Ohm's law

Purpose

- To show that the observation called Ohm's law holds for resistors

- To verify formulae for single resistances that are equivalent to resistors in series and in parallel

- To examine the effect of 'grounds'

Equipment

- ♦ Resistors of approximately 8.2 kΩ, 27 kΩ and 100 kΩ that are attached to dual binding-posts
- ♦ 2 Digital Multi-meters
- ♦ 3 pairs of 12 inch banana-to-banana leads (stackable)
- ♦ 1 pair 36 inch banana-to-banana leads (stackable)
- ♦ DC power supply

Verify that you have all of the equipment listed. Notify your TA if anything is missing.

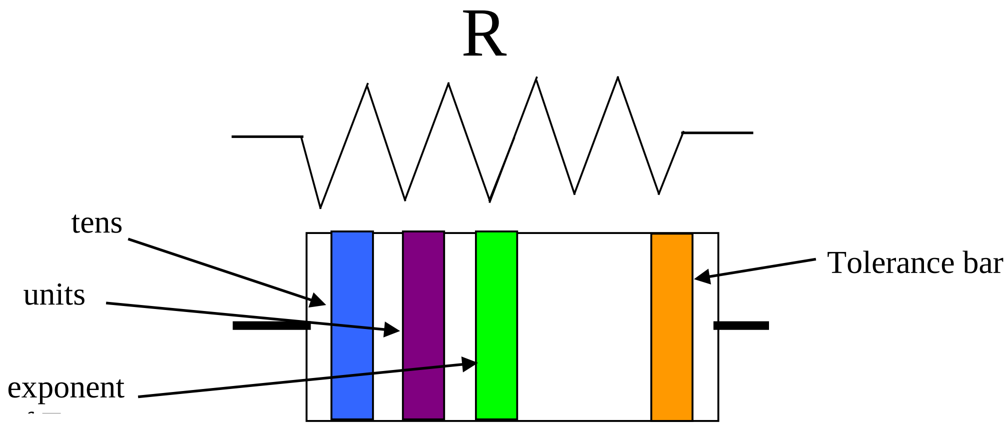
Introduction

In this lab experiment you will build simple circuits and verify a fundamental relationship known as Ohm's law. This law is an observation for a certain class of substances and concerns the resistance that they offer to the flow of current. Suppose that current I flows through a piece of wire. The electric potentials at the ends of the wire are $V_A$and V_B so that the difference in potential across the wire is $\Delta V = V_B - V_A$. The resistance of any substance is <u>always</u> defined by,

$$R \equiv \frac{\Delta V}{I}.$$

<u>Ohm's law states that the resistance is constant</u> (assuming that the temperature of the conductor carrying the current is kept constant). G. Ohm observed this behavior only for pieces of wire. However, the observation holds more widely and any substance that obeys Ohm's law is said to be <u>ohmic</u>. Lengths of wire are ohmic while semi-conductors are generally non-ohmic. A resistor is a device that offers a certain resistance and can be as simple as being a length of wire. A film of carbon provides the resistance in the resistors that we use. This carbon film is encased in a ceramic cylinder. Leads come from either end.

Resistor Color Codes



Resistors often have four colored bars. The tolerance bar is separated from the others. The resistor should be held so that this bar is at the right. The tolerance bar is gold in the diagram above. The colors of the first three bars on the resistor give the (nominal) resistance of the resistor as follows:

Black	**0**
Brown	**1**
Red	**2**
Orange	**3**
Yellow	**4**
Green	**5**
Blue	**6**
Violet	**7**
Gray	**8**
White	**9**

The first three bars on the resistor pictured above are blue, violet and green. The corresponding numbers are 6, 7 and 5 and the resistance is $67 \times 10^5\ \Omega$. This is the ***nominal*** resistance and is the resistance that the manufacturer intended to produce. The tolerance bar is the claim that the nominal resistance is accurate up to a certain degree. If the tolerance bar is silver then the actual resistance of the resistor is expected to be within 10% of this nominal value. The tolerance bar may also be gold [in which case, the actual resistance is expected to be within 5% of the nominal resistance] or may be absent [in which case, the actual resistance is expected to be within 20% of the nominal resistance].

Because the nominal resistance differs from the actual resistance, use the color bars only as a guide to the resistance of a resistor. In calculations, use the measured resistance rather than the nominal one if accuracy is important.

Ohm's law

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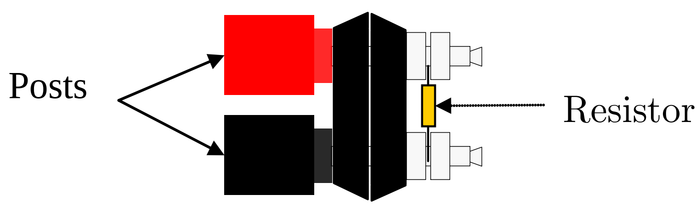
In order to see if a substance (such as a resistor) actually behaves as Ohm described, we look at the definition of resistance: $R \equiv \frac{\Delta V}{I}$. If resistance is constant then the current flowing must be proportional to the changes in voltage. If we measure both the current through an object and the change in potential across it, then we can calculate the resistance and see if it changes. (Suppose that an object has potential P_1 at one end and potential P_2 at the other so that the voltage across the object is $\Delta V = P_2 - P_1$. This will cause a certain current I to flow. If we choose the potential such that it is zero at one end (say $P_1 = 0$) , then the voltage across the object is $P_2 - 0 = P_2$. In this case, voltage is the same as the potential. This is not just a numerical fluke: the same current I flows in each case so that there is no physical change in what is happening. But now we see that the potential (difference from zero) is the cause of current!)

We'll need a power supply to cause current to flow continuously, resistive substances (called 'resistors'), meters to measure voltage and current and bits of wire to provide conductive paths for current. The resistors are attached to binding posts:



These posts allow you to connect banana-to-banana cables to the ends of the resistors. (The posts are either red or black but these colors have no significance.)

In this experiment you will be using a power supply (of voltage V_S), a meter that is configured as an ammeter, a meter that is configured as a voltmeter and resistors. <u>Always take the DMM out of the circuit before changing its configuration</u>.

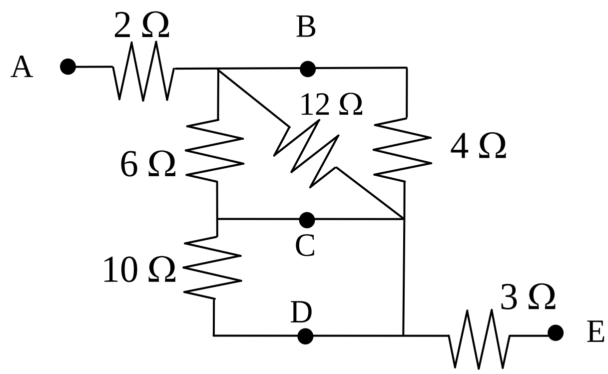
Combinations of Resistors

Resistors can be wired in parallel or in series with each other. Two circuit elements are wired in series if the current passing through one ***must*** pass through the other. Resistors are in parallel if the voltages across them is the same (because their ends are connected to each other). [It is worth recalling that you have seen both characterizations of series and parallel before. We used the words flow (current) and pressure (voltage) back then.

It is usually assumed that <u>pieces of wire are ideal conductors</u> in the sense voltage doesn't change across them [i.e. that wires have no resistance].

A resistor is kept at a constant temperature while current flows through it. The potential difference across the resistor is kept constant. **Someone says: "Current is used up as it moves through a resistor. Since we know $\frac{\Delta V}{I} = R$, then the resistance can't be constant". What is wrong? Explain. [2]**

Copy the following diagram into your pre-Lab. (In the following diagram, all wires are assumed to be ideal [and so have no resistance]).

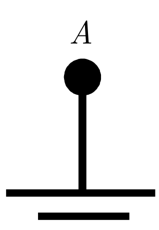


Find the resistances between the following points; (If you use any equations then write them with your answer.)

- **A and B [1]**
- **E and D [1]**
- **D and C (Give your reasoning.) [3]**
- **C and B (Give your reasoning.) [2]**
- **A and E (Give your reasoning.) [2]**

We use a battery to cause a continuous potential difference by getting charges to separate. **Explain why the terminals of a battery have to be connected together before current flows**. **[2]**

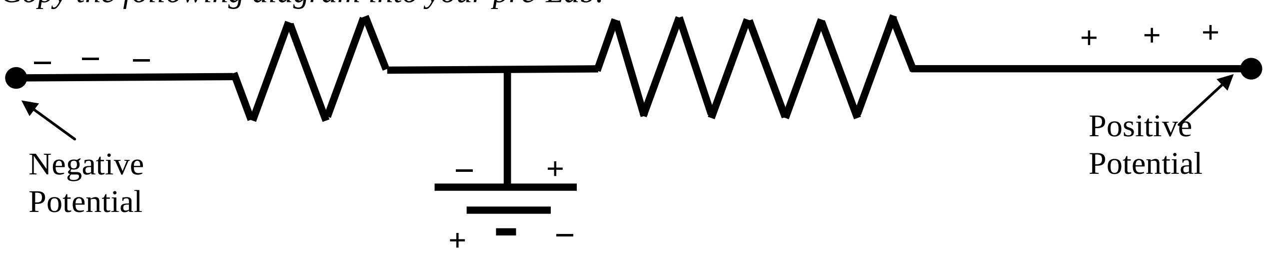
The symbol:



stands for a conducting path from point A to the ground. *The potential of ground is chosen to be zero*.

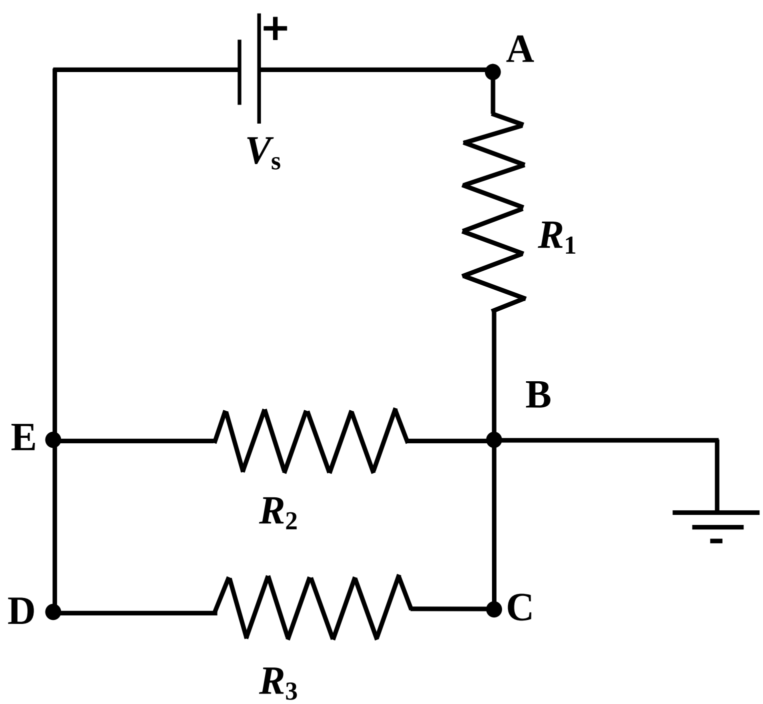
In the following diagram, the black lines represent (ideal) wires. An excess of positive charges are in the region labeled 'high potential'. Assume that this part of the wire always <u>*stays*</u> at high potential. An excess of negative charges are in the region labeled 'low potential'. The left end of the wire is maintained at this low potential.

Copy the following diagram into your pre-Lab.



The resistors are not of the same size. Draw arrows on the copy of this diagram **to show where positive charges will flow. [1]**

During the lab, you will build the following circuit. *Copy the following diagram into your pre-Lab.*



On the copy of this diagram in your pre-Lab, <u>draw arrows</u> <u>**beside the resistors**</u> R_1, R_2 **and** R_3 **to** <u>**denote the direction of (conventional) current through the resistors**</u>. **[3] In each case, explain why the current flows in the way you have drawn. [2]**

Instructions

Please copy the following table into your report:

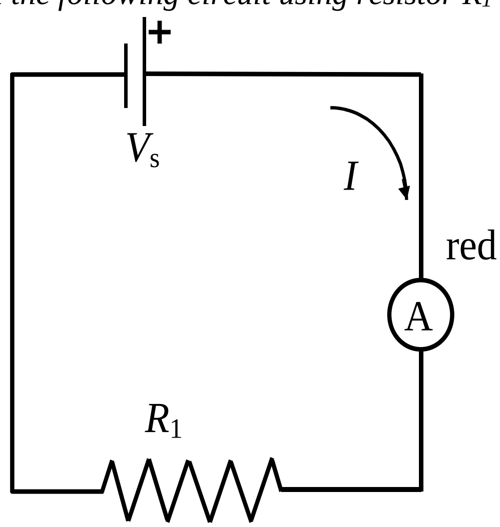
Table one

	Nominal resistance kΩ	Tolerance of the resistor	Measured resistance kΩ
R_1			
R_2			
R_3			

Use the color bars on your resistors to identify the resistor with the nominal resistance of 8.2 kΩ. This resistor is called R_1. ***Record the <u>nominal</u> resistance and tolerance of <u>R_1</u>*** **[1]** *Set the DMM to a suitable range for measuring R_1. Plug a red lead into the port labeled Volts & Ohms on the DMM. Plug a black lead into the port of the DMM labeled COM.* ***Measure the resistance of*** $R_1 \simeq 8.2\ \mathrm{k\Omega}$ ***and record it in table one in your report*. [1]**

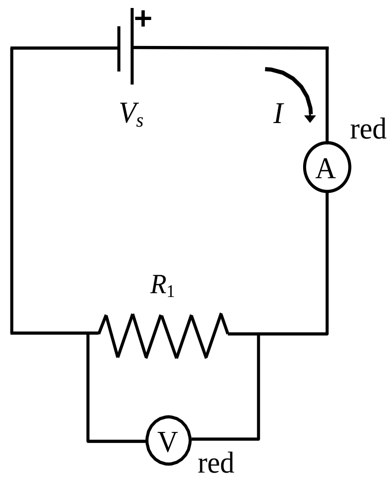
The nominal resistances of R_2 and R_3 are 27 kΩ and 100 kΩ. ***Fill in the remainder of the first table*. [2] Are the values you measured for each resistor within the indicated tolerance according to the color codes on the resistor? Show your calculations. [2]**

With the <u>power supply off</u>, *build the following circuit using resistor R_1 and the ammeter.*



Now include a voltmeter to produce the following;

Circuit 1



The addition of the voltmeter allows the measurement of voltage across R_1 at the same time as current is measured through R_1.

There are three pairs of output terminals on the Tektronix CPS250 power supply. Two of these outputs have voltage and current knobs. The A/B switch on the power supply allows you to monitor the output at either the A or B output terminals. Slide it to monitor output A. Slide the 'A/B Output' slide switch to INDEPENDENT. *Please copy the following table into your report:*

Table two

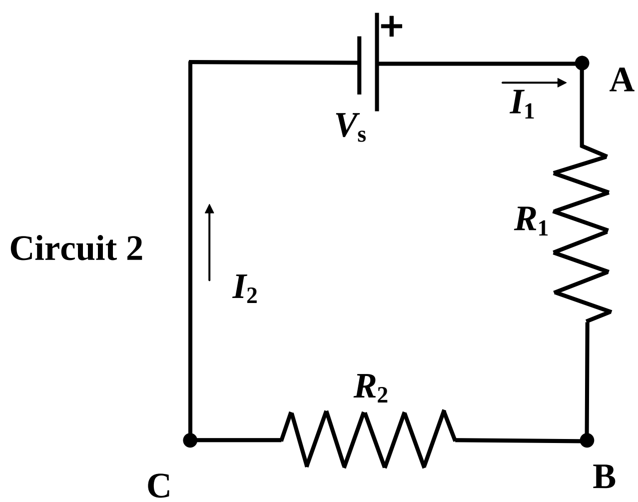
Voltage of the Power Supply V_S (volts)		Current out of the Supply (milliamps)	Voltage Across Resistor (volts)
nominal	measured		
12			
10			
8			
6			
4			
2			

Turn all voltage and current controls fully anticlockwise and switch on the supply. Turn the current control a quarter turn from zero. Turn the voltage control on the power supply so that there is a nominal voltage of

+12 volts between the terminals. (The 'built-in' meters on the CPS250 report this nominal voltage. This nominal voltage is already in table 2.) ***Use the voltmeter to measure the voltage across the power supply. Record this voltage in table 2.*** **[1]** (This voltage is also called the voltage V_S between the terminals of the power supply.) ***Measure and record the current sent by the supply using the ammeter*.** **[1]** ***Measure and record the voltage across the resistor*.** **[1]** This completes the first row of the table when the voltage of the supply is 12 V.

Repeat the measurements in the previous paragraph when the voltage of the supply is nominally $10\ V, 8\ V, 6\ V, 4\ V$ *and* $2\ V$. ***Record the results in table two*.** **[10] Why are the voltages that are measured across the power supply and across R_1 nearly the same? [1] For circuit one, use Excel to make a graph of current (I) through the resistor versus voltage (ΔV) across the resistor. [4] Why don't we use the nominal voltage for this graph? [1]** This graph is called a 'characteristic' for the resistor. Ohm's law states that the slope of the characteristic will be a constant (provided temperature doesn't change). **Does your resistor satisfy Ohm's law? Explain how your graph tells you this.** (Hint: you might want to fit a curve….) **If this 'law' is satisfied, find R_1. [3]**

Build circuit two.



Please copy the following table into your report:

Table 3

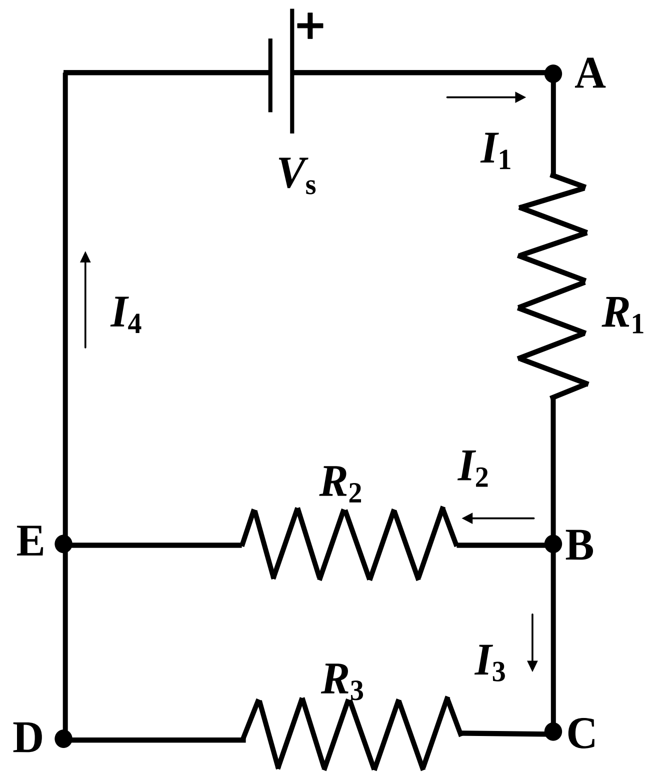
I_1	
I_2	
V_{AB}	
V_{BC}	
V_{AC}	
V_S	

Set the supply output voltage to a nominal voltage of 12 volts. ***Measure the currents and voltages; I_1, I_2, V_{AB}, V_{BC}, V_{AC} and V_S. Record them in your copy of the previous table.*** **[6] What is the relation between I_1 and I_2? [1]** The voltage (a.k.a. potential difference) between points *A* and *B* is $V_{AB} \equiv V_A - V_B$. **Use this expression to simplify the expression; $V_{AB} + V_{BC}$. [1] Do your measurements give the same answer as with your simplified version of $V_{AB} + V_{BC}$? [1]**

Use your measured data to show that $V_{AB} = I_1 R_1$ and that $V_{BC} = I_2 R_2$. Show your calculations. [2] (These relations will only have the right sign if you got the ammeter the right way around!) In your report, **draw a circuit that is equivalent to circuit two but with the two resistors replaced by one resistor with their equivalent resistance**. **[3]**

Now build circuit 3 (below).

Circuit 3



Please copy the following table into your report:

Table four

Circuit 3	*Measured Values*	Circuit 3 (With Ground connection)	*Measured Values*
I_1		I_1	
I_2		I_2	
I_3		I_3	
I_4		I_4	
V_{BE}		V_{BE}	
V_{CD}		V_{CD}	
V_{AB}		V_{AB}	
V_S		V_S	

As before, turn the voltage control on the power supply so that there is a nominal voltage of about +12 volts between the terminals. **Record the eight currents and voltages: I_1, I_2, I_3, I_4, V_s, V_{AB}, V_{CD} and V_{BE} in the second column of your copy of table four. [6]**

How is V_{BE} related to V_{CD}? Explain. (I hope that you realize that you have seen this in the pre-Lab for electricity five where you found the product across two obstacles of unequal size.) **[2]**
Is the current flowing into the negative terminal of the power supply equal to the current flowing out of the positive terminal? [1] How is $V_{AB} + V_{BE}$ related to any other voltage that you have measured? [2] Are the following true (up to sign)? V_{AB} equals $I_1 R_1$; V_{BE} equals $I_2 R_2$; and V_{CD} equals $I_3 R_3$. Show the necessary calculations. **[3]**

In your report, **draw a circuit that is equivalent to circuit three and contains only one resistor. What is the value of the only resistor? Show your calculations.** (Hint: can you divide circuit 3 into two pieces through which all current from the battery must flow?) **[3]**

Connect point B of circuit 3 to the green ground connection on the power supply. **Measure the currents I_1 through I_4. Record the eight currents and voltages: I_1, I_2, I_3, I_4, V_s, V_{AB}, V_{CD} and V_{BE} in the third column of table 3. [6] Are the currents the same as before making the connection to ground? Explain why or why not. [2]** (Notice that you made a prediction about this in your Pre-Lab.)

Be sure to turn off all the instruments. Remember leave the apparatus as it was when you arrived. Ask your TA to check your apparatus before you turn in your reports

Shut-down the computer.

Ohm's law
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PRE-LAB

NAME:____________________________ Course & Section_______________________________

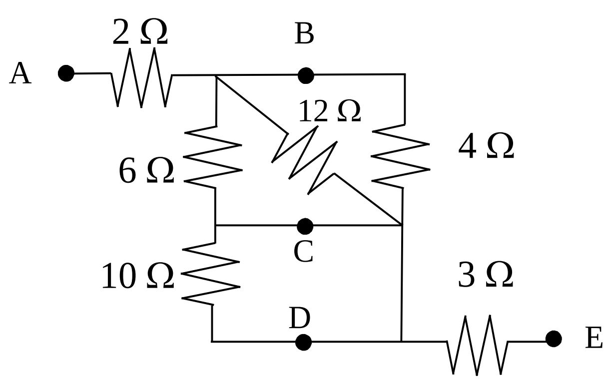
Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

Someone says: "Current is used up as it moves through a resistor. Since we know $\frac{\Delta V}{I} = R$, then the resistance can't be constant". What is wrong? Explain.

____

____**[2]**

(All wires are assumed to be ideal.)



Find the resistances between the following; (If you use any equations then write them with your answer.)

- A and B ____ [1]
- E and D ____ [1]
- C and B (Give your reasoning for this one.)

  ____

  ____ [2]

- D and C (Give your reasoning for this one. Hint: **<u>think</u>** of this like the previous answer where one of the resistors gets very small. Don't plug numbers into a formula and hope-for-the-best!)

  ____

  ____

  ____[3]

- A and E (Give your reasoning for this one.)

  ____

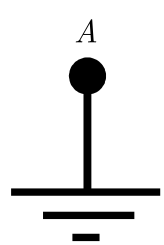
  ____ [2]

We use a battery to cause a continuous potential difference by getting charges to separate. Explain why the terminals of a battery have to be connected together before current flows.

____

____**[2]**

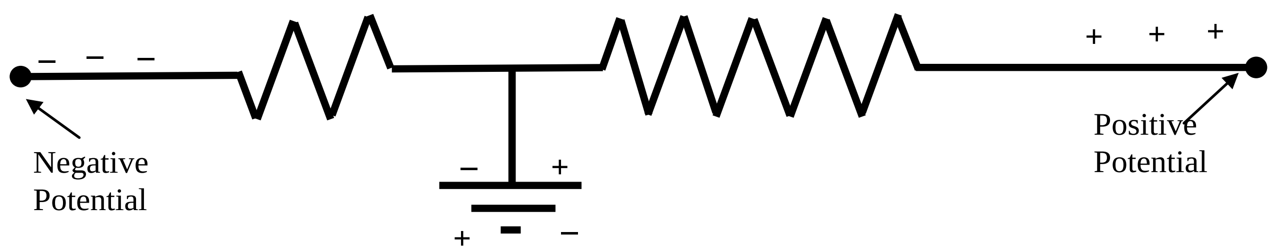
The symbol:



stands for a conducting path from point A to the ground. *The potential of ground is conventionally chosen to be zero.*

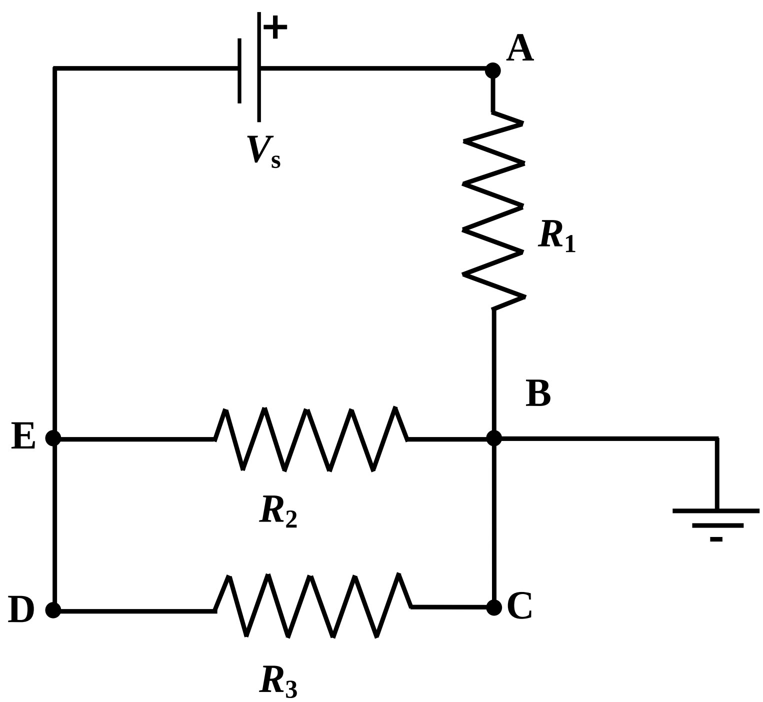
In the next diagram, the black lines represent ideal wires. An excess of positive charges are in the region labeled 'high potential'. Assume that this part of the wire always <u>*stays*</u> at high potential. The left end of the wire is held at a negative potential. Assume that this part of the wire always <u>*stays*</u> at low potential.

The resistors are not of the same size. Draw arrows on this diagram **to show where positive charges will flow.**



[1]

During the lab, you will build the following circuit. <u>**Draw arrows** beside the resistors</u> R_1, R_2 and R_3 to <u>denote the direction of (conventional) current through the resistors.</u> **[3]**



In each case, explain why the arrows point in the way that you have drawn.

____

____**[2]**

REPORT

NAME:____________________________ Course & Section: ___________________

Feel free to draft your answers in pencil but remember that the report to be given to your TA must be in pen.

Table one

	Nominal resistance kΩ	Tolerance of the resistor	Measured resistance kΩ
R_1			
R_2			
R_3			

[3]

Are the values you measured for each resistor within the indicated tolerance according to the color codes on the resistor? Show your calculations.

____

____

____**[2]**

Table two

Voltage of the Power Supply V_S (volts) nominal	measured	Current out of the Supply (milli amps)	Voltage Across Resistor (volts)
12			
10			
8			
6			
4			
2			

[12]

(In circuit 1), why are the voltages that are measured across the power supply and across R_1 nearly the same?

____

____**[1]**

For circuit one, use Excel to make a graph of current through the resistor versus the voltage across the resistor. **[4]**

Why don't we use the nominal voltage for this graph?

____ **[1]**

Does your resistor satisfy Ohm's law? Explain how your graph tells you this. If this 'law' is satisfied, find R_1.

____ **[3]**

Record the currents and voltages for circuit *two* in the next table. The following questions refer to this circuit.

I_1	
I_2	
V_{AB}	
V_{BC}	
V_{AC}	
V_S	

[6]

What is the relation between I_1 and I_2?

____ **[1]**

The voltage (a.k.a. potential difference) between points *A* and *B* is $V_{AB} \equiv V_A - V_B$. Use this expression to simplify the expression; $V_{AB} + V_{BC}$. Do your measurements give the same answer as your simplified version of $V_{AB} + V_{BC}$?

____ **[2]**

Use your measured data to show that $V_{AB} = I_1 R_1$ and $V_{BC} = I_2 R_2$. Show your calculations. (These relations will only have the right sign if you got the ammeter the right way around!)

____

____ **[2]**

Draw a circuit that is equivalent to circuit two but with the two resistors replaced by one resistor with their equivalent resistance. What is the value of this equivalent resistance? Show the necessary calculations. **[3]**

Record the eight currents and voltages: I_1, I_2, I_3, I_4, V_s, V_{AB}, V_{CD} and V_{BE} (in circuit *three*)

I_1	
I_2	
I_3	
I_4	
V_{BE}	
V_{CD}	
V_{AB}	
V_s	

[6]

How is V_{BE} related to V_{CD}? Explain.

____

____ **[2]**

Is the current flowing into the negative terminal of the power supply equal to the current flowing out of the positive terminal?

____**[1]**

How is $V_{AB} + V_{BE}$ related to any other voltage that you have measured?

____

____**[2]**

Are the following true (up to sign)? V_{AB} equals $I_1 R_1$; V_{BE} equals $I_2 R_2$; and V_{CD} equals $I_3 R_3$. Show the necessary calculations.

____

____

____

____**[3]**

Draw a circuit that is equivalent to circuit three and contains only one resistor. What is the value of the only resistor? Show your calculations.

[2]

The currents in circuit *three* when point B is connected to ground;

I_1	
I_2	
I_3	
I_4	
V_{BE}	
V_{CD}	
V_{AB}	
V_S	

[6]

Are the currents the same as before making the connection to ground? Explain why or why not.

____

____

____**[2]**