Name: ____________ Perm Number: __________ TA: __________

Practical Electronics Boot Camp

Version 2.01 Spring 2026 Professor Everett Lipman

Due no earlier than Wednesday, April 8.

This boot camp will count as one lab. Each question or task has the point value shown in the corresponding box. You should have any available TA initial and score the box once you have completed the assigned question or task.

1. Purpose. In most physics classes, we begin with a small set of elegant fundamental laws and then derive mathematical explanations for a wide range of phenomena. Verifying these explanations is typically left to others, or to history.

This class is fundamentally different. Here we will arm you with a wealth of practical skills so that you can bring to bear the full power of modern technology when you set out to make new physical measurements. Or when you set out to make a decent living, if you don't happen to become one of the three string theorists in the world who will be offered permanent jobs the year you get out of grad school.

It is assumed that you are a complete beginner when it comes to practical electronics. During this one-week boot camp, you will learn to

- Read circuit diagrams
- Make solder connections
- Use a solderless breadboard for prototyping
- Use common electronic test equipment
- Debug circuits

Later during the quarter, we will do a circuit assembly boot camp, in which you will wire a circuit in permanent form and package it to make a complete device.

You have one week to complete this handout, so start early and don't slack off. If it doesn't kill you, this training will make you far more powerful as a physicist. It will also enable you to impress potential employers and all your friends.

You are expected to learn the majority of this material on your own, but don't hesitate to ask the TAs for help if you are stuck. Especially if what you are about to do could damage the equipment.

2. Safety. The electronics lab is not an inherently dangerous place, but we will be working with electricity, and using potentially hazardous equipment.

Electrical safety will be covered in class. The most important points to remember are that

1. Any current through your body greater than 10 mA is potentially dangerous.
2. The resistance between any two points on your body varies greatly depending on whether you are sweaty, what sort of sunscreen or other products you may be wearing, etc. Typical values are between 1 kΩ and 4 MΩ. If your skin is punctured, your resistance can be as low as 100 Ω.
3. The voltage from common batteries ($\leq$ 12 V) is typically safe.
4. The voltage from a wall socket can easily kill you.

There are several types of mechanical hazard you will encounter in this class. The first is small flying bits of metal.

1. When using wire cutters, use eye protection (open frame glasses are acceptable).
2. When soldering, you must wear lab-issued safety glasses to protect your eyes from flying drops of solder that can be flicked off the iron

We will be using soldering irons and heat guns. Soldering irons typically run at around 380 °C, whereas your skin will burn above about 50 °C and boil above 100 °C. Paper will ignite at about 230 °C. Heat guns are not hair dryers. They produce air at dangerous temperatures, typically around 200 °C or more. Always rest your soldering iron in its holder, and do not place soldering irons or recently used heat guns near anything flammable.

You **MUST** tie back long hair and contain loose clothing when working with heat or rotating machinery.

Model safety glasses for the TA. (2) ____ ______

Place a soldering iron in its holder. (2) ____ ______

What is the minimum number of people allowed to be working in the lab? (2) ____ ______

3. Stripping Wire. Most electronic connections are made with copper wire. Copper has very good electrical conductivity, and it is relatively easy to make reliable connections between copper and other metals. Wire is supplied in diameters defined by the American Wire Gauge (AWG). You can read about AWG in the handout on the course web page.

Before connecting wire, you must strip off the insulation. This is done with a wire stripper, such as the one provided in the lab. To use the stripper, place a short length of wire in the slot labeled with the appropriate AWG number, close the jaws, and pull the wire straight out. It is *very important* to use the correct hole, so that you avoid nicking the metal part of the wire. Nicked wire is prone to breakage, often causing hard-to-find circuit failures. This can be intensely frustrating.

We will typically use 22 AWG wire, which can fit in your breadboard without damaging the sockets. 22 AWG wire has a diameter of 0.64 mm. A good length to strip for breadboard connections is about 5 mm. For binding post connections, 10 mm works well. *Do not* strip more than 10 mm of insulation from a wire unless you have a good reason. Bare wires often cause short circuits, for example when a lead connecting a part mounted to the wall of an enclosure touches a lead on the circuit board.

Strip the ends of a piece of 22 AWG wire.

(6) ____ ______

4. Soldering Basics. Solder is used universally in electronic assembly to make permanent electrical connections between two conductors. It is a combination of metals chosen to have high conductivity and a low melting temperature.

Solder is supplied in the form of a wire with a hollow core containing a chemical called *flux*. Soldering flux, not to be confused with any sort of surface integral, removes the oxide layer that typically builds up on metals exposed to air. This allows the molten solder to wet the metal surface and make a good electrical contact. Your choice of flux has a *very* large effect on your soldering experience. We use rosin-based flux, which makes hand soldering much easier, but has the disadvantages that it leaves a residue and also creates some fumes. When you are soldering, open the room doors so that there is plenty of fresh air in the lab, and do not intentionally breathe the fumes coming off the solder. Some types of soldering flux are intended for other applications, for example plumbing. Do not ever use acid-core solder for electronics.

We will be using Kester 24-7068-1402 lead-free #48 rosin-core solder. It is 0.79 mm in diameter, made from an alloy of tin (96.5%), silver (3.0%), and copper (0.5%).

In electronic circuits, solder is intended to make an electrical connection, not to bear a load. If there will be significant force on the connection you are making, you should have a separate mechanical arrangement to relieve the strain.

For more information about soldering, including helpful photographs, read pages 110–115 and 119–125 in *Make: Electronics* (MkE). You can find copies of this book in the lab.

5. Care and Feeding of Your Soldering Iron. Because it is very hot, the tip of a soldering iron is prone to rapid oxidation. This can cause serious difficulties with soldering, since the oxide layer typically has very poor thermal conductivity. An oxidized tip looks dark gray or black. In order to prevent oxidation, you should "tin" the tip of your soldering iron every few minutes by melting solder onto it and then dipping it a few times in the tip cleaner cup filled with brass shavings. The tip should be shiny all over, with no gaps, and should not have any excess solder on it. You should tin the tip and turn off the iron if it will not be used for a long period of time.

If a tip is badly oxidized and solder will not wet it, it will need to be chemically or abrasively cleaned before it can be used again. This has to be done carefully in order to avoid destroying the plating, so please ask a TA for help if solder will not adhere to the tip of your iron.

Solder two wires together as shown on page 120 of MkE. (6) ____ ______

6. Heat Shrink Tubing. Heat shrink tubing is used to insulate solder connections. It is made of plastic, and will shrink to approximately 50% of its original diameter, conforming to the material it surrounds. The tubing diameter should be selected so that it is large enough to slip over the finished connection, but not so large that it won't grip the wires after it has contracted.

A heat gun is used to activate the tubing. Remove the hot air stream immediately after the tubing has contracted to avoid melting and burning. Make sure to put the tubing on the leads *before making the connection* if the connection will prevent the tubing from being placed on the wire. Keep the tubing as far as possible from the connection while you solder to avoid premature shrinkage.

Cut two 20 mm lengths of heat shrink tubing and place them on the leads of the 9 V battery clip from your boot camp parts kit. Cut two 10 cm pieces of 22 AWG wire, one black and the other red, and strip the ends. Solder the 22 AWG leads to the battery clip leads, maintaining the wire colors. Make sure the connection is compact, so that the tubing can slide over it (see page 123 in MkE).

Have the TA check your solder connections.

(6) ____ _____

Center the tubing over the solder connections and use the heat gun to shrink it (see page 124 in MkE, but do not put your fingers near the hot air stream).

Have the TA check your insulated connections.

(6) ____ _____

7. Measuring Resistors. From what is available in the lab, select two 5% tolerance resistor values that differ by more than a factor of 1.4 but less than a factor of 10. Call them R_1 and R_2. Get 3 of R_1 and 2 of R_2.

Demonstrate to the TA that you understand the color code on each of your resistors (see pages 15–16 in MkE).

What is the nominal value of R_1? __________

What is the nominal value of R_2? __________

(4) ____ _____

Use an Agilent U3401A multimeter to measure the resistance of two R_1 resistors and two R_2 resistors. The manuals for the meters are on the course web page, and some helpful material can be found on pages 9–10 and 13–16 of MkE. You will need to figure out which test leads to use. Look for leads on the racks hanging from the lab benches. A TA can help you locate appropriate probes for the ends of the leads elsewhere in the lab.

Measured value of the first R_1? __________

Measured value of the second R_1? __________

Measured value of the first R_2? __________

Measured value of the second R_2? __________

(6) ____ _____

Keep track of which resistors you measured first and which you measured second.

Mount the third R_1 in the "helping hand" holder. Connect the test leads and measure its resistance. Set the heat gun on high, hold the hot air stream on the resistor for 4 seconds, then measure the resistance again.

Measured value of the third R_1 cold? __________

Measured value of the third R_1 hot? __________

(6) ____ _____

Set aside the third R_1 and do not use it again until it is cool and you have checked that its resistance is still within 5% of the nominal value.

8. Parallel and Series Resistors. Take the R_1 and R_2 you measured first and solder them in series. Measure the resistance through the series combination.

What value do you expect to measure? __________

What is the measured value? __________

(6) ____ _____

Take the R_1 and R_2 you measured second and solder them in parallel. Measure the resistance through the parallel combination.

What value do you expect to measure? __________

What is the measured value? __________

(6) ____ _____

9. Breadboard Binding Post Connections. The solderless breadboard is an essential tool for constructing temporary circuits, testing them, and revising them. Read pages 43–44 and 68–70 in MkE to see how your solderless breadboard is wired.

Orient your breadboard base so that the binding posts are on your left. We will be using the breadboard that is now closer to you.

Strip 10 mm of insulation off one end of a piece of red 22 AWG wire. Unscrew the red binding post and put the bare wire end through the hole. Adjust the wire so that the insulation is clear of the binding post, then screw down the post so that so that you firmly clamp down on the bare wire. The insulation should not be clamped.

Neatly route the red wire to the positive rail between the two breadboards (at the top of the closer breadboard). Cut the wire so there will be no excess length and strip 5–10 mm of insulation from the end. Using needle-nose pliers or a plastic lead bender, put a 90° bend in the wire. Insert the wire in the leftmost hole of the positive rail. Similarly connect a black wire from the black binding post to the negative rail closest to you, at the bottom of the closer breadboard. In the future, if you find it convenient, you can use jumpers from your wire kit to connect the positive and negative rails that are presently disconnected to the ones that are live.

Have the TA check your breadboard connections.

(6) ____ ______

Strip 10 mm at the ends of the leads from your 9 V battery clip. Connect the positive lead (red) to the red binding post by loosening the screw and putting the lead through the hole with the lead that goes to the breadboard. Then retighten the screw. Similarly connect the negative lead. Strip both ends of two 30 mm pieces of 22 AWG wire and insert these wires in the two live rails. Set your multimeter to measure DC voltage and connect the two 30 mm wires to the appropriate ports on the meter. Plug the 9 V battery into the clip.

What voltage do you measure? __________

(4) ____ ______

Remove the 9 V battery from the clip and disconnect the clip from the binding posts. Retighten the posts. Leave the 30 mm wires in the breadboard.

10. Power Supply. We will now use the GW Instek GPE-3323 power supply, the manual for which is available on the course web page.

Using a red banana plug wire, connect the power supply channel 1 (CH1) positive terminal to the red binding post on your breadboard. Connect the CH1 negative terminal to your black binding post using a black banana plug wire. Turn on the power supply. Turn off the output button on the right-hand side of the power supply panel. Set the two buttons in the upper right of the panel to their outermost positions so that the two channels are independent. Turn the channel 2 current and voltage knobs fully counterclockwise to turn that channel off.

Set the CH1 current limit knob to the middle of its range. Set the CH1 voltage to 5.0 V. Set up the multimeter to measure the voltage between the two 30 mm wires on your breadboard. Turn on the power supply output.

Demonstrate for the TA that you can control the voltage shown on the multimeter using the power supply. *(6)* ____ ______

When you turn on the output, the current reading for CH1 will go to zero. With the output on, the current displayed is the actual current, not the limit, even though a limit may still be set.[1] The multimeter has a very high input resistance when it is measuring voltage, so almost no current is flowing through the meter.

11. Power Supply Current Limiting. The 5% resistors in the lab are rated at 0.5 W. This is the maximum power they can be allowed to dissipate.

Turn on the power supply, and turn off the power supply output. Get a 47 Ω 5% resistor and, using a plastic lead bender and one or more jumpers from your wire kit, neatly connect the resistor across the live rails on your breadboard. Turn both sets of voltage and current knobs fully counterclockwise. Set the voltage on CH1 to 6.0 V. Turn on the power supply output. Since the current limit is set to zero, the voltage will also drop to zero. Raise the current limit on CH1 to 100 mA (0.1 A), then lower the voltage on CH1 to 2.0 V.

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[1] With these power supplies, the output must be on and a load connected in order to set the actual current limit.

How much power is the resistor dissipating?

____

(6) ____ ______

Turn up the voltage on the power supply until it stops increasing.

What is the power supply voltage? __________

(3) ____ ______

How much power is the resistor now dissipating? __________

(4) ____ ______

What is the maximum current you could use if the resistor were 33 Ω? __________

(6) ____ ______

Turn off the power supply output and lightly touch the resistor. It should be noticeably warm.

12. Battery Internal Resistance. Using an appropriate 5% resistor, measure the internal resistance of your 9 V battery. An appropriate resistor will enable a precise measurement, but will not exceed its rated wattage in your circuit.

Draw the circuit you used in the space above.

(6) ____ ______

What value of the internal resistance did you measure? __________

Explain your measurement to the TA.

(6) ____ ______

Measure the internal resistance of one of the CR2032 button cell batteries in the lab.

What value did you measure? __________

(6) ____ ______

13. LED Circuit. Turn off the power supply output.

We will now build a circuit to power the light emitting diode (LED) from your boot camp parts kit. The LED has two terminals, the anode and the cathode. As is the case for most semiconductor diodes, under normal operation current can flow from the anode through the diode to the cathode, but not the other way around. The circuit symbol for a diode contains an arrow pointing from the anode to the cathode, in the direction of the current flow. Read pages 16–25 in MkE for more information about LEDs.

Next to the cathode of the LED, there is a flat area on the rim, near where the leads meet the package. This is the best way to identify the leads. The anode lead is typically longer, but leads are often cut down for various reasons.

The cathode must be more negative than the anode for the LED to work. For a red LED, there is a voltage drop of about 2.2 V from anode to cathode under normal operating conditions. Blue LEDs have voltage drops around 3.2 V. The current should not be allowed to exceed about 20 mA through an LED, so we need to use a current limiting resistor.

Neatly construct a circuit that connects your positive breadboard rail to one side of the 390 Ω resistor from the boot camp parts kit, the other side of the resistor to the LED anode, and the LED cathode to the negative rail.

Have a TA inspect your circuit before you apply the power. *(8)* ____ ______

Set the power supply to 9.0 V with a current limit greater than 50 mA (it is unreliable with a current limit ≤ 40 mA). Turn on the power supply output.

What is the voltage across the LED? ________

(4) ____ ______

What is the current through the LED? ________

(4) ____ ______

What is the total power (light+heat) dissipated by the LED? ________

(6) ____ ______

14. Oscilloscope and Function Generator. In this section, we will learn to use two of the most powerful tools in the electronics lab. Each station is equipped with a Keysight EDU33212A function generator and a Keysight DSOX1202A oscilloscope. The manuals for both are available on the course web page. If there is something you don't understand about how to set up or use one of these instruments, you should read the appropriate manual. At this point you should also read pages 35–37 and Appendix D in the *Learning The Art of Electronics* (LAoE), and Appendix O in *The Art of Electronics* (AoE).

Begin with the function generator and oscilloscope off. Get a cable with BNC connectors on both ends from one of the racks in the lab. Carefully examine the BNC connector and figure out how to plug it in to the function generator 50 Ω Channel 1 output. If a 90° T adapter is attached to the output, use one of the available ends. Lock the connector by turning the shell.

Have the TA inspect your connection.

(4) ____ ______

Connect the other end of the BNC cable to the oscilloscope CH1 input. Turn on the oscilloscope power. It will take some time to boot up.

Turn on the function generator. Select a sine wave output with 1.0 kHz frequency and 1.0 V amplitude. Set the DC offset to zero.

Have the TA check your function generator setup.

(4) ____ ______

Press the Auto Scale button on the oscilloscope. After a few seconds, the yellow channel 1 trace should appear on the screen showing the sine wave from the function generator. Digital oscilloscopes typically will have an Autoset button, and it is convenient, but your goal should be to understand enough about the oscilloscope to set up the display without using the button.

By pressing the CH 2 button, you can turn the channel 2 trace on and off. Turn off the channel 2 trace.

Verify that the channel 1 input is set for DC coupling and 50 Ω impedance. Adjust the DC offset on the function generator and see how it affects the oscilloscope trace.

Demonstrate to the TA that your oscilloscope input is properly set and that you understand the DC offset control.

(3) ____ ______

Set the DC offset back to zero.

Adjust the function generator amplitude so that the sine wave is 6.0 V peak-to-peak (p-p).

(2) ____ ______

Experiment with the channel 1 Vertical adjustment knob and the Horizontal knob to change the oscilloscope display.

Demonstrate to the TA that you can find and change the number of volts per vertical division and the duration of a horizontal division on the oscilloscope display.

(6) ____ ______

Demonstrate to the TA that you can adjust the vertical offset of the CH 1 oscilloscope trace display.

(3) ____ ______

This will be particularly useful in the future when you have traces from both channels on the screen at the same time.

Figure out how to use both the horizontal and vertical cursors, and how to turn them on and off. To start, press the Cursors button under Measure.

Demonstrate to the TA that you can measure the amplitude, frequency, and period of your sine wave using the cursors, and that you can turn them off.

(4) ____ ______

Figure out how to use the Measure menu on the oscilloscope. Often in a laboratory you will be asked to do something that you do not know how to, and which is not obvious. In such a situation, it is frequently helpful to Read The Fine Manual (RTFM).

Demonstrate to the TA that you can measure V_{RMS} for your sine wave using the automatic measurements. (4) ____ ______

Experiment with different waveform settings on the function generator. Set the output to a 6.0 V p-p square wave.

Use the oscilloscope cursors to measure the rise time of the square wave from its low state to its high state. (6) ____ ______

Set the function generator output back to a 6.0 V p-p sine wave. Figure out how to adjust the trigger level.

Demonstrate for the TA that you know how to find the trigger level on the display, and can shift the trace by adjusting it. (4) ____ ______

Learn the difference between Auto and Normal triggering modes. If necessary, RTFM.

Explain the difference to the TA, and demonstrate by raising the trigger level above the peak signal level.

(4) ____ ______

15. Potentiometer. In your boot camp project kit, there are three potentiometers, which have round bodies with adjustment shafts sticking out. Two are 500 kΩ, and the third is 5 kΩ. The 5 kΩ potentiometer has an integrated switch, which is activated at the counterclockwise extreme of the shaft motion. It should be obvious which two solder terminals are connected to the switch. Ignore these terminals for the moment.

Using a multimeter, measure the resistance between the three possible pairs of remaining terminals as you turn the shaft. Look at the datasheet for the 5 kΩ potentiometer on the course web page (this may not match your potentiometer exactly).

Explain to the TA how the resistance varies between the pairs of terminals as you turn the shaft.

(4) ____ ______

With the shaft facing you and the three non-switch terminals down, the contact at bottom left is #1. The middle non-switch contact is #2. By placing its variable resistance in series with a speaker, we will use this potentiometer as a volume control. We all expect intuitively that a volume control will make the sound louder if we turn it clockwise.

Which two non-switch terminals should we connect in series with the speaker? __________

(2) ____ ______

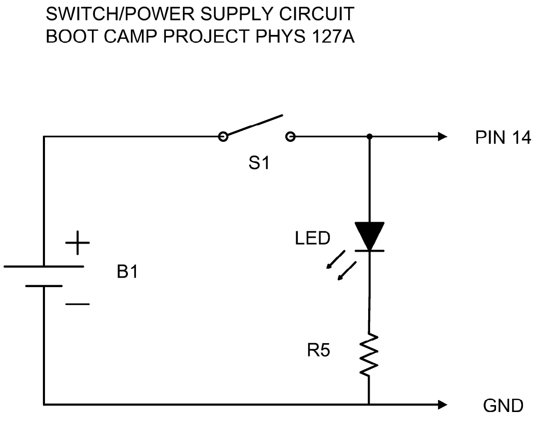
Cut and strip four 20 cm 22 AWG leads. We will solder these to the potentiometer terminals. When you do this, make sure that the leads project away from the potentiometer in the direction *opposite to the shaft!* In other words, the wires should project away from you if shaft is facing you. You will eventually mount the shaft through a hole in a box, and you don't want the wires to be heading into the box wall.

Solder one lead to each of the switch terminals, and one lead to each of the two volume control terminals.

(4) ____ ______

16. Power Indicator Circuit. Orient your breadboard base with the binding posts to the left. Run wires from the red and black binding posts to the inner positive and negative rails, respectively, on the lower breadboard.

Turn off the switch on your 5 kΩ potentiometer. Using this switch and the LED and 390 Ω resistor from your boot camp project kit, neatly assemble the circuit shown in Fig. 1. Use a plastic lead bender to form the resistor leads to the correct spacing. For each connection, use a jumper wire of the correct length from your kit. Avoid crossing wires and running wires at an angle. This will eventually make your troubleshooting much easier. You will be graded on the neatness of your breadboard circuits.



S1: SPST switch located on rear of R3, vol. control (5K)
B1: 9-volt battery
R5: 390-ohm resistor
LED: Light emitting diode

Figure 1: Power indicator circuit.

Set your power supply to 9.0 V and use it in place of the battery. Check your wiring carefully. Make sure that you have the LED polarity correct, and that you haven't connected it directly across the power rails.

When you are sure the circuit is correct, turn on the power supply output and then the potentiometer switch. If the LED does not light, or if you see smoke or smell burning electronic components, immediately turn off the power supply output.

Demonstrate your circuit for the TA. *(8)* ____ ______