Physics 222
Lab Physics for Science & Engineering II
Experiment Name: Circuit Fundamentals

THEORY

Purpose

Students will build basic circuits to explore the effects of several electronic components. Proper usage of the digital multimeter and DC power supply will be introduced.

Voltage, Current, and Resistance

-- *Voltage* –

When referring to circuits, the electric potential difference ΔV between two points is often referred to as the voltage between those two points. The S.I. unit is volt, abbreviated V.

-- *Current* --

Current refers both to the qualitative motion of charged particles, ex: “After connecting the battery, there was a clockwise current in the circuit” and the rate at which charge passes through some area, ex: “The current through the resistor is 5.00 milliamps”. The S.I. unit for current is ampere, which is equivalent to a coulomb per second. Amperes are commonly called “amps” and abbreviated A. The direction of current is defined to be the direction that positively charged particles move (or would move if they could), so current flows from high potential to low potential.

-- *Resistance* –

If something has high resistance, that means it is difficult for charge to flow through it and the current will be small. The resistance of an insulator (like air or plastic) is usually so large that the current will be negligibly small, close to zero. The resistance of a short length of copper wire or other conductor is usually very small. Circuit elements called resistors are used to add resistance to a circuit. The S.I. unit for resistance is the ohm, abbreviated Ω.

-- *Relating All Three* –

A potential difference causes charged particles to want to move – in other words, voltage causes current. The resistance determines how large or small the current is overall and in different branches of the circuit – in other words, resistance regulates current.

A useful analogy involves gravity. The gravitational potential is proportional to height, so that the top of a mountain would be a point of high potential and a valley would be low potential. A stream of water would flow down the mountain, in the direction of decreasing potential. The rate at which the water flows is affected by the width and depth of the water channel and how much sediment is clogging up the stream. In this analogy, the difference in height between the top and bottom of the mountain is the voltage, the rate of water flow is the current, and the dimensions of the water channel and amount of sediment are the factors affecting the resistance.

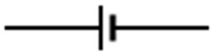
Electronic Components

Electronic components, also called “circuit elements”, are the devices used in circuits to manipulate electricity in specific ways. We will use several different components throughout our study of electrical circuits. They will be listed along with their symbols and a brief description here. Some of these components are intrinsically polarized, which means that plugging them into the circuit backwards will damage them. **You MUST be conscientious when plugging polarized components into your circuit!**

-- *Resistor*--

A resistor is a conductor that is manufactured to provide a specific resistance when placed in an electrical circuit. The amount of resistance that a resistor provides is usually denoted on the resistor by three bands of color, called the “resistor code”. (A fourth gold or silver band denotes the tolerance of the resistor.) In the near future, we will learn to decipher this code. For now, the colors for a certain resistance will be given in the procedure. You may also measure the resistance of a resistor with your ohmmeter.

-- *Voltaic Cell (Battery)* --



The symbol that you see above is the symbol for a “Voltaic Cell”, which contains a chemical reaction designed to produce an electrical potential difference between two metallic plates (a positive “anode” and a negative “cathode”) in a very reproducible way. When these cells are connected in series, it is called a “battery” (or, in some literature, a “pile”). In this course, we will use the above symbol to represent any direct current (DC) voltage source; this could be a Voltaic Cell, a battery, or a DC power supply. **Note that the negative side of the cell is depicted on the right-hand side in the above symbol.**

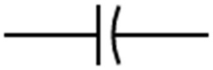
-- *Incandescent Light Bulb* --

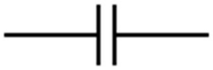
An incandescent light bulb consists of a very fine, thin wire called a “filament” inside an evacuated glass bulb. When electrical current is passed through the filament, it becomes so hot that it glows. The symbol above is used to denote an incandescent bulb in circuit diagrams.

-- *Light-Emitting Diode (LED)* --

A light-emitting diode (LED) is a semiconductor device in which, when a voltage is applied, electrons are allowed to fall into lower energy “holes” (a place with a missing electron). When the electron falls into a hole it loses energy, which is emitted in the form of light. **Note that LEDs are polarized, and must not be plugged into the circuit backwards. The negative side of the LED is on the right-hand side as depicted in the above symbol.**

-- Capacitor --





Both of the symbols above are used to denote capacitors. The symbol on the left-hand side depicts a polarized capacitor, while the symbol on the right-hand side depicts a non-polarized capacitor. A capacitor is a device which stores electrical potential energy (short-term) as a potential difference between two separated conducting plates. **Note that our capacitors are polarized, and must not be plugged into the circuit backwards. The negative side of the capacitor is depicted by the curved line in the above symbol.**

-- Jumper --

A "Jumper" is the word that we will use for a piece of wire with negligible resistance that can fill in the discontinuities on your circuit board.

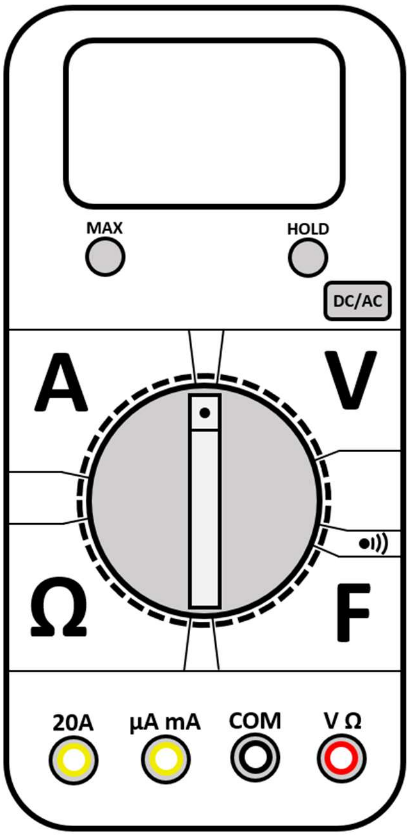
Series vs. Parallel

When electronic components are in series, there is only one path through which the current can flow. This means that the current will be the same through components in series, while the voltage will change.

When electronic components are in parallel, the current will split between the multiple parallel branches. This means that the current will differ between components in parallel. However, because each parallel component will be connected across the same potential difference, the voltage will be the same.

Using the Digital Multimeter (DMM)

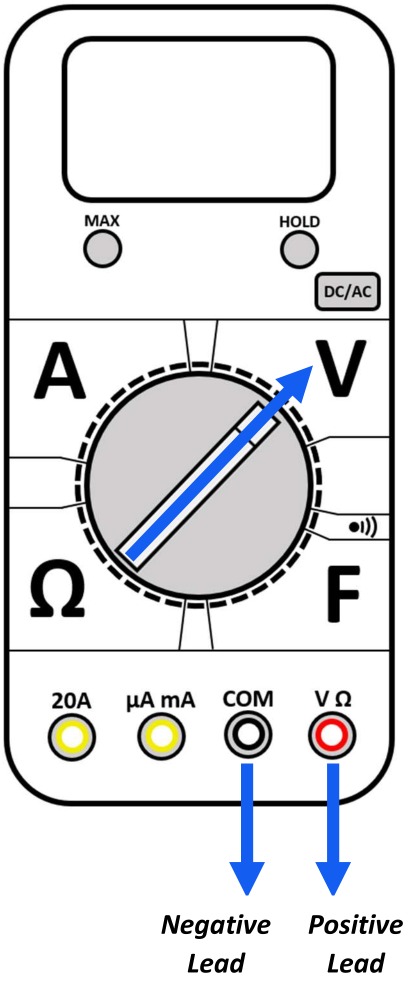
The Digital Multimeter (DMM) is a tool for measuring and analyzing many different characteristics of an electrical circuit. The DMM that we will use in this course is the **BK Precision 388B**, which is depicted below.



In this experiment, we will use four of the multimeter's functions. We will use its voltmeter (V), ammeter (A), ohmmeter (Ω), and continuity tester (●))). You can change the function of the DMM by rotating the "Function/Range/Power Switch" (What we will colloquially call the "center dial") to the desired setting. You must also ensure that your wire leads are plugged into the appropriate input jacks at the bottom of the DMM (**20A**, **μA mA**, **COM**, and **V Ω**).

-- Voltmeter –

The voltmeter will be used to measure the voltage across components in our circuit. **When measuring voltage, it is crucial that the voltmeter ALWAYS be placed in PARALLEL to the ΔV that you are measuring!** ***In other words, you will always measure voltage ACROSS a circuit element, and never through it!*** The dial on the voltmeter should be set to the lowest voltage setting that is still larger than the voltage that you wish to measure. The schematic symbol for a voltmeter is given above. The picture below depicts the correct set-up for using the DMM as a voltmeter.

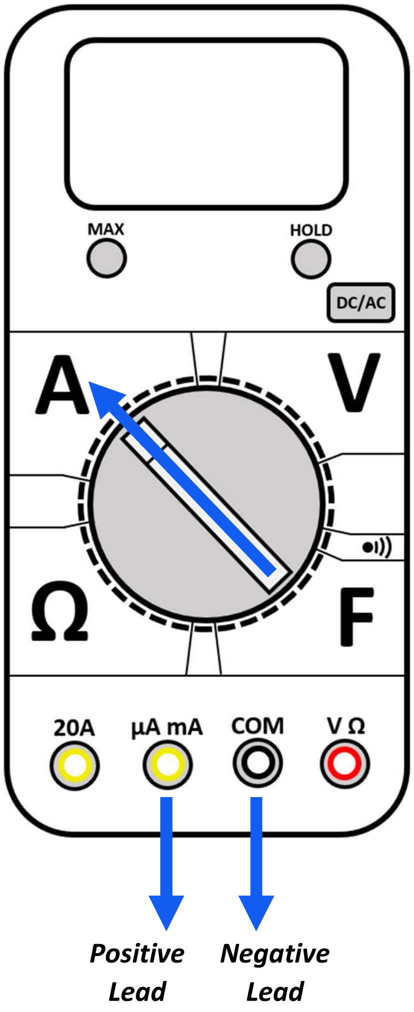


The relevant specifications for direct current (DC) voltage measurement settings for this course are:

Range	Resolution	Accuracy
400 mV	100 µV	± (0.5 % rdg + 1 dm)
4 V	1 mV	
40 V	10 mV	
400 V	100 mV	
1000 V	1 V	

-- Ammeter --

The ammeter will be used to measure electrical current through components in our circuit. **When measuring current, it is crucial that the ammeter ALWAYS be placed in SERIES with the current that you are measuring! In other words, you will always measure current THROUGH a circuit element, and never across it!** The dial on the ammeter should be set to the lowest current setting that is still larger than the current that you wish to measure. The schematic symbol for an ammeter is given above. The picture below depicts the correct set-up for using the DMM as an ammeter. **When measuring current using the depicted input jacks, you must never exceed 2 amps!**

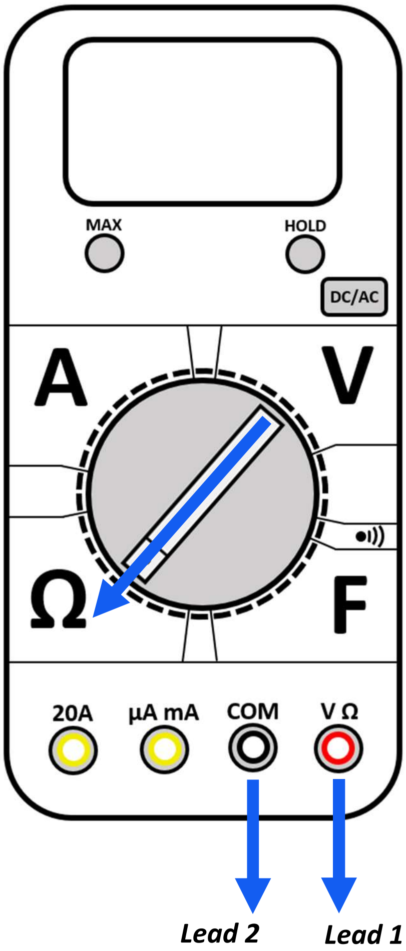


The relevant specs for DC current measurement settings for this course (using the **µA mA** jack) are:

Range	Resolution	Accuracy	Burden Voltage
400 µA	0.1 µA	± (1.0 % rdg + 1 dgt)	600 mV max.
4 mA	1 µA		
40 mA	10 µA		
400 mA	100 µA		
2000 mA	1 mA	± (2.0 % rdg + 1 dm)	900 mV max.

-- Ohmmeter --

The ohmmeter will be used to measure the electrical resistance of components in our circuit. The dial on the ohmmeter should be set to the lowest resistance setting that is still larger than the resistance that you wish to measure. In this experiment, you will only use the ohmmeter to measure the resistance of individual resistors. The schematic symbol for an ammeter is given above. The picture below depicts the correct set-up for using the DMM as an ohmmeter.



(As there is no "negative resistance", the polarity of the leads does not matter.)

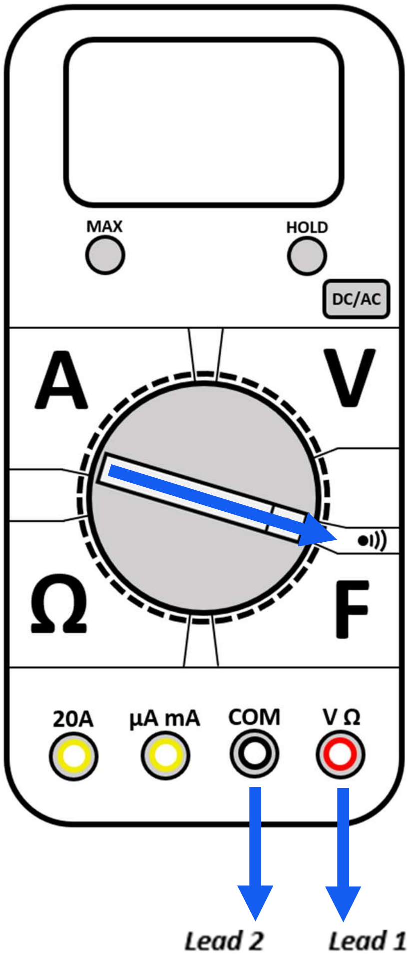
The relevant specifications for ohmmeter settings for this course are:

Range	Resolution	Accuracy
400 Ω	0.1 Ω	± (1.0 % rdg + 4 dgts)
4 kΩ	1 Ω	± (0.75 % rdg + 4 dgts)
40 kΩ	10 Ω	
400 kΩ	100 Ω	
4 MΩ	1 kΩ	
40 MΩ	10 kΩ	± (2.0 % rdg + 5 dgts)

-- Continuity Tester --

The continuity tester is denoted by the symbol: •))

The continuity tester is in essence an Ohmmeter, which measures resistance. It is, however, specifically for measuring small resistances which are oftentimes negligible. If you want to determine if there is a continuous electrical connection between two points, you can place the continuity tester in parallel to those two points. If the resistance between those two points is less than 100 Ω, an alarm will sound. The picture below depicts the correct set-up for using the DMM as continuity tester.



(As there is no "negative resistance", the polarity of the leads does not matter.)

Using the Power Supply

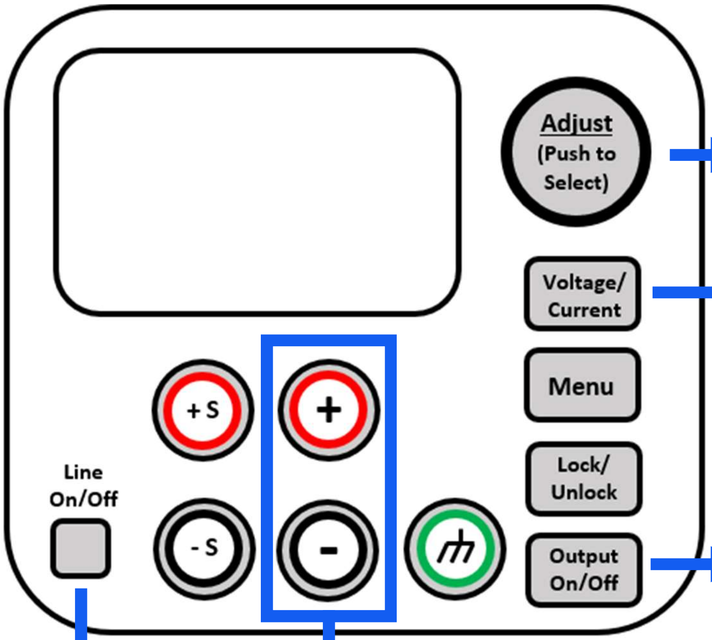
The power supply that we will use throughout our study of electrical circuits is the **Keysight E36104B**. It is a direct current (DC) power supply in that it takes the alternating current (AC) supplied by a common household electrical outlet and converts it to DC for use in the types of circuits we will build. Using a power supply to provide DC voltage is much more convenient for the study of electrical circuits than using a battery for two significant reasons:

1) The chemical reaction in a battery slows down and wears out as it is being used. This degradation results in a loss of voltage over time.

2) A power supply is easily tunable to whatever voltage/current is needed for a given application. Most chemical voltaic cells only produce approximately 1.5 volts. This includes many standard "battery" sizes such as AA, AAA, C, and D. (A "9-volt" is a true battery or "pile" because it consists of 6 internal voltaic cells connected in series. A 12-volt car battery contains 8 cells.)

   If we were to use batteries to supply a needed voltage (e.g. 24.3 V) it would require a long chain of cells connected in series, as well as "voltage dividers" to achieve the required results with any degree of accuracy.

The Keysight power supply is depicted below with the purpose of several controls described:



"Adjust" Knob
Turning this knob will change a selected digit value of the output current *or* voltage from the positive and negative terminals. Pressing the knob like a button will allow you to select which digit is being changed.

Voltage/Current Selector
Pressing this button will switch the "Adjust" Knob between affecting the current output and affecting the voltage output.

Output On/Off
Pressing this button will turn the output voltage between the positive and negative terminals on and off without shutting down the entire power supply.

Positive and Negative Terminals (Output)
Use these terminals to supply voltage to your circuit via wire leads.

Menu and **Lock/Unlock**
Students should not need to press these buttons during any experiment in this course.

Line (Main) Power Switch
This button turns the entire power supply on and off. In general, this should be turned on at the beginning of the experiment and turned off at the conclusion. ***Use this to kill power should you detect a "burning" smell!***

Power Supply Safety

The Keysight E36104B power supply has numerous safety features which make it ideal for use in our lab setting. These features include built-in overvoltage and overcurrent protection as well as built-in overtemperature protection. These features together, along with the maximum possible power output being 35 Watts (maximum 35 Volts at a maximum of 1 Amp), should provide reasonable barriers against the more serious hazards that come from working with electricity.

However, these power supply safety features will **only** protect persons and property from harm or damage…

IF AND ONLY IF EACH STUDENT CAREFULLY FOLLOWS THESE SAFETY RULES
as well as **THE POWER SUPPLY USAGE DIRECTIONS FOR EACH EXPERIMENT!**

The following general safety rules will be in force anytime a power supply is used throughout the semester:

1) If the power supply output should **NEVER** be ON when unconnected wire leads are "dangling" from the output terminals and resting unconnected on the lab bench!

2) There will be no liquids on or around the lab benches when power supplies are present. This means:

    A) There will be **NO DRINKS** on or around the lab benches.

    B) Hands and Arms **MUST** be **COMPLETELY DRY** when using the power supply or handling the circuit.

    C) If there is a spill of any kind on or near your circuit or power supply, **DO NOT TOUCH THE CIRCUIT, POWER SUPPLY, OR PUDDLE**. Notify your TA **IMMEDIATELY**!

3) Do not allow papers or other clutter to accumulate on or near the power supply or circuit. This is a **FIRE HAZARD**.

4) If you must move the power supply, pick it up by its handle, but **DO NOT lift it more than ONE INCH** from the lab bench surface. A dropped power supply could be internally damaged, making it **DANGEROUS** to use. If you do drop or in any way damage the power supply you are using, Notify your TA **IMMEDIATELY**!

5) Each week you will need to set the maximum allowable output current for your power supply. **EVERY TIME** you change this value, you **MUST get your TA's approval** before turning on the output voltage.

    Setting this value incorrectly could cause your circuit elements, wire leads, or circuit board to overheat, burn up, or even **CATCH ON FIRE**.

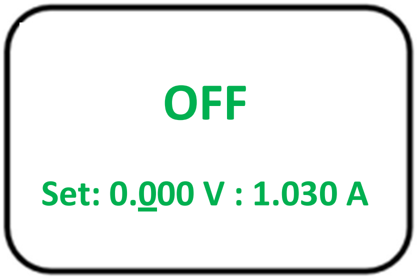
    It is normal for resistors to get quite warm or even slightly hot. For this reason, the resistor plugs should be gripped **only by the sides**, and not front to back. However, if you detect a "burning smell coming from your power supply or circuit OR you see any smoke coming from your circuit, **KILL THE POWER BY PRESSING THE "LINE (MAIN) POWER SWITCH"** and notify your TA **IMMEDIATELY!**

FAILURE TO FOLLOW THESE RULES WILL RESULT IN EJECTION FROM THE LAB AND A GRADE OF "ZERO" FOR THE WEEK!

Operating the Keysight E36104B the Power Supply

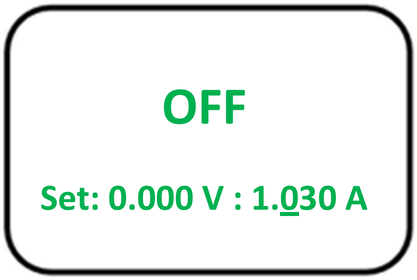
1) Before plugging in your power supply ensure that the **Line Power Switch** is in the **OFF** position. Once this is confirmed, plug the power supply into a wall outlet, and **only then** turn the Line Power **ON**.

2) The screen should look like:



The blinking line under the tenths place of the voltage value means that turning the **Adjust** knob will affect that digit. The voltage value that you set on this screen will be the *starting voltage* when you turn the output on. **There is no need to adjust the voltage at this time, so you should leave the starting voltage at 0.000 V.**

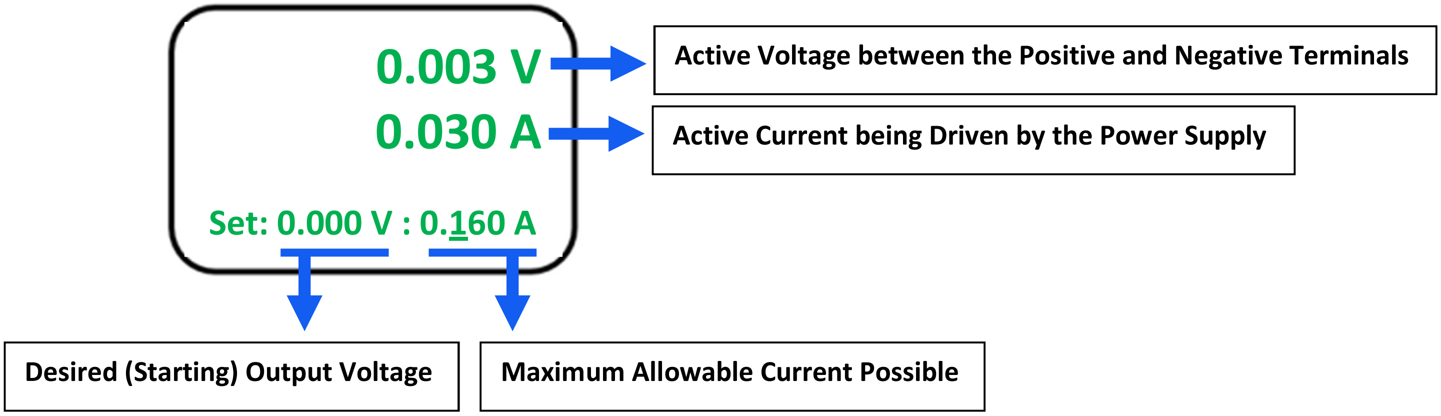
3) Press the **Voltage/Current** button to shift the blinking line to the current display. The screen should look like this:



With the blinking line now under the tenths place of the current value, you are ready to set the power supplies' **maximum allowable current**. Use the **Adjust** knob to set the maximum allowable current to the value given to you by the lab manual or your TA. **Press the Adjust knob like a button to control which digit you are affecting!**

BEFORE PRESSING THE "OUTPUT ON/OFF" BUTTON, YOUR TA MUST APPROVE YOUR CIRCUIT!

4) *Once your TA has approved your circuit* and you press the **Output On/Off** button, your screen will display the following (assuming the maximum allowable current was set to 0.160 A):



5) You should now press the **Voltage/Current** button to switch the **Adjust** button back to affecting the Desired Voltage. Press the Adjust knob like a button to change which voltage digit you are affecting.

   Most experiments will require you to vary the voltage in this manner.

   Do not press the Voltage/Current button again unless directed to do so by the lab manual or your TA!

PROCEDURE

Part 1: Inspecting the Circuit Board

The circuit board in front of you is not designed for practical, real-world applications; it is designed specifically to give you, the student, an understanding of basic circuitry and a straightforward platform for taking measurements this semester. There are 10 discontinuities on this circuit board where electronic components may be placed, as well as 12 wires to conduct electricity between those components.

1) Flip the circuit board over so that you can see how the discontinuities and wired connections are arranged. Draw a circuit schematic of this arrangement on your worksheet.

2) Review page 8 of this document and set your DMM to function as a continuity tester. Insert 12” wire leads into the appropriate input jacks.

3) Flip the circuit board right-side up. Using the DMM’s continuity tester, confirm that electricity can pass freely through the wired connections, and cannot pass through the discontinuities. If there are any problems with the circuit board, notify the TA.

Part 2: Measuring Resistance

4) Review page 7 of this document and set your DMM to function as an ohmmeter.

5) There are three resistors at your lab station; two 100 Ω resistors (Brown, Black, Brown), and one 22 Ω resistor (Red, Red, Black). Confirm by measurement that their resistance is relatively close to these nominal values by plugging them directly into the appropriate input jacks on the ohmmeter.

   Set the ohmmeter such that it displays the maximum number of sig-figs possible. Record these values on your worksheet. Include uncertainties with each measurement.

Part 3: Using the Power Supply

6) Review pages 9 – 12 of this document. With nothing plugged into the output terminals of the power supply, follow the directions on pages 11 – 12 to turn the power supply on.

   Set the desired voltage output to 0 V and the maximum allowable current to 0.160 A. **Do not change this current value for the remainder of the experiment!**

   Don’t turn on the output voltage yet!

7) Review page 5 of this document and set your DMM to function as a voltmeter. Using 12” wire leads, connect the output terminals of the power supply to the appropriate input jacks on the voltmeter.

8) After getting TA approval, turn on the output voltage.

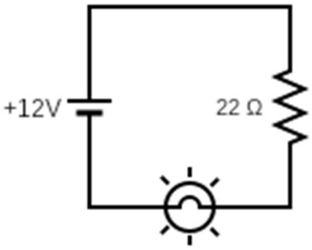
9) With the desired output voltage on the power supply still at 0 V, compare the reading on the voltmeter to the active voltage display on the power supply. How do they compare? Can you measure more sig-figs with the voltmeter or off of the power supply display? (Make sure you are using the best voltmeter setting!)

10) Use the Adjust knob on the power supply to vary the output voltage. Note how the voltmeter responds, and how the various voltmeter settings measure the different voltages.

Part 2: Lighting the Light (of Knowledge)

-- *Circuit 1* --

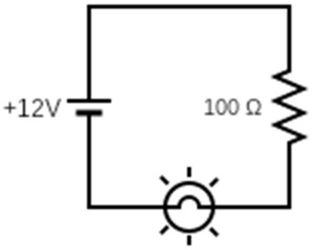
11) Build a series circuit on your circuit board consisting of a 22 Ω resistor (Red, Red, Black), a light bulb, and the power supply. You will need at least one wire jumper to complete ("close") the circuit!



12) What do you observe when you close the circuit by turning on the power supply output? Give qualitative reasons for the effect(s) you observe.

-- *Circuit 2* --

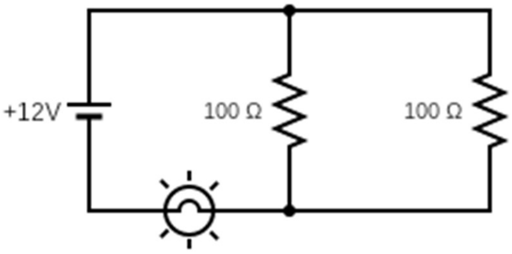
13) Remove the 22 Ω resistor and replace it with a 100 Ω resistor (Brown, Black, Brown).



14) What do you observe when you close the circuit? How does this differ from Circuit 1? Give qualitative reasons for the effect(s) you observe.

-- *Circuit 3* --

15) Add a parallel branch to Circuit 2 which includes an additional 100 Ω resistor.



16) What do you observe when you close the circuit? Give qualitative reasons for the effect(s) you observe. (You may want to insert and remove the second resistor several times while observing.)

17) Recall that: **VOLTAGE IS ALWAYS MEASURED IN PARALLEL!**

    Using the voltmeter, measure and record the voltage drops across each parallel resistor. How do these voltage drops differ? Does this make sense? Based on the behavior of the light bulb, does this mean that the equivalent resistance of resistors in parallel is higher or lower than their arithmetic sum?

18) What do you predict would happen if we continued to add additional parallel 100 Ω resistors? What do you predict would eventually happen to the bulb if we continued to add more and more parallel 100 Ω resistors?

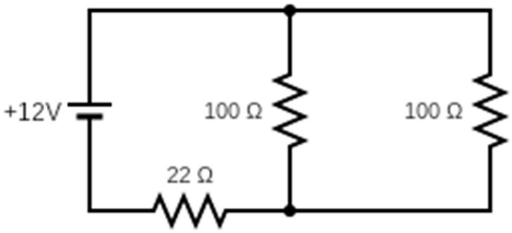
19) Simulate the bulb burning out by removing it from the circuit board. Measure and record the voltage drops across each parallel resistor. How does this remind you of a fuse or circuit breaker?

-- Circuit 4 --

20) Review page 6 of the document and set your DMM to function as an ammeter.

21) Recall that: **CURRENT IS ALWAYS MEASURED IN SERIES!**

    Plug the 22 Ω resistor where the bulb used to be. Measure and record the current flowing through all 3 resistors. Use the ammeter setting that provides the maximum number of sig-figs. Include uncertainty with each measurement!



22) Looking at the schematic, visualize the electric current as something analogous to water that is flowing through the circuit. Using this model, can you make quantitative sense of the current measurements that you took? How do the three current measurements relate to each other?