Assembly Instructions for the "Plumber's Polarimeter"

Mark N. Kobrak
Brooklyn College – CUNY
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Objective: Build a polarimeter that is inexpensive, robust, easy to maintain and capable of performing simple polarimetry measurements on concentrated sugar solutions. Device must be simple enough that it can be assembled and maintained without the need for advanced training or tools.

Materials:

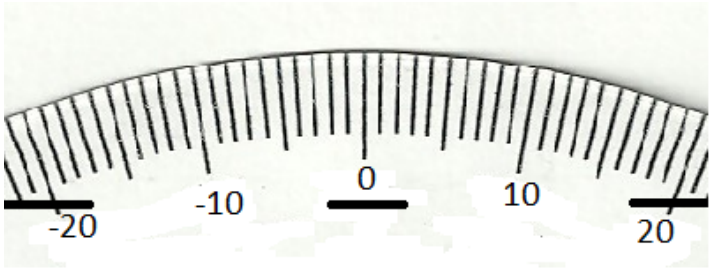
Item	Cost
2 Zeikos ZE-CPL49 49mm Multi-Coated Circular Polarizer Filter	$11.98
1 PVC Schedule 40 1.5" Compression Repair Coupling (Mueller, UPC: 032888601079	$2.76
Sourced from https://www.plumbersstock.com/product/2968/1-1-2in-pvc-dresser-coupling/	
100 mm Pathlength Optical Glass Cuvette (sold online by LabShops)	$29.99
2 Stainless Steel Clamp Type 40, 2 1/16th" to 3"	$2.00
1 2" Clevis Hanger	$2.50
1 30mm 8.5 cm x 5.4 cm PVC plastic sheet (used gift card or ID card will do, or ID card blanks can be ordered for the purpose)	*neg.*
Two 1"-long adhesive Display Holders (we used Deflect-o Supergrip, available at office supply stores, ~$5.50 per pack of 50)	$0.22
One rubber band	
Total:	$49.45

Also need a stock of:

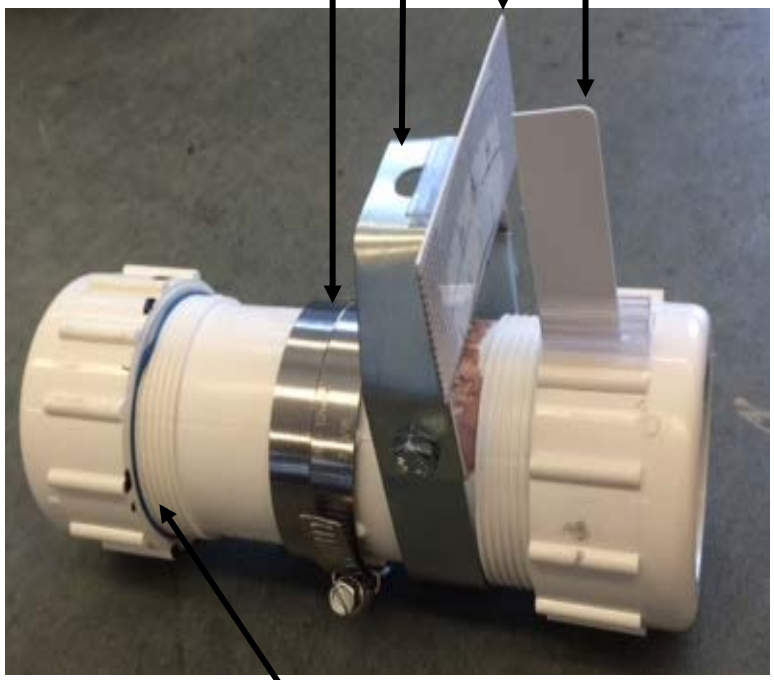
Frost King Rubber Pipe Insulation tape (2" wide, 1/8" thick, 30' long)	$8.87
Hot glue gun (superglue will work, but is more difficult and quite messy)	
4"x1.5" printable mailing labels	
Clear Packing Tape	
Latex gloves	

Assembly time is under 45 minutes, and per unit times can be reduced significantly by economies of scale.

This is the angle gauge, sized appropriately for use. Copy the graphic to a 2.5"x1" mailing label and print a page.

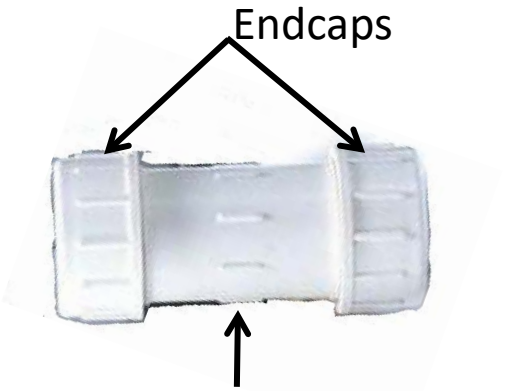


Finished Device:



Assembly Instructions:

1. Unscrew the end caps of the PVC pipe coupling. Discard the rubber gaskets.



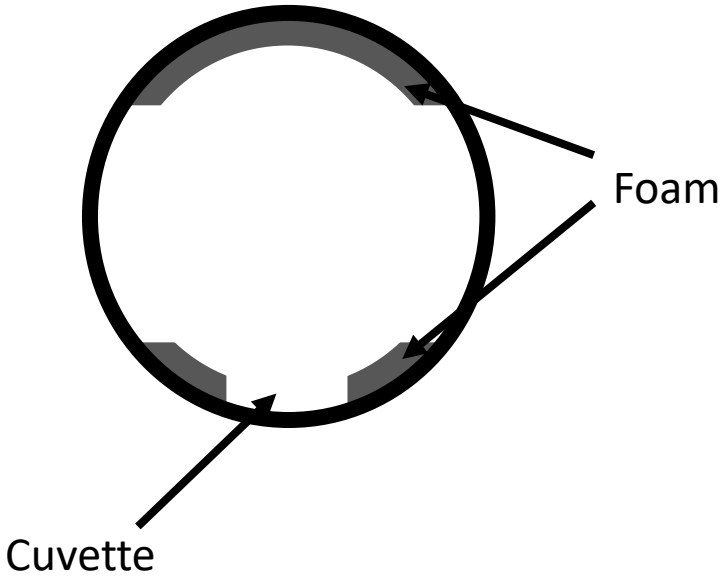
2. Examine the polarizing lens and find the way that it fits best in the PVC end cap. Position inside of end caps of pipe coupling, with the ridged side facing outward from the end cap. Use hot glue gun to secure in place (3 large globs at intervals around the rim seems to work well).
    a. Companies seem to supply slightly different lenses under the same serial number. Make sure the lens fits inside the cap before starting.

    b. If you are not sure which side should be facing out, hold the lenses back to back in your hand and look through them. Point the lenses at any light source and rotate them. If the lenses are properly aligned, the light will disappear as you rotate.

This side should be glued to end cap.

c.If a hot glue gun is not available, you can use a superglue. However, the glue tends to dissolve the plastic rims of the lenses, leaving a black residue on anything it contacts. It is recommended that you where latex gloves and take care not to stain the lenses.

3. The PVC tube interior needs to be modified using the rubber pipe insulation tape to accommodate the cuvette. Cut one 5 cm long strip and run it down the tube, starting from the end. Place two other strips on the opposite side of the tube, separated by a distance of about 1 cm. Test that the cuvette slides in and out of the slot easily; there should be just enough pressure from the tape to hold it in place, but not so much that it breaks the cuvette. The slot is now the bottom of the polarimeter.

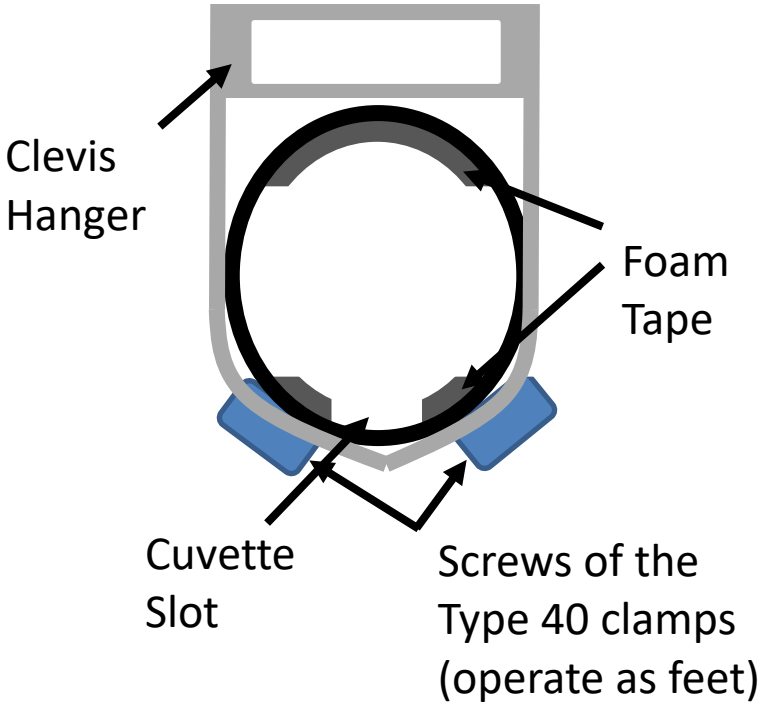


4. The two Type 40 stainless steel clamps are used to prevent the finished polarimeter from rolling (accumulating breakage fees from students for a device capable of rolling downhill would be unsportsmanlike). Slide them both onto the tubing and put them directly at the ridged section at the middle of the tube. Position them so that the screws are just to opposite sides of the cuvette slot, and tighten the screws to lock them into place.

Type 40 Clamp

Clevis Hanger

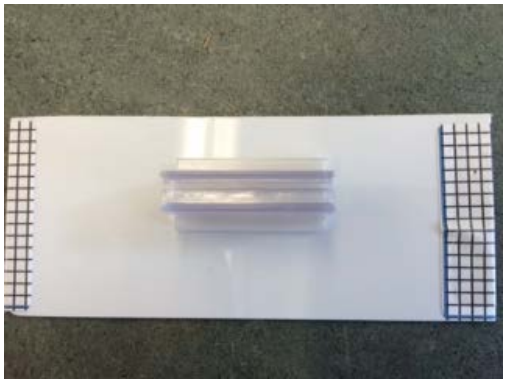
5. Unscrew the Clevis hanger and slide the horseshoe part over the body of the pipe coupling, so that it sits between the type 40 clamps and one end of the coupling. The end where it sits is now the front end of the polarimeter. Re-secure the top part of the hanger using the bolt, and slide the Clevis hanger along the body until it sits next to the threads of the pipe coupling. The cross-section should now look like this:



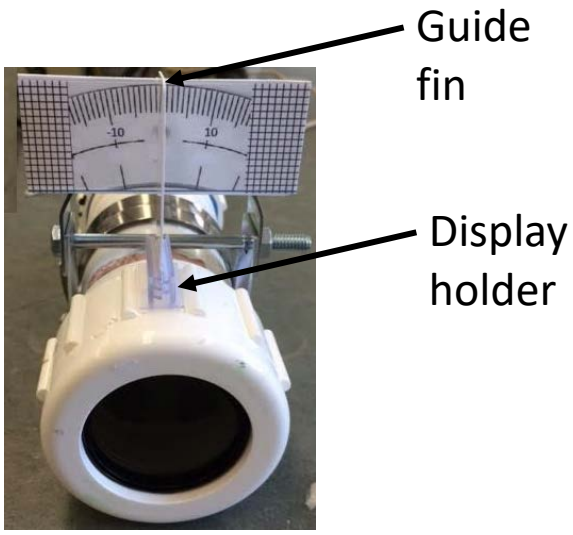
6. Screw the end caps back on the tube. Confirm that the device is stable in an upright position, and adjust the position of the Type 40 clamps if it is not.
7. Now, it is necessary to make the angle gauge and the guide fin. This is done using the plastic card. As noted in materials, a discarded plastic ID card or commercial gift card of appropriate size are used; the advantage to this material is that it is suitably rigid and waterproof. Heavy paper or thin cardboard will do as well, but these steps assume a card of the appropriate size:
    a. Print a sheet of the Angle Gauge labels shown on the first page of these instructions.
    b. Lay one lengthwise across the card. Ideally, the label should be just long enough that the ends curve around the card.
    c. Cut off the strip of plastic above the guide, then shorten it to a length of about 6 cm. Set this aside and save it for use as the guide fin.

    d. Cover the front of the angle gauge with transparent packing tape, so that the label is waterproof. The edges of the tape can wrap slightly around the edges of the card, but do not completely cover the back side.

e. Affix one of the display holders to the back of the card, running lengthwise along the back. It should be centered along the long side, and high enough up the short side that its center sits at the dot on the angle gauge sticker (the dot just below the zero mark on the angle grid). If the edges of the angle gauge label are available, you can use the guidelines to align the display holder.

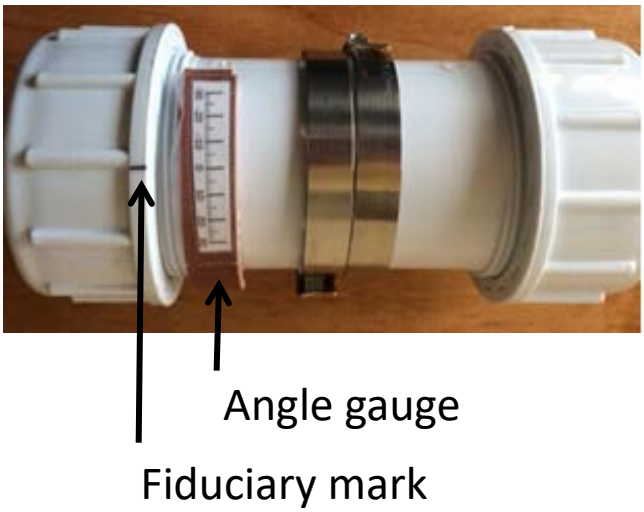


f. Place a second display holder on the eyepiece of the PVC coupling. It should be aligned so that it runs parallel with the direction of the pipe body, and points directly away from the center of the cylinder. When the device is in use, the guide fin sits in this holder.



8. Mount the angle grid on the Clevis hanger as shown. It may be necessary to slide the angle grid along the Clevis hanger to center it. If everything is aligned properly, it should be possible to rotate the eyepiece so that the guide fin points onto the angle gauge directly.
9. The instrument is usable in this form, but the calibration tends to drift. To avoid this, unscrew the back (calibration) endpiece and put a rubber band in the threads roughly 3/4ths of the way in. Screw the endpiece back in until it comes into contact with the rubber band and requires some resistance to turn, but is not actually jammed. This will prevent the endpiece of moving except when desired.

NOTE: It is possible to simplify the design by skipping the angle fin and the Clevis hanger/angle grid assembly, and simply marking an angle grid and fiduciary mark on the PVC. An example is shown below. However, our experience is that this significantly reduces the accuracy of the instrument.



Usage:

Depending on construction, the device is accurate to +/-2°. This is suitable for studying concentrated sugar solutions (e.g. sugar concentrations greater than 50.0g/mL) or for other liquid samples with strong optical activity. Keep in mind the risk of spillage if the instrument is tilted. If using hazardous liquids, gloves and goggles are recommended, and the instrument should be mounted on a stand rather than held in the hand during measurements. The eyepiece is sufficiently large that goggles do not need to be removed to take measurements.

Make sure the Angle Grid and Guide Fin are in place. If the guide fin does not point directly along the markings on the angle grid, make the appropriate adjustments. Remember the angle gauge can slide back and forth, and the bracket holding the Guide Fin can be wiggled to adjust it.

Now, unscrew the Angle Adjust so that it comes completely off, taking care not to drop it as it comes loose. Looking inside, you should see two pieces of foam tape bracketing a slot where the cuvette will go. The angle grid should be directly above the slot. If it is not, adjust the Clevis hanger.

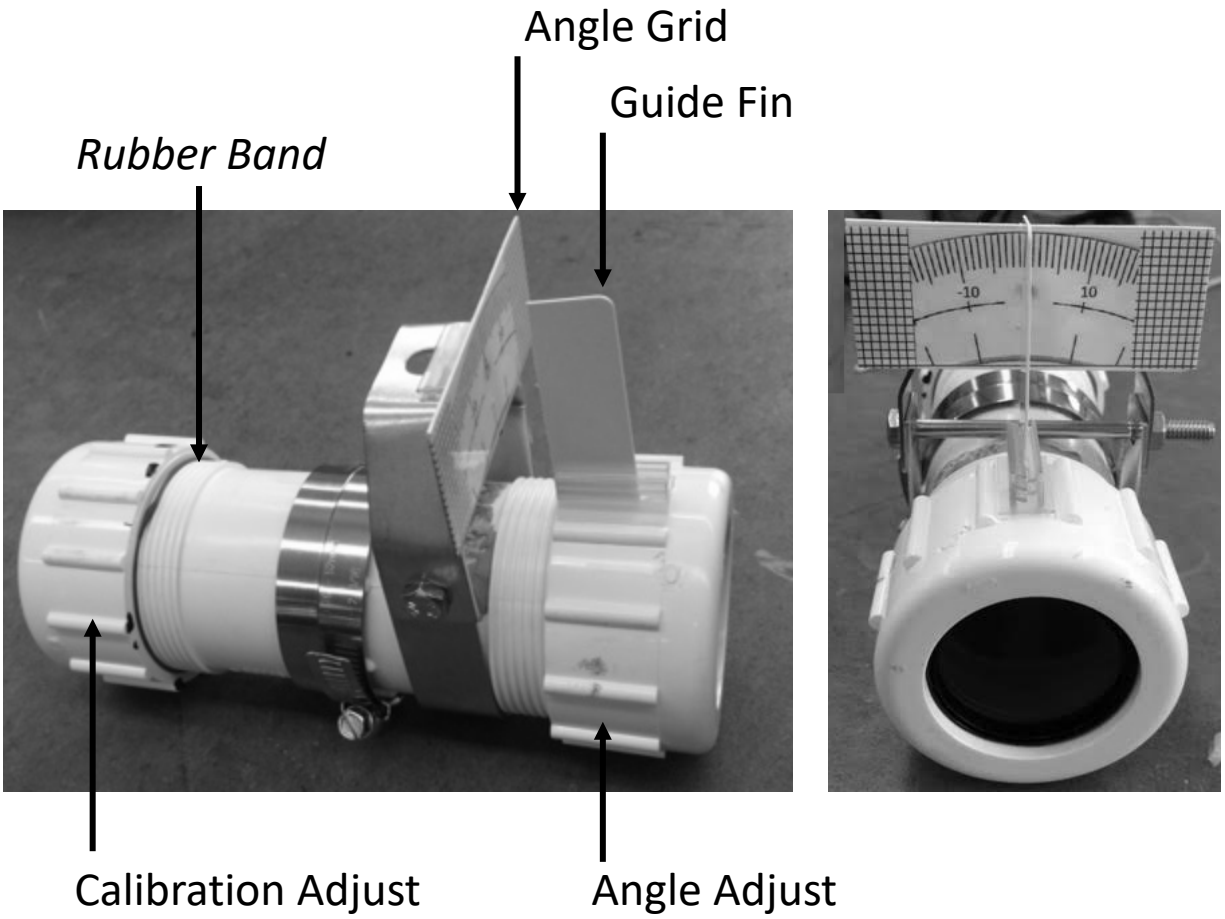


Figure 6: Side and front views of the polarimeter.

Make sure that the angle grid is straight up and down, not tilted backward. If you have trouble keeping it upright, hand-tighten the screw at the side of the bracket. Also, make sure that the 0° marker

on the Angle Gauge sits directly over the center of the polarimeter tube. If it does not, you should slide it until it does. When the body is properly configured, screw the Angle Adjust back on.

You are now ready to calibrate the instrument. Look at the Calibration Adjust, and confirm that there is a rubber band in the threads. If there is not, obtain a rubber band and move it into the threads by partially unscrewing the Calibration Adjust and then screwing it back over. The point is that the rubber band should slow the motion of the Calibration Adjust, but not stop it completely. This is so that the calibration does not drift during the experiment.

It is recommended that you clamp the polarimeter in place on a stand while in use. Make sure that it is level (so that the loaded cuvette does not spill) and pointed at an appropriate light source. Make sure that the polarimeter is suspended over the base of the stand, or it may tip during use.

Now, look through the polarimeter at a light source. A monochromatic light source such as an LED bulb is recommended as providing the best results, but any bright light source or even sunlight will do (obviously do not use one that could damage the eye). Rotate the Angle Adjust until the gauge reads zero (i.e the Guide Fin is lined up with 0^o on the Angle Gauge). You will probably see some light coming through the polarimeter. Rotate the Calibration Adjust until you can no longer see any light. *Tip: Look directly at the light; it is at its darkest when you can no longer see the shape of the bulb.* Double-check that you have not inadvertently changed the Angle Adjust; if it still reads 0^o, the instrument is calibrated.

Depending on conditions, you may not see perfect darkness. Sometimes the light will remain slightly visible, becoming pale and dim but never quite becoming invisible. If this occurs, try to find the dimmest point. Alternately, if you observe that the light becomes very dim and changes color (going from yellowish to blueish, for instance), try to find the point right at the middle of that color change. The behavior has to do with the imperfect optical properties of polarizing materials, which interact with different frequencies of light differently.

The calibration should not change during the rest of the experiment, but you can check it as you go. You will find that even when the polarimeter is loaded with the cuvette, you can look around the cuvette and see the lens behind it. You can check the calibration at each trial by setting the Angle Adjust to 0^o. If you can see light around the sides of the cuvette, the polarimeter is out of calibration and you should re-calibrate as described above.

Now, load the cuvette with your sample. It should be about 2/3rds full; higher can lead to leakage or spillage (this corresponds to roughly 30 mL of sample). Put the cap on the cuvette, then unscrew the eyepiece on the polarimeter , taking care not to let it fall when it comes off. Insert the cuvette in the slot in the body of the polarimeter, making sure to slide it far enough in that it will not come in contact with the eyepiece (but do not push it all the way against the back). **Once the cuvette is in place, you must hold the polarimeter level or it will leak and spill.** Replace the eyepiece, screwing it back sufficiently far that there is no danger of it coming off. Try to screw it far enough in that it rotates freely, but the Guide Fin is close enough to the angle grid to make the angle easy to read.

Rotate the eyepiece so that the Guide Fin is at 0^o, and look through the eyepiece at the LED bulb. You should see an odd optical effect, where the cuvette itself appears transparent but the visible parts of the lens behind it appear opaque. If you can see through the rear lens when the instrument is set to 0^o, that means your calibration is off and you should recalibrate as described in the previous section. You do not have to unload the polarimeter, just rotate the Calibration Adjust and look around

the cuvette to observe the back lens. When the back lens is opaque and the angle reads 0^{o}, the instrument is calibrated.

When the instrument is properly loaded and calibrated, slowly rotate the Angle Adjust. The back lens should darken, and the cuvette should darken and eventually become opaque. As noted previously, it may not become completely opaque, but you may observe a color change that corresponds to the point at which the measurement should be taken.

Cleaning the Polarimeter:

Even small amounts of leakage from concentrated sugar solutions can lead to significant residue. To clean the instrument after use, take out the cuvette, and rinse thoroughly with tap water and then distilled water from your spray bottle. Set it aside to dry.

Take both ends off of the polarimeter and run tap water through the central tube. If there are stubborn patches of material, use soap and water to remove them, but try not to loosen the foam tape. Try to avoid getting the Angle Gauge wet (you can remove it during cleaning).

Rinse the endcaps thoroughly with water, and then spray with distilled water from a spraybottle to avoid residue on the lenses. Clean with a lens cloth if necessary, but soap is not recommended for the lenses.

Allow the parts to dry, then screw the endcaps back on. Remove the Angle Guide, flatten the Angle Grid against the body, and return your equipment.

Storage and Maintenance Notes:

The guide fin can be removed for storage, and the Clevis hanger folds down to make it possible to stack the instrument. Depending on storage arrangements, it may be productive to remove the angle grid and store that separately as well.

Cuvettes should not be stored in the instrument.

Most other problems with the instrument will be easily repairable. The gobs of hot glue are usually strong enough that a popped lens can be slipped back into place and remain there for the rest of the experiment (additional hot glue can be applied afterward). They can also be repaired with superglue, but see notes in the assembly instructions about the reaction between superglue and the lenses. The angle grid and pointer should not break, but are obviously easily replaceable if they do. It is a good idea to have a stock of rubber bands on-hand while in use, in case of breakage.

If a component of the PVC pipe cracks, or one of the lenses breaks, the remainder of the unit can be set aside against the failure of a future instrument (in which case the pieces can be combined to make a single unit).