Physics 364, Fall 2014, Lab #1 **Name:** ______________________

(using breadboards; measuring voltage, current, and resistance)

Wednesday, August 27 (section 401); Thursday, August 28 (section 402)

Course materials and schedule are at `positron.hep.upenn.edu/p364`

Lab Reports

Most of the learning that you do in this course will happen while you and your lab partner work through the lab assignments. You will first see the ideas from the course in each week's reading assignment, but the most effective way to assimilate these ideas is to put them to use in the lab. Building, measuring, and debugging circuits in the lab gives your own brain a chance to interact with the components, the instruments, your classmates, and the instructors. Brains seem to learn faster when they are doing things than when they are watching other people do things. It's also much easier to stay awake when we spend the class time actively building, studying, and debugging circuits together.

So the lab reports — which make up 40% of your course grade — give you credit for working through all of the lab exercises and pausing along the way to analyze what you see.

In past years, we used free-form lab notebooks, to give students practice documenting their lab work in the way that working scientists often do. This year we've switched to a fill-in format, instead, so that you can spend less of your lab time writing and more time *doing.*

As you and your partner work through the parts of each lab, there will be blank spaces for you to answer questions, sketch circuits, record measurements, or draw simple graphs. Put your name on the first page of the handout, and write your answers on the lab handout itself as you go along. You and your partner will normally build and measure each circuit together, but each person must turn in his or her own paper at the end of class. We strongly encourage you to cooperate with your lab partner and other classmtes in reasoning through through the lab questions, but you will turn in your own paper that reflects your thinking.

Don't waste time making your work look polished. Just write clearly enough that we can follow your reasoning. Most importantly, your written work should convince us that you thought about the questions asked in the lab assignment. We'll use single-sided printing for the handouts, so that you can continue writing on the back if you need more space.

We make the papers due at the end of each day so that you aren't tempted to spend time at home writing beautiful reports, and so that we can turn back graded work promptly. But if you need extra lab time to finish a given assignment, no problem — just let us know.

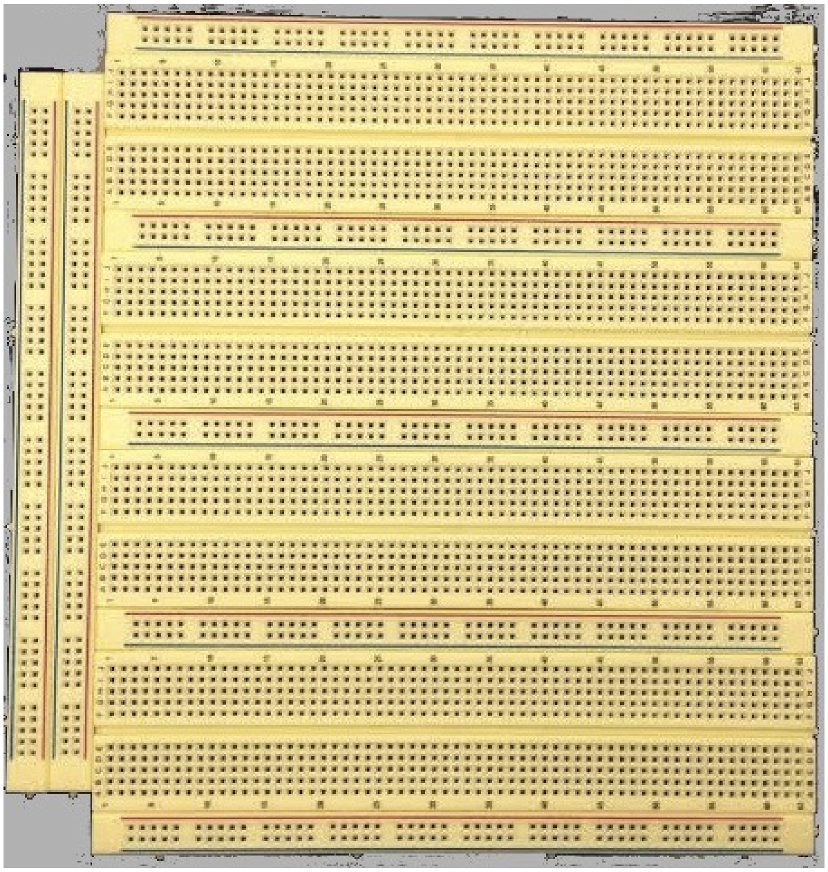
We will also ask you to note the time you start working on each section of the lab, so that we can adjust the pace of the course for the future. We want the pace to be quick, but still comfortable for you. If necessary, we'll make some parts of future labs be "optional/extra-credit." So don't worry if you don't quite finish all of today's lab.

Don't hesitate to ask your fellow students or the instructors for help in figuring out what to do in the lab! This is true every day, but especially on this first day, since you are starting off today without having read any background material. You can learn a lot from each other by discussing what you are doing as you go through the labs.

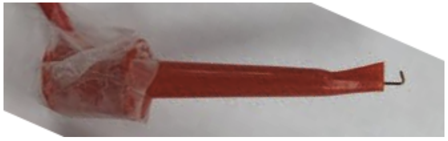
Part 1: beeping out the breadboard

Start Time: ________________

We will spend a good deal of the classroom time this semester building circuits on breadboards. The point of a breadboard is to hold the pieces of a circuit in place and to maintain desired electrical connections between components, simply by pressing the wire leads of components into suitably chosen holes on the breadboard. The breadboard follows a pattern in which many adjacent holes are electrically connected to one another on the back side of the breadboard. Your first assignment is to decode this pattern.



Use the Amprobe hand-held meter (shown above-left) to figure out which holes in the breadboard (shown above-right) are internally electrically connected to one another. The easiest way to connect the meter to the breadboard is to use cables that have a "banana" connector on one end (left photo below) and a spring clip (right photo below) on the other end.



The convention is to use a black cable in the meter's **COM** ("common") receptacle and a red cable in the meter's **VΩ** (for measuring volts or ohms) receptacle. Use your wire strippers to strip about 0.5 cm of insulation off each end of a short (maybe 5 cm) piece of red wire and a short piece of black wire, and grab one end of each wire with the spring clips on the corresponding cable. Then you can stick the free end of each little wire into a hole on the breadboard. If you turn the meter's dial to the **Ω** ("ohms") position (three clicks from the left), it will report the resistance, in ohms, measured between the two cables. With the wires separated, the meter should read "O.L" for "overload" (meaning very large resistance), and with the wires touching one another, the meter should read a fraction of an ohm. Try it.

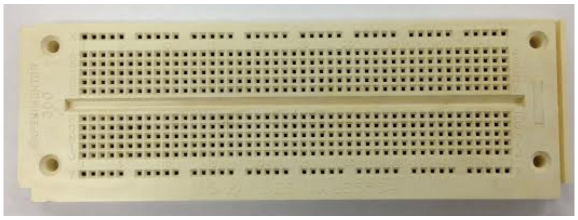
Reading with wires touching each other: ________________________

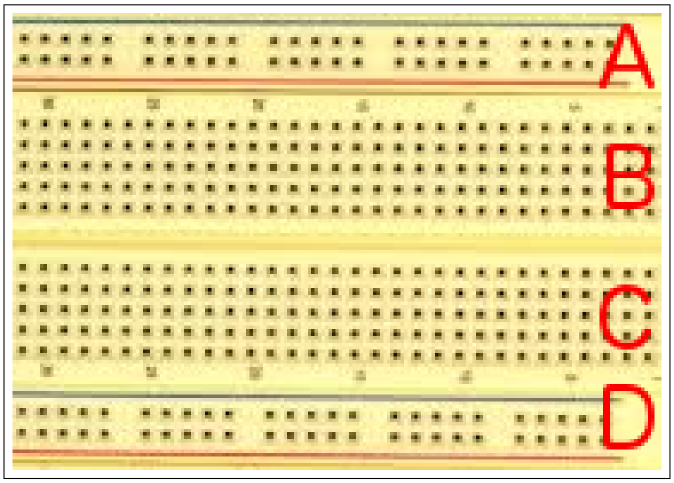
Reading with wires not touching: ________________________

Try plugging the wires into adjacent holes on the breadboard until you find at least one pair that is internally connected and at least one pair that is not internally connected.

Now press the yellow button on the meter to enable "beep" mode, also known as continuity-testing mode. Listen to the meter as you touch the wires together. This mode is handy for probing what is connected to what, as you can focus your eyes on the breadboard and let your ears read the meter.

As a hint about what is connected to what inside the breadboard, the two photos below show the front and back sides of a small section of breadboard. You can see the horizontal and vertical strips of metal that wire some rows and some columns together.

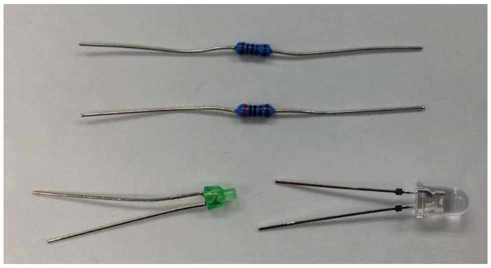




Now probe a section of the breadboard with the two wires that are connected to your meter, and work out the pattern of which holes are connected to which other holes. **Draw lines on the figure at right to indicate which holes are internally connected together in regions A, B, C, and D.** You can stop once you've drawn enough lines to make it obvious to us that you see the pattern.

Part 2: decoding and measuring resistor values   Start Time: ____________

The top-left drawer on your workbench, labeled "current lab components," should contain three LEDs (Light-Emitting Diodes) and about five resistors. The left photo below shows two resistors on top and two side-by-side LEDs on the bottom. Notice that the resistors have stripes. The right photo below is a close-up of one resistor.



Unless you're looking at this handout online, you can't read the colors. From left to right on this resistor (above-right photo), the stripe colors are yellow, violet, green, black, brown. The brown stripe on the right is wider than the others. The color code is

0	1	2	3	4	5	6	7	8	9
black	brown	red	orange	yellow	green	blue	violet	grey	white

My 8th-grade science teacher, whose first name was Roy, made us memorize the funny name "ROY G. BiV" for the colors of the rainbow. So my mnemonic for resistor colors (which skip "indigo") is to count on my fingers as I say, "black brown ROY G BV grey white."

The five stripes on the pictured resistor read **4, 7, 5, 0, 1.** The wide brown ("**1**") stripe on the right means "1% tolerance" i.e. the measured resistance should lie within ±1% of the labeled value. The next-to-right stripe (black = **0** on this resistor) is the exponent. So the pattern **4, 7, 5, 0, 1** is decoded as $\mathbf{475} \times 10^{\mathbf{0}} \ \pm \mathbf{1}\%$, which is 475 Ω. If the exponent stripe were red (instead of black), for example, then we would have $475 \times 10^2 = 47.5$ kΩ.

(Resistors with 5% and 10% tolerance are in widespread use. They will have only four bands, not five, and the color of the right-most band will be gold for 5% or silver for 10% tolerance. But in Physics 364 we will mostly use 1% resistors.)

For each of the five resistors in your "current lab components" drawer, first record the colors, then decode them to read the nominal resistance, then finally measure the resistance with the Amprobe hand-held meter in "ohms" (**Ω**) mode. The easiest way to do this is to grab the two ends of each resistor with the spring clips.

This will be pretty boring after the first couple of resistors, but you only have five resistors to measure! And it gives you a chance to check your understanding of the resistor code (which you'll use again and again this semester) and to check that you understand how to read the resistance displayed by the meter. **(Space provided on next page.)**

color pattern	**labeled resistance**	**measured resistance**

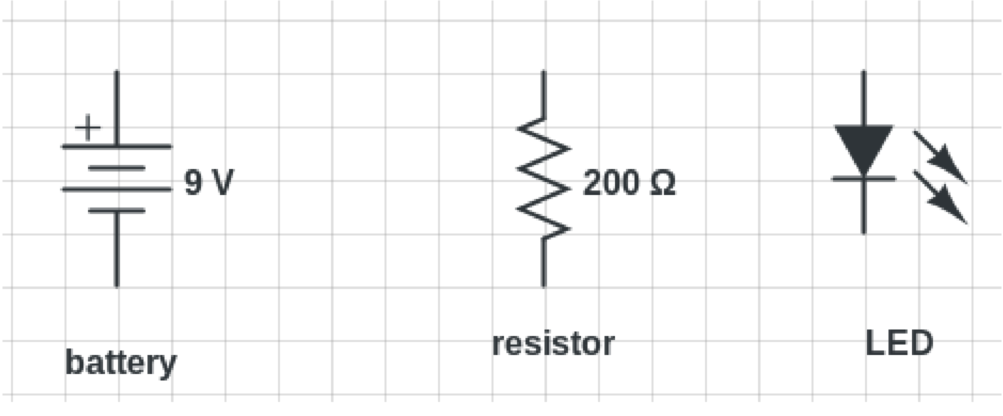
Part 3: first circuit **Start Time:** ____________

Next you'll use the breadboard to build your first circuit, which will consist of three components in series: a 9-volt battery, a 200 Ω resistor, and a red LED. A convention used in low-voltage electronics is red wires for positive voltage and black wires for ground (nominally "ground" means zero volts w.r.t. Earth's surface). So if the wires on your battery holder have been soldered in the conventional way, the battery should maintain the red wire at a higher potential than the black wire, with a potential difference that is nominally 9 volts.

Start by putting your Amprobe hand-held meter into "DC volts" mode. (You want the "**V**" with a straight line, two clicks from the far left. The "**V**" with a squiggly line, one click from the left, is for measuring sinusoidal (AC) voltages.) Use the meter to measure the battery voltage, when nothing (except for the meter) is connected to it.

battery voltage (no load): ____________

The figure below shows the schematic symbols used for a battery, a resistor, and a Light-Emitting Diode, respectively. While the resistor is symmetric (behaves the same way when connected backwards), the battery and LED are not. The convention for LEDs is that the longer lead is the positive side. The LED's schematic symbol, as drawn below, shows the positive side on top. If you connect an LED backwards, no current will flow through it.



In the space below, draw a schematic diagram for a circuit in which the battery, the 200 Ω resistor, and the red LED are all connected **in series**. Try to orient the battery and LED symbols such that the LED will light up. Check with your neighbors to see if you all have similar diagrams! **(Draw your schematic diagram in the space below.)**

Now use the breadboard to wire up the physical circuit corresponding to your diagram. While this circuit is simple enough that you could just twist the wires together, or make your lab partner hold the components together in the air while you measure them, we want you to get used to building circuits on the breadboard. A couple of weeks from now, you'll be building larger circuits, for which the breadboard really helps.

If you can (though this isn't always easy), try to arrange the components on the breadboard so that they at least vaguely resemble your schematic diagram. Once your circuits become more complicated, this habit will make it much easier for you to look simultaneously at your breadboard and your schematic diagram and to understand quickly what is going on.

Look around at a couple of your neighbors' breadboards and see if they have good ideas for laying out the circuit on the board. Or maybe you have a good idea to share with them. In any case, all successful designs should have the property that the LED actually lights up. If you accidentally leave out the resistor, you may find that the LED instead burns out!

Now use the Amprobe hand-held voltmeter to check the "loop rule" (a.k.a. Kirchoff's voltage law) for your circuit. **Draw your three measured voltages in on your schematic diagram.** Do the voltages add up as Mr. Kirchoff predicts? **(Your comment here.)**

Since you've already measured the resistance of the (nominally 200 Ω) resistor, you can predict the current flowing in your circuit. **What is your prediction?**

By the way, nearly all of the resistors we'll use this term have a $\frac{1}{4}$-watt power rating. That means they have a large enough surface area to dissipate 0.25 W into the surrounding air without becoming too hot. If you apply too large a voltage across the terminals of a resistor, so that the dissipated power is well above the resistor's power rating, the resistor can become hot enough to burn your fingers. So be careful!

Calculate the power now being dissipated in the $200\ \Omega$ **resistor in your circuit.**

Calculate the largest voltage you can safely apply across the leads of a $100\ \Omega$**,** $\frac{1}{4}$**-watt resistor.**

Calculate the largest voltage you can safely apply across the leads of a $10\ \Omega$**,** $\frac{1}{4}$**-watt resistor.**

The largest voltages that we will routinely use in the lab are about ±15 V. **Calculate the smallest** $\frac{1}{4}$**-watt resistor across which you can safely connect 15 volts.** Keeping these numbers in the back of your mind may prevent you from burning your fingers!

Next, use the Amprobe meter to measure the current in your circuit. Measuring currents requires a different technique from measuring voltages: to measure a current, you have to interrupt the circuit so that the current you want to measure **flows through** the meter. To protect themselves from damage, most current meters include fuses that blow (i.e. become non-conducting) if too large a current flows through the meter. Also, the way a digital current meter actually works is to measure the voltage drop across a (small) known resistor.

(In Lab 2, we'll see the different principle by which an old-fashioned non-digital current meter works.) For all of these reasons, most multimeters require you to plug the meter's red cable into a different front-panel input when measuring current than when measuring voltage or resistance. Also, there are often two different current inputs: one for measuring small currents and one for measuring large currents. If you look at the yellow writing on the front of the Amprobe meter, you'll see a "**mA**, μ**A**" port that is fused for 400 mA, and a separate "**10 A**" port that is fused for 10 amps. Before measuring currents, you want to consider how likely you are to exceed the rated maximum. It's also a good habit to start out on the largest scale and then to work your way down, so that you're less likely to blow a fuse if a current is larger than you expect.

You've already calculated your circuit's current to be well under 400 mA, so you can safely use the milliamp setting. **Record your measured current, and compare with what you calculated earlier.** If the agreement is poor, ask for help.

By the way, the known resistance used by the Amprobe current meter on the milliamp scale is 10 Ω, according to its user manual. By about what fraction do you expect the presence of the current meter to affect the current that you are trying to measure? By much less than a percent? By roughly a few percent? By more than 10%? If you need help thinking about this, feel free to ask or to discuss!

Now, leaving the current meter in place, use the benchtop Tenma 72-1020 multimeter (with another pair of clip leads) to measure the battery voltage, the voltage drop across the 200 Ω resistor, the voltage drop across the LED, and finally the voltage drop across the Amprobe current meter. *On/off switch is on back of Tenma meter.* **(Your values here.)**

Does Kirchoff's voltage law still make sense? Is the voltage drop across the current meter consistent with the meter's stated resistance of 10 Ω on the milliamp scale?

Finally, here's some possibly fun physics. Try replacing the red LED with a green LED. Now try a blue LED instead. What are your measured voltage drops (across the LED) when you use a red LED? A green LED? A blue LED? Is there a simple explanation for which is largest and which is smallest? (Think "electron volts.") **(LED voltages and your comment.)**

Part 4: battery imperfections

Start Time: ______________

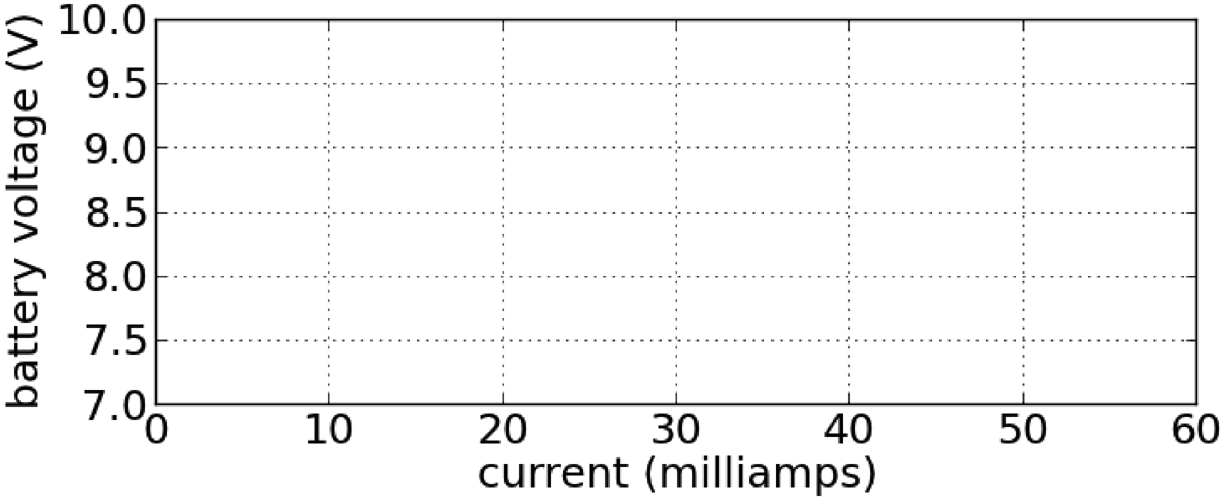
Now remove the LED and resistor, and measure the battery voltage when there is no current flowing through your circuit (except the tiny current that flows through your voltmeter). **(Your measured battery voltage.)**

Now connect in series the battery, the Amprobe current meter (which should still be set up to measure milliamps), and a single 10 kΩ resistor. Use the hand-held Amprobe meter to measure the current, and use the benchtop Tenma meter to measure the battery voltage. **Draw your circuit, including both meters, and record your results.**

Now replace the 10 kΩ resistor, successively, with a 2 kΩ resistor, then a 1 kΩ resistor, then 500 Ω, then 200 Ω. Fill in the table below.

resistance	**circuit current**	**battery voltage**
(open circuit)	0.0 mA	
10 kΩ		
2 kΩ		
1 kΩ		
500 Ω		
200 Ω		

Using your data above, make a rough graph (i.e. don't spend too much time on it) of battery voltage vs. the current that flows through the battery. Use the grid below to save time.



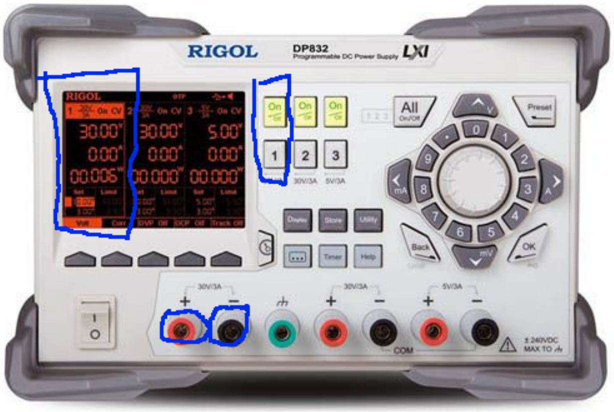
If you were to draw a straight line through your V-vs.-I data points, what (very roughly) would its slope be? What are the units of this slope? What is your interpretation of this non-zero slope? (Have you ever noticed that if you turn on your headlights before starting your car, the headlights dim while you engage the car's battery-powered starter-motor?)

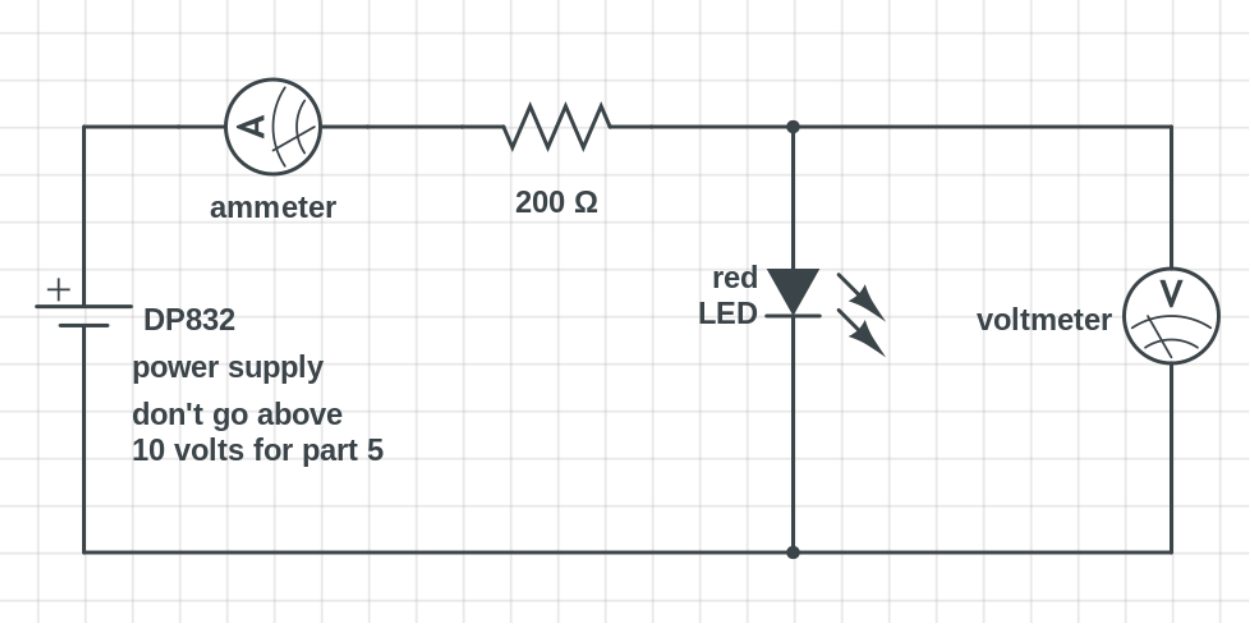
The 9-volt batteries used in today's lab are "heavy duty" batteries. You are probably more familiar with alkaline batteries. When we repeated the above measurement with an ordinary alkaline 9V battery, we found an intercept of 9.01 volts and a (downward) slope of 2.3 Ω.

Part 5: current vs. voltage for LED

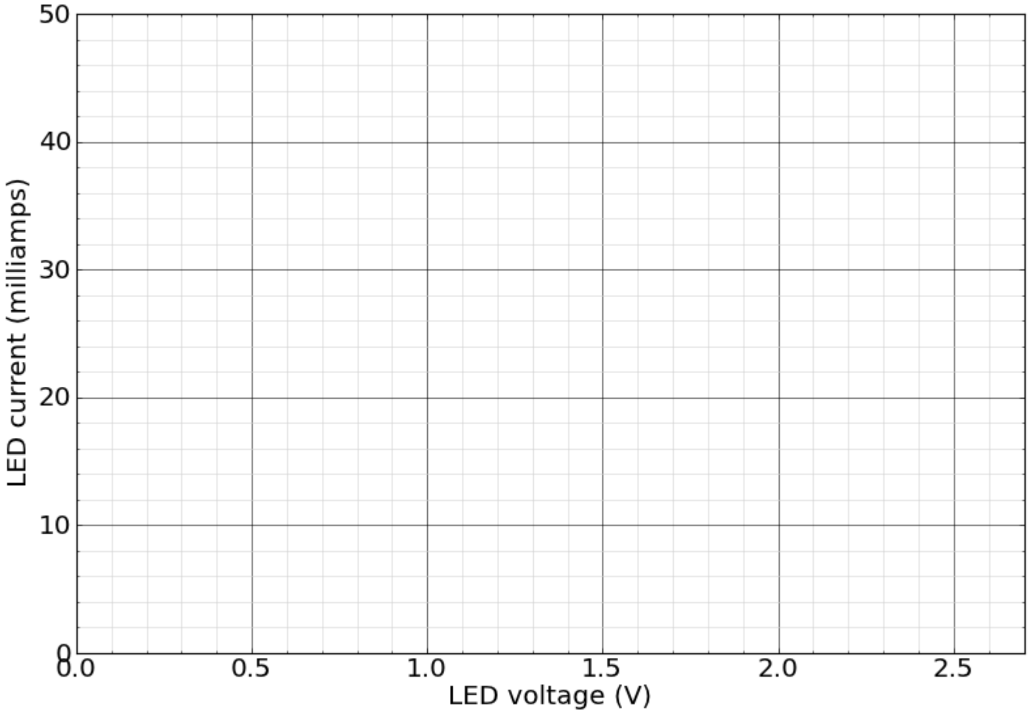
Start Time: ____________

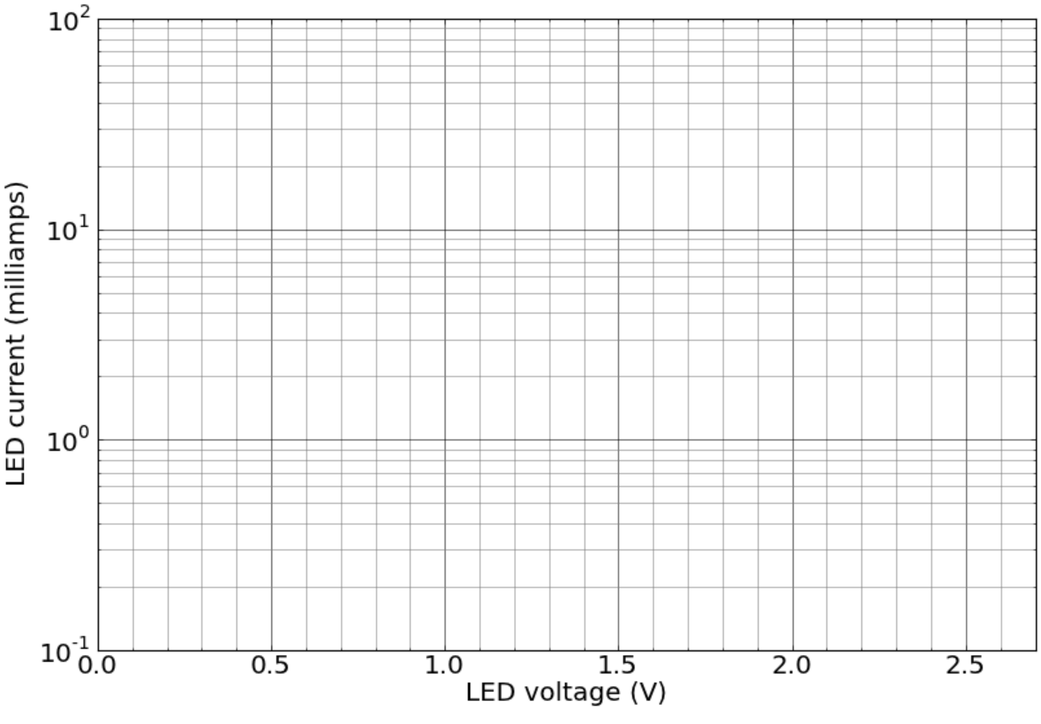
We'll introduce one more piece of lab equipment today: the Rigol DP832 benchtop power supply. (See photo below.) Unlike a battery, a benchtop power supply is essentially a "perfect" voltage source, meaning that the voltage provided by the output of the power supply does not decrease as the current increases, i.e. the slope of the power supply's V-vs.-I curve is negligibly small, as long as the current remains below the power supply's 3-amp current rating. Once this limit is reached, the power supply will reduce the supplied voltage such that the 3.0-amp limit is not exceeded. You can also program the power supply to set the current limit lower than 3.0 amps, e.g. to prevent a malfunctioning circuit from overheating.





Using Channel 1 (the left pair of outputs) of the power supply, wire up the circuit shown in the above schematic diagram. Use one meter to measure the current that flows through your circuit and the other meter to measure the voltage across the LED. Vary the power-supply voltage in the range 0–10 volts in whatever steps you need so that you can trace out the I-vs.-V curve of the LED. Try not to let the LED current get too far above its 30 mA rated maximum, so that you don't cook the LED. On the graph below, plot the current that flows through the LED **as a function of the voltage across the LED**. The 200 Ω series resistor will cause the voltage drop across the LED to be smaller than the power-supply voltage. We've included the resistor here to make it a bit harder to cook the LED. (Once you've mapped out the shape of the curve, you'll see why it is so easy, without the resistor, to burn out an LED.) Just collect enough points to see the shape of the curve. We've provided both linear and semi-log scales for your graphing.



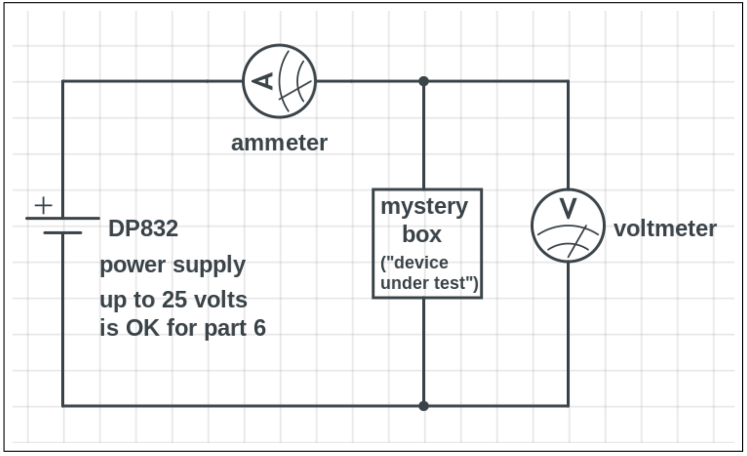


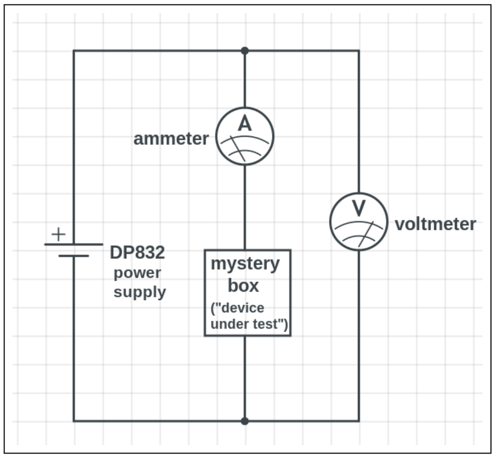
How would you describe the shape of the LED's current-vs.-voltage curve? (It's a one-word answer — a function that occurs quite often in physics!)

Can you guess what might happen **(but don't do it!)** if you were to put 5 volts directly across the diode? (Hint: power = current × voltage.)

Part 6: mystery boxes **Start Time:** ____________

Now that you are set up to measure I vs. V, measure several points (just enough to see the shape of each curve) for the I-V curve for each of the two "mystery boxes" labeled "**A**" and "**B**." (There should be at least 5 copies of each of the two types of mystery box.) These mystery boxes won't need the 200 Ω resistor for protection, because they won't exhibit the exponential behavior you saw in Part 5. There are actually two sensible ways you could make your measurements, both shown below.





You really want to measure the current that flows through the mystery box vs. the voltage across the mystery box. If you use the setup on the left, what are you assuming about the current that flows through the voltmeter? If you use the setup on the right, what are you assuming about the voltage drop across the ammeter? **(Your thoughts — briefly!)**

For today's two mystery boxes, it won't matter which of the two configurations you choose. But we'll see next time that if the resistance of the "device under test" is very small (on the order of 1 Ω), then you need to account for the non-negligible voltage drop across the ammeter, and if the resistance of the D.U.T. is very large (on the order of 10 MΩ), then you need to account for the non-negligible current through the voltmeter. This is because the internal resistance of a current meter (for modest currents) is typically on the order of 1 Ω, and the internal resistance of a digital voltmeter is typically 10 MΩ.

OK, on to the mystery boxes! Remember to try both positive and negative voltages, because not all devices' I-V curves are symmetric. You can safely apply up to 25 V to each box. One of the two boxes will have an I-V curve whose shape is so boring that it should be quite easy to guess what's inside. The other box, whose curve should be quite unusual, contains a device that we'll encounter again in a future lab. Once you're done, you can look inside. Can you identify (some or all of) the contents?

Graph both curves on this grid, and label them "box A" and "box B." For the box whose curve has a very simple shape, see if the slope of the curve seems roughly consistent with what you see inside the box.