

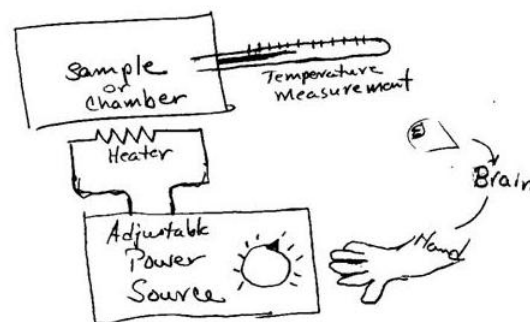
Controlling the temperature is a very important aspect of many experiments, especially those involving the physical properties of materials at different temperatures or some phenomena like crystal growth in glass like our candy glass. Typically the scientist will have temperature controlled ovens or even “hot stages” (or cold) for their samples. These can be custom designed or sometimes purchased and are usually too expensive for the young student. However there are lots of ways to build your own temperature controlled chambers from materials readily available from materials and tools available at home. I will describe a few of the options that I have considered and tried. Each may have some advantages and disadvantages and should be selected and tailored based on your particular need.

Some Basics:

The pieces of simple manual temperature control:

Adjustable/ variable power source + heating element +
temperature measurement

+ human being to adjust the appropriate power level



The controller and the heating element must be matched for each other:

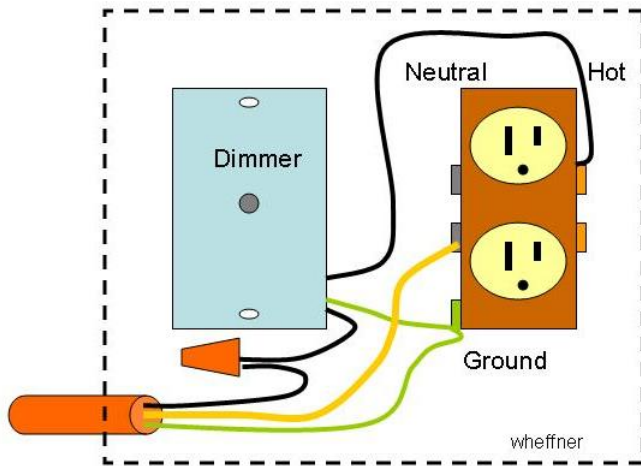
Your burner on the stove can deliver perhaps 1000 Watts of power ($P=V \times I$). You would need a controller that could deliver 1000 W at 120 V in order to use the range burner at the temperature used for cooking. Variable voltage power sources for this level of power are not cheap. However the dimmer switch used to control lower power light bulbs are cheap (about \$5 for the dimmer switch) and readily available at any hardware store. We will provide directions for building your own dimmer switch controlled voltage supply below. The dimmer switch can be used to drive up to about 500 W and many are even rated to 600W, but it is best to design for somewhat lower heating loads. I recommend that your heating elements be kept less than 200W to be on the safe side. (This translates to a resistance of $R > 50$ ohms, from $R = V^2 / \text{Power}$.)

Some cautions before beginning:

The dimmer switch should only be used to control “resistive” loads, i.e. heating elements.
1. You will be working with electrical wiring for house level voltages, i.e. 110 V. Make sure the apparatus is unplugged whenever you are working with the wires or have the unit open. The 110 V from the electrical outlet can shock and even kill you.

2. Dimmer switches are not meant to control voltage to motors or other electronic equipment. If you want to understand why and or how they work I recommend you take a look at How Stuff Works at: <http://home.howstuffworks.com/dimmer-switch.htm>

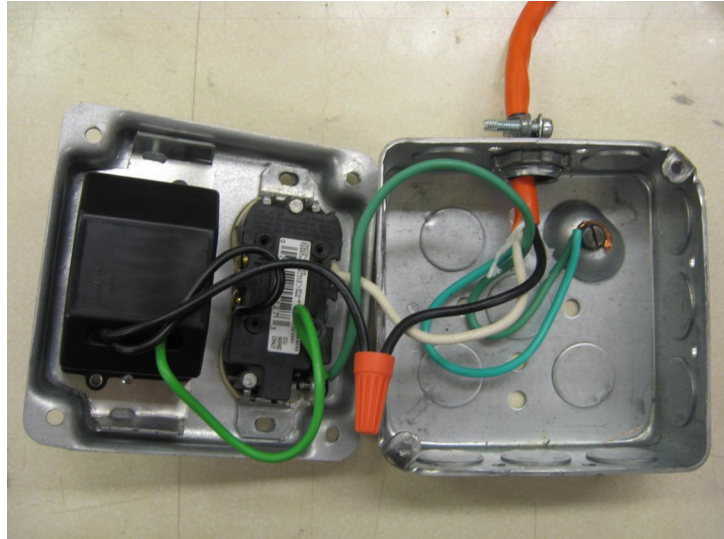
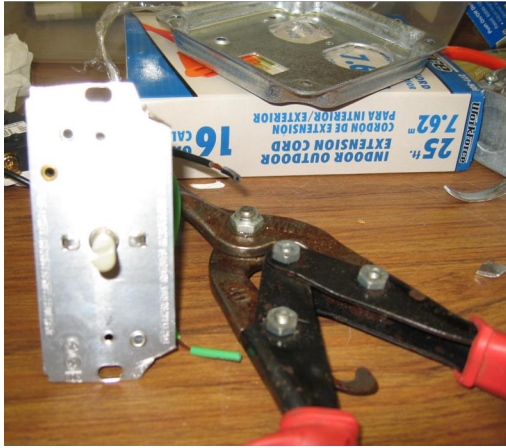
Building the Dimmer Switch Power Source:



The components to build the dimmer switch controller are shown here together with the schematic and a photo of the finished box. The electrical box is a 4" square surface mount box (with 1/2" knockouts Raco # 8192 from Home Depot). The cover which holds the receptacle and the dimmer switch is called an "exposed work cover for 4" square box" (with 1 duplex receptacle and one switch, Raco 906C). You will also need a cable;

(I use the cheapest 3 prong power cord that I can find, about \$5, and then just cut off the plug end to use.) You will also need a cable clamp for the 1/2" knockout hole, see photo. The Dimmer switch used is a Leviton 600W (No. 6681-1W from Home Depot).

You will need to trim off some of the aluminum face plate (heat sink) of the dimmer. Otherwise it will not fit this cover. The photo below shows the cutting of the corners of the dimmer switch to fit in the metal face plate.



Step by step instructions:

1. Cut off the corners of the dimmer's aluminum face plate as described above and bend the edges, so it fits into the cover. You will also need to snip the four "ears" of the receptacle so it fits into the cover. You can use pliers and twist them off.
2. Remove one of the 1/2" (smaller) knockouts by pushing with a screwdriver and then twisting off with a pliers. Insert the wire clamp and tighten to the hole with pliers.
3. Cut the three pronged cord to the desired length; (I like a nice long, 10' cord). Remove some of the outer jacket to expose about 8" of wire. Next cut the black white and green wires to reach the components with some length to spare and strip the ends exposing about 1/2" of wire.
4. Connect the white wire to one of the silver colored screws on the receptacle. Connect the black wire from the power cord to one of the black wires of the dimmer by twisting together (clockwise) and then twist on the orange wire nut provided with thee dimmer. The other black wire from the dimmer should be attached to one of the yellow (brass colored) screws of the receptacle.
5. The green (ground) wires should all be connected together and there should be a connection to the metal box as well. Attach the green (ground) wire from the dimmer to the ground screw on the receptacle along with the green wire from the power cord. In the figure above I used an extra green wire (from the left over end of the power cord) to connect to the lower case of the box as well, but this is not really necessary as the bottom of the box will be connected to ground once the cover plate is screwed to the bottom.

Heater Options;

Remember that the dimmer switch can only drive lower power devices - with $R > 50$ ohms. Some of the lower power resistive heating elements that I have identified around the home include:

- The light bulb (40- 100 W)
- Hair flattener elements (you can get lower cost unit with 2 elements for under \$15).
- Immersion heaters
- Some automatic coffee makers

- the ones that have a clock and can set the turn on time typically have a 200 ohm heating element. We see a lot of these thrown away even though the heating plates are often fine. Don't bother with the cheaper coffee makers as they usually have a very low resistance, typically 800W element, and they contain a high temperature cutoff switch which they use to control the temperature.

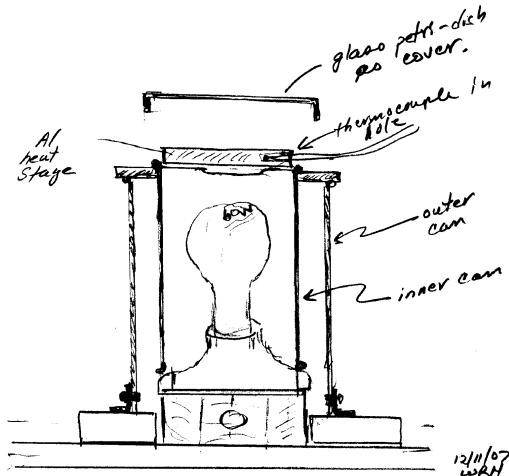
But the light bulb is a great place to start as they are easy to obtain and there are lots of nice lightbulb sockets, including porcelain ceiling light sockets which can stand the heat.



Simple Light Bulb Hot Stage:

Original Version:

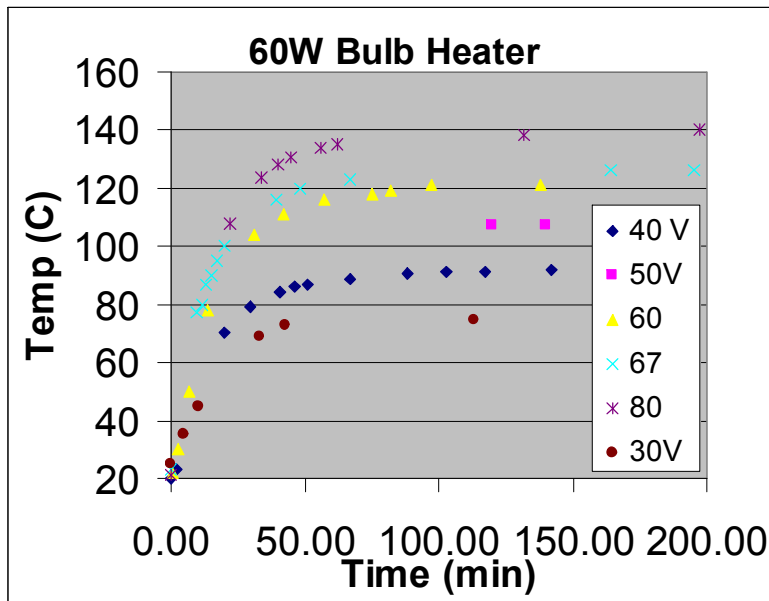
Here is my original version. It was simple, requiring a one pound and three pound coffee cans. But it was slower to achieve temperature than the later version to follow on the next page. It also used a circular aluminum plate for providing some thermal mass with a hole drilled in the plate for a thermocouple. The circular aluminum plate would be too difficult for the student to obtain and cut. For these and other reasons, I suggest you begin with the later version on the next page, but I include this to show that many alternatives are possible.



Sketch of the light bulb hot stage

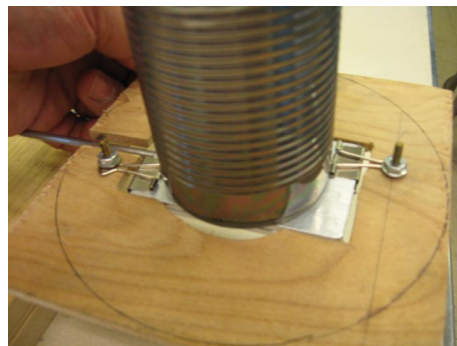
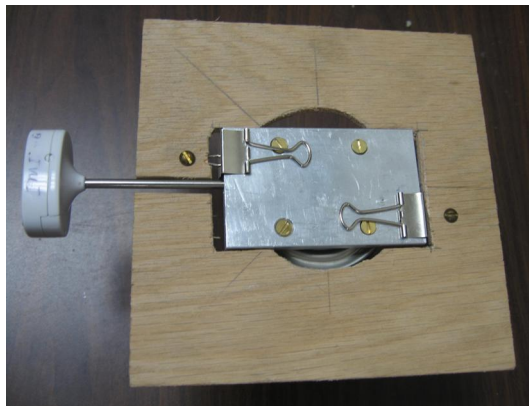
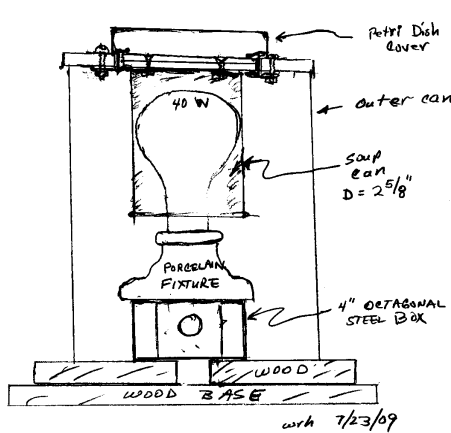
Photo of author's original version, 12/07

some performance data (60W Bulb)



Latest Light Bulb Sample Heater (Soup Can Model)

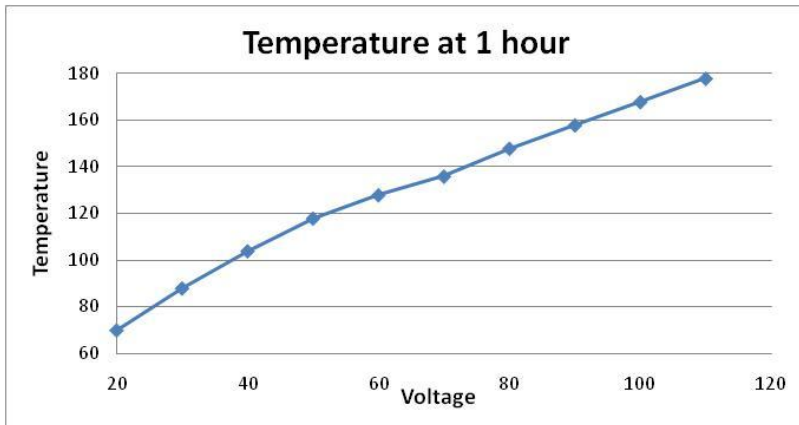
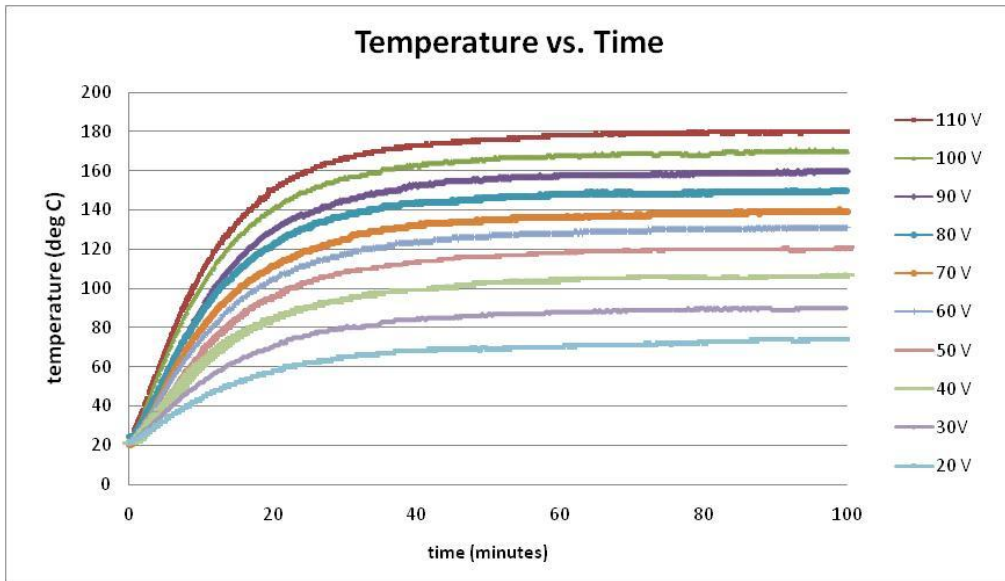
The Soup Can Version was designed to bring the light bulb heating element in close proximity to the aluminum hot plates to minimize the heatup time (thermal lag). The aluminum hot stage is made from two pieces of 1/8" x 2" aluminum bar (3.25" long) which is readily available at most hardware stores. The plates are bolted together and attached to the soup can as shown. Details of the screw hole sizes and positions are shown in a sketch below. A hole for the digital thermometer (or thermocouple) should be drilled thru the center of the two plates. (The use of two joined plates makes the drilling much easier as the drill can be encouraged to follow the mid-seam and thus not run crooked).



The aluminum hot stage is attached to a plywood square base utilizing simple binder clips. The binder clips reduce the thermal loss from the hot stage. A rectangular hole must be cut in the plywood, slightly larger than the hotstage baseplate. A large coffee can holds the plywood frame with hotplate as shown. A Petri dish is placed over top of the hotstage to prevent heat loss through convection and provide the oven chamber with viewing.

The dimmer switch heater is used to adjust the voltage for achieving temperature control and a voltmeter is highly recommended to measure the actual voltage and help with obtaining the control parameters.

The response characteristics using a 40W bulb are shown below. Note that at full voltage it takes about 12 minutes to heat from room temperature to the 120 C around which many of our experiments are centered. To obtain the shortest warmup time we typically heat to the desired temperature at full power and then drop the voltage back to the value appropriate to provide to achieve long term stability at this temperature. The plot of Temp at 1 hr vs voltage is useful to hit the target temperature without too much waiting.



The lowest cost temperature probes suitable for the sample heater are the digital cooking thermometers as shown below. The Sunbeam models below have good high temperature performance although they should be checked for calibration (e.g. in boiling water). If you have access to a thermocouple probe and meter, you can probably get away with a much smaller temperature probe hole, and I have found them generally to be more accurate than the digital thermister types.



approx \$18



approx \$10



CenTech Digital Meter with Thermocouple probe for about \$25 (from HarborFreight.com).

Appendix A:
Details of the Hot Stage Dimensions and Hole Details

