2O ELECTROLYTE RINSE
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Cu_2O ELECTROLYTE 10% cupric sulfate pentahydrate 30% lactic acid 16% sodium hydroxide	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE
	Cu_2O ELECTROLYTE RINSE

General:

The labels above are generic, but **before** making the solution find out what local rules are regarding: labeling of chemical bottles for short term use, labeling of chemicals used for waste, and so on.

In general, the first time a container is rinsed with water for cleaning, that mixture goes into the waste bottle along with used fluid. After that, unless the fluid contains unusually toxic materials (this electrolyte does not), all further cleaning may be performed in a sink.

Information about the solution (for waste handlers):

The solution, once made, is effectively a 10 wt% solution of cupric lactate with an excess of sodium lactate and sodium hydroxide making the pH approximately 9. This formulation was invented by Jesse E. Stareck in U.S. Patent #2,081,121, though the specific concentrations used here are based on a publication by A. E. Rakhshani and J. Varghese in *Thin Solid Films*, **157:** 87 – 95 (1988). The most notable hazard is the high salt content and is thus highly corrosive to metals. However, the substance is only mildly irritating to the skin, and can simply be washed off quickly.

The solution dries rapidly due to its low water content, and thus precipitates out copper lactate and sodium lactate particles and possible carbonates as a result of carbonic acid solubilization from atmospheric exposure. Eye exposure is clearly hazardous. Free copper content is difficult to estimate, as the copper-lactate system is only one of many possible systems and it is possible that the ligation is weak with a dynamic exchange. Extensive storage reveals a red precipitate, or possibly electrolysis deposition (perhaps via oxygen reduction) onto the walls of the bottle. This substance is most certainly the reduced oxide, cuprous oxide, a non-toxic solid (to humans, but mildly toxic to marine life). The film can be easily dissolved by mild sulfuric acid. Under extremely long storage times a solid white crystalline material forms whose identity is unknown, but immediately redissolves in fresh water.