Student Worksheet

Building a Rainbow

A nanometer (1 million times smaller than this dot → ·) is a length scale that is close to the size of molecules and atoms. Unusual things happen to materials that are made at this size.

For example, the material cuprous oxide, which is just copper reacted with air, is normally a ruby-red compound. Now, light that we can see all travels at the same speed (extremely fast!) and has a wavelength from 400 nanometers (bluish) to 600 nanometers (reddish).

Because cuprous oxide absorbs very little of this light, when a thin film of it is made, thinner than the wavelength of light, a nanoscale effect is observed. This effect is called the **thin film interference effect** and is cause by light bouncing off the top of the film and off the surface on which the film is sitting. At the right angle of viewing, only a particular color in the light will be in perfect coherence from the two reflected light waves. The color depends strongly on the thickness of the material. This phenomenon is often seen on oil slicks in water puddles, for example.

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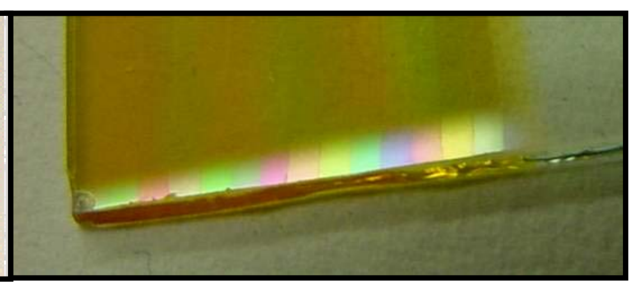
Cuprite gemstone (2 mm)



University of Washington

Cuprite rainbow (thickness varies)

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Materials:

Bring your own pen and paper.
One person per experiment group should bring a watch or timer.
Obtain two 100 mL beakers, one should already be labeled "ELECTROLYTE RINSE".
Obtain an electrical equipment kit.
Obtain a blue fine point permanent ink pen.

Find the following shared materials:

- Voltmeter
- Electrolyte
- Gloves and Tissues
- Methanol and Deionized water squirt bottles
- Dust-off compressed air container for drying
- Electrolyte waste bottle, labeled "Cu_2O ELECTROLYTE WASTE", with funnel

Safety equipment:

Gloves are recommended, but most importantly, wash any electrolyte contact with the skin in running water immediately before the electrolyte dries.

Aprons are recommended for those concerned about their clothes, otherwise the volume of liquid is not a significant hazard.

Goggles are useful, but any eye protection is sufficient. More important is to not wear contact lenses as trace vapor may condense around edges of contact lenses and precipitate salts on the eye.

Generic Material Safety Data Sheets (MSDS) for all chemicals are attached at the end, but should come with any chemicals purchased.

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Experimental Procedure

List out a clear step-by-step procedure for students to follow. Note places for them to make observations, record data, etc.

It may be useful to include figure(s) or schematic(s) – see example below.

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Experimental Procedure:

Laying out the equipment:

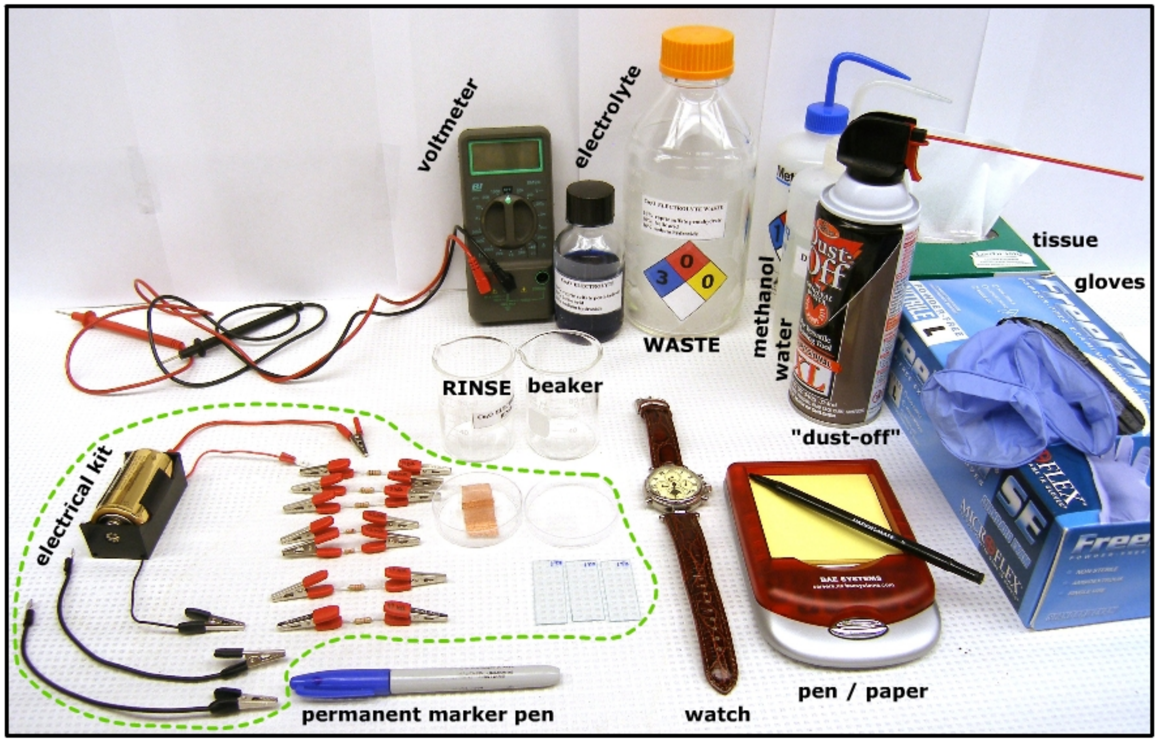

Figure 1: Layout the materials similar to that shown above. Make sure you have access to all these items and note that some items might appear different in your particular classroom environment.

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Experimental Procedure (continued):

Preparing the fabrication of cuprous oxide (Cu_2O) thin films:

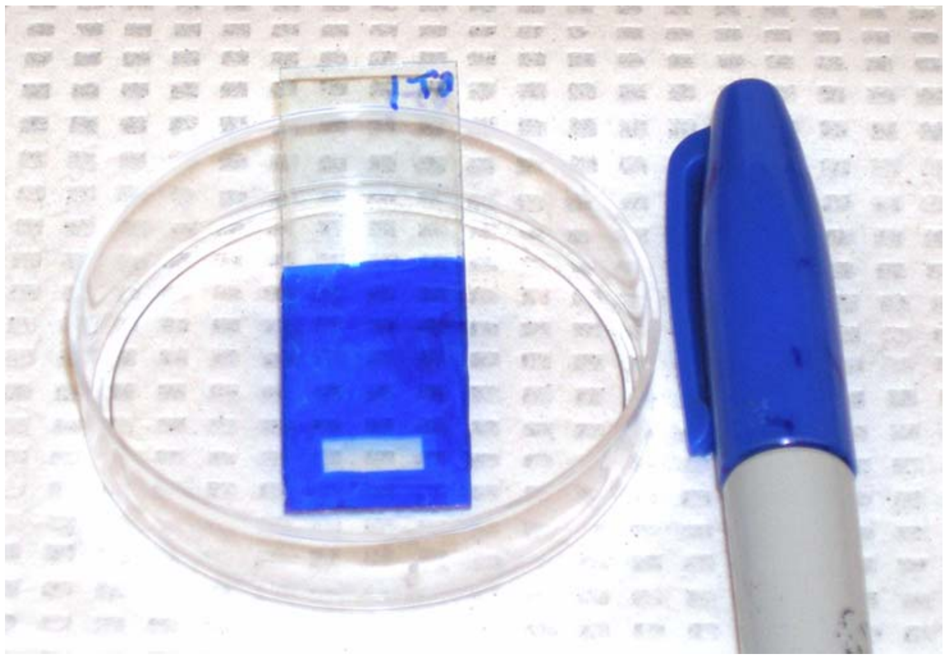

Figure 2: "Mask" the ITO glass slide with the permanent marker pen. This allows the Cu_2O to grow on only the area where you leave a "window". Also mask the edge of the glass as well. **Note: It is not important to mask the back as the back is not conducting. The front is the side where the word "ITO" is clearly written from left to right when looking**

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Experimental Procedure (continued):

Connect the cathode (black wire from battery) to glass slide and check:

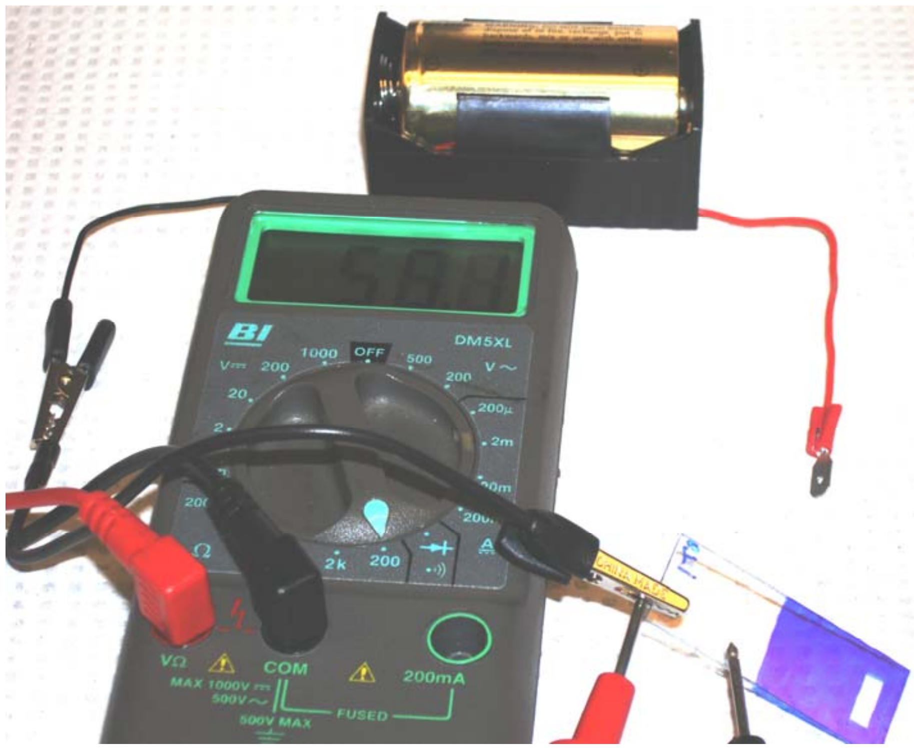

Figure 3: Use the battery and a black cathode cable. Use the 'gator clip to grab the male clip on the black cathode cable, and the black cathode cable's 'gator clip to grab the ITO slide. Check for good contact by measuring the resistance (Ω) between any metal contact and any surface of the ITO glass. Use an ohm range of 200 ohms or so and you should read somewhere between 30 and 70 ohms. This is good. If the number is 1 or it is a dashed line, then you have no contact, try repositioning the clip.

Experimental Procedure (continued):

Prepare the electrochemical cell:

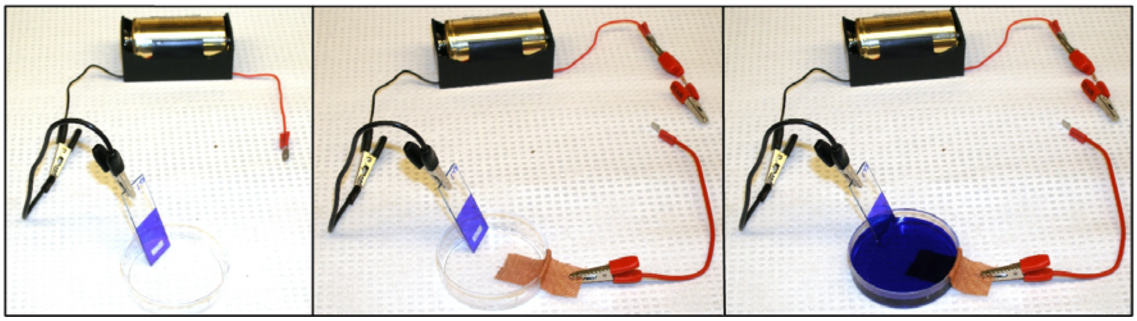

Figure 4: **1)** Bend the cathode (black) wire so that it rests easily in the bottom of the deep Petri dish (left image).

2) Take an anode (red) wire and attach it to a copper mesh and lay it over the rim of the Petri dish. Also, pick a *resistor* and attach it the to anode clip at the battery. The resistance you need is not known yet. But try this calculation: measure each edge of your window in centimeters. Multiply each dimension together, then by 50. Now, take 1.5, divide by your number, and multiply by 1 million. This number is an estimate of the resistance you need. You can add resistors if you need to get the right number, but a typical value is 20,000 – 30,000 Ω. **Note: at this time, the gator clip at the resistor is NOT connected to the terminal on the anode (red) cable.** See middle image.

3) Take some ELETROLYTE and carefully pour it into the Petri dish until it covers the exposed window of the ITO slide, and even a little higher (right image).

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Experimental Procedure (continued):

Plan setup and run an experiment!

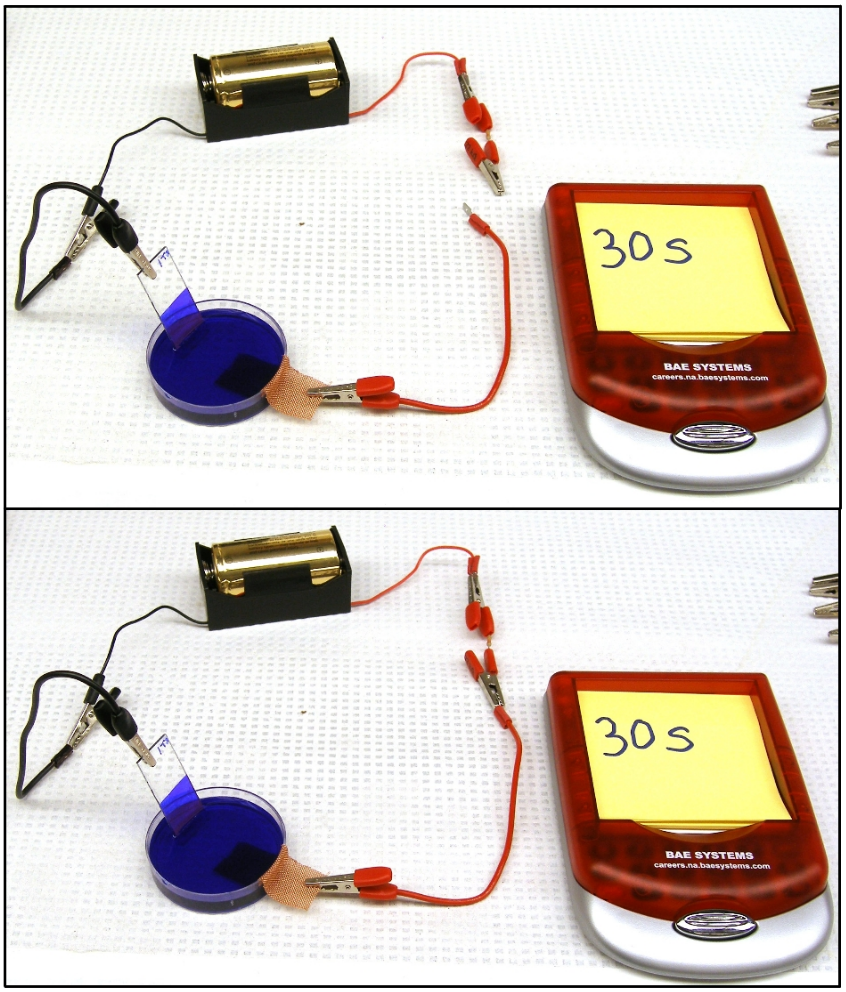

Figure 5: Choose a time for an experiment, and run it! 15s to 60s are good starting points, but if the color does not change often enough, you might want to use longer time intervals. As long as the circuit is open (upper figure), nothing happens (**OPEN CIRCUIT**). Start timing the moment you clip the resistor's alligator clip to the anode (red) terminal lead (**CLOSE CIRCUIT)** making the final electrical contact (lower figure).

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Experimental Procedure (continued):

Making and recording observations.

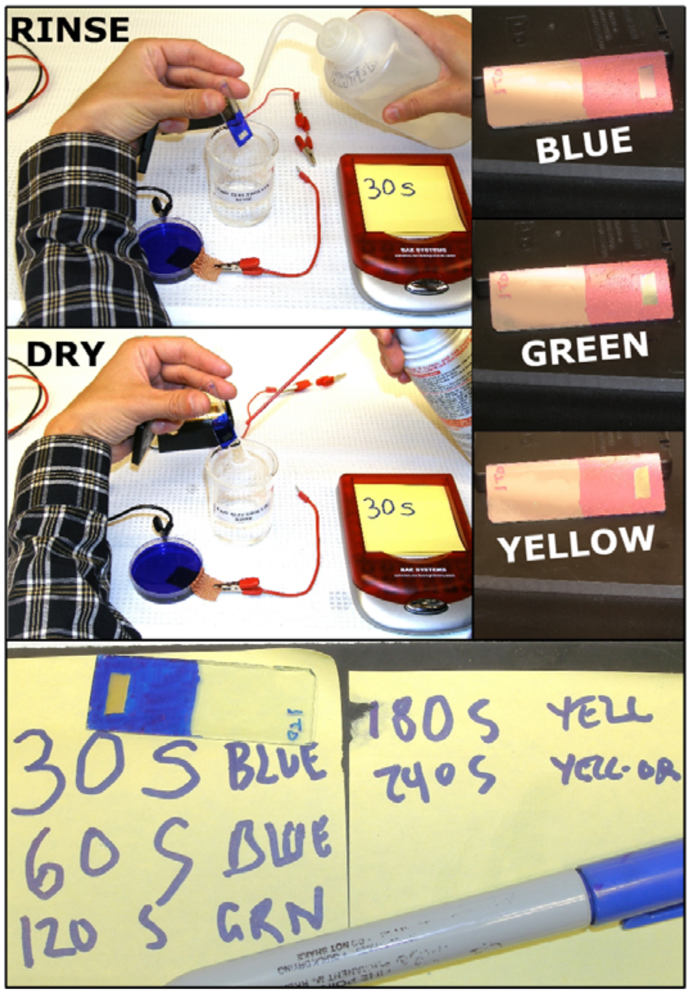

Figure 6: Between runs, rinse (upper left), and blow dry (middle left), the electrode. Observe the color changes over time (right) and record them (bottom). Make sure that you look at the color with the light directly reflecting off the surface, because Cu_2O is naturally slightly yellow even when this thin. Ensure partners agree on the color, and have another lab partner reproduce your work on another electrode using the **same masking area**.

Experimental Procedure (continued):

The CHALLENGE: Building a rainbow

This here is my personal secret, so unfortunately your own creativity will be required to do it (perhaps some bonus points are due here…) BUT, HERE ARE SOME HINTS…

You have now practiced building thin films which give rise to different colors due to the thin film effect. Remember that the material is the same, but because the film is thinner than the light's wavelength, the color is mostly a result of the nanoscale thickness of the film.

The challenge here is that previously the area was ALWAYS THE SAME, so the current is always the same. This means we can always use the SAME RESISTOR ALL THE TIME, how convenient…

If we want to build a rainbow over the surface, we need to expose more and more area, meaning more and more current, meaning a different resistance each time, what a pain!

Here's a trick: Use two ITO pieces, one piece is big, the piece we care about is much smaller and masked so that the TOTAL AREA, although it is changing, it changes so little each time you want to change a color on the small piece, it makes really no difference overall, so again we use the same resistor. We'll need a deeper container, perhaps that other beaker you never used will be handy…

One problem, all the data you collected was based on one area, the area you masked. That's okay, you want your other ITO surface to be Cu_2O coated anyway, so first find the condition that gets you similar results time-wise, or even collect new data. (Remember, you will need less resistance for the larger area, try the calculation again).

Also, how will you controllably insert the working (smaller) ITO electrode in the solution? One choice is to always remove it, rinse off the old mask in methanol, and remask it with a slightly bigger window. Can you think of a more elegant method? Perhaps stack a bunch of pennies and remove them one at a time? What about those camera tripods? They say duct tape works wonders in all walks of life. Perhaps an empty paper towel roll duct-taped to a tripod..., whatever.

Conclusion:

Write a paragraph to describe the results of the experiment and your reflections on your experiences during this lab.

[The hope here is that students should start becoming aware that elements and compounds are insufficient in explaining the phenomena in the world, and that nanoscale effects are observed when materials that are very small are made. Thus, size is also important, and the observation that by merely changing the size of something, and nothing else, can profoundly influence our impression of what we observe the object to be. There can be so many numerous ways this is expressed that no answer should be construed as wrong, and credit should be awarded to any honest attempt to write anything that appears as if students are very confused by the simplicity of the procedure and the dramatic variations in results, especially if they compare with other groups. No one will get the same results with such crude equipment.]

Summary Questions:

Provide some summary questions to aid students' reflections here – for example:

1. Where *does* color come from, the material or the light?
2. When does size matter?
3. What kinds of materials could stop the *thin film* effect?

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