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| Name | ________________________ | Date | ________ | Time to Complete | ____h ____m |
| Partner | ________________________ | Course/ Section | ______/_______ | Grade | ___________ |

# Simple Circuits

**Introduction**

In this laboratory you will explore simple DC (direct current) electrical circuits. The primary goal of the lab will be to develop a *model* for electricity. A model is a clear mental picture that helps to explain how a physical system behaves and allows you to correctly predict what will happen in new situations. Note that a model is not a complete theory. A theory is a complete explanation in terms of known physical laws and mathematical equations. A model is the conceptual basis on which the complete theory is constructed.

The method we will use to help you develop your model is a three-step procedure: *predict/test/evaluate*. You probably already have some concept, some idea of what electricity is and how it behaves. It may be right or wrong. Whatever it is, it is your initial model. You will be asked to predict what you think will happen in a given electrical circuit, based on this model. You will then test your prediction by making measurements on a real circuit. This, essentially, is how all good science is done. We make predictions based on what we think is a correct explanation of a system, then experiment to verify or refute our prediction. If the prediction was correct, that says the model is at least partially right. If the prediction was wrong, that says the model is either wrong or incomplete, and must be revised. The goal, of course, is to develop a model that always results in correct predictions. When we have done that, we can then say with some justification that we understand the system. So don't worry if your predictions are wrong at first. You will not lose points for incorrect predictions. In fact, correcting an erroneous model often results in more effective learning than simply verifying a correct one. So use this opportunity to make some mistakes and to learn from them.

## 1. A simple circuit

### a. Making a bulb light – part 1

**Introduction**

Your first objective is to make a bulb glow using a power supply, wires, and a bulb in a socket. A power supply is much like a battery, it is a source of *Electromotive Force* (*EMF*). *EMF* is the term used to refer to the potential difference (or "voltage") that a battery develops across its terminals when nothing is connected to it. For example, an ordinary flashlight battery (D-cell) has an *EMF* of about 1.5 Volts.

**Procedure**

- Secure a #502 bulb in one of the sockets provided if it is not already.
- Examine your power supply. The two right knobs give you fine and coarse control over the supply voltage. As a safety feature the two left knobs limit the current that can be drawn from the supply. The left-most knob, *fine-current-control*, should be turned fully clockwise. The next knob, *coarse-current-control*, should be turned fully counter-clockwise. These settings will protect the data-acquisition equipment

by limiting the current to a maximum of 300 mA. **Never touch these knobs again during this lab**.

- Connect a red wire to the positive terminal of the power supply and a black wire to the negative terminal and turn on the power supply. Adjust the right voltage control knobs for a supply voltage of 5.0 V. The power supply is now a source of 5 Volts of *EMF*.
- Experiment and see what it takes to light the bulb. (Turn off the supply when you are done.)

**Conclusion**

When you have gotten the bulb to light, make a quick sketch of the working circuit in the box below. *Your sketch should look like the actual apparatus, not generic symbols*. Be sure to clearly indicate what wires were connected where.

## b. Making a bulb light – part 2

**Introduction**

Hopefully you found that in order to light the bulb you need to create a closed path. But what about the details? In particular, how is the filament (the part of the bulb that actually glows) connected to the external wires from the power supply? In this section you will investigate these questions.

**Procedure**

- Use the magnifying glass to inspect the bulb. Identify the filament and see how it is connected to the base of the bulb.
- Unscrew the bulb from the socket. Turn the power supply on and make the bulb light by touching the connecting wires directly to the bulb itself. See just where on the bulb you have to make the connections in order to get the bulb to light.

**Conclusion**

In the box below draw an accurate sketch of the bulb. Include the filament *and show where you think the two wires that you see inside the bulb connected to the filament are connected internally to the casing of the bulb*. (Have your friendly instructor check your drawing.) Also show clearly how you connected wires from the power supply to the *external* casing of the bulb.

## c. Measuring current

**Introduction**

To light the bulb, you need current which requires a complete circuit. How does current behave in the circuit? Is current the same in the wire leading from the positive terminal of the power supply to the bulb as it is in the wire leading from the bulb to the negative terminal, or does the bulb somehow "use up" current? In this section you will investigate these questions.

**Prediction**

Make a prediction about how you envision current in this circuit. On *Figure 1* below, draw *three* arrows, one after the other, *alongside* the wire connecting the positive terminal of the supply to the bulb. Let the direction of the arrows indicate the direction of current and let the length of the arrows reflect how you think the strength of the current changes along the wire. Draw *three more* arrows, one after the other, alongside the wire connecting the negative terminal of the supply to the bulb. Let the direction of the arrows indicate the direction of current in this wire and let the length of the arrows reflect the strength of the current, especially with respect to the strength in the other wire.

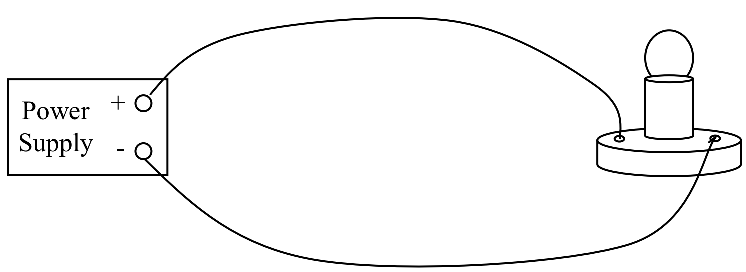
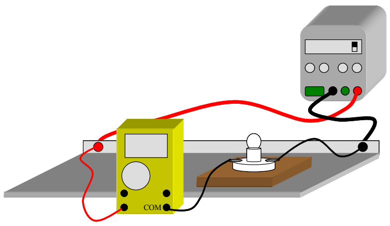



*Figure 1*: Current prediction

Does your picture show the current in the two wires having the same or different strength?

## Procedure

- Screw the #502 bulb back into the socket and construct the circuit shown in *Figure 2* below. As shown, include the multimeter in the circuit to measure current in the wire which leads from the positive terminal of the power supply to the bulb. (Make sure the multimeter is configured to measure current.)



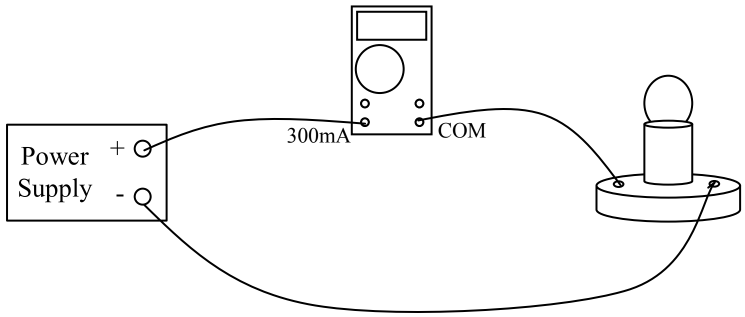



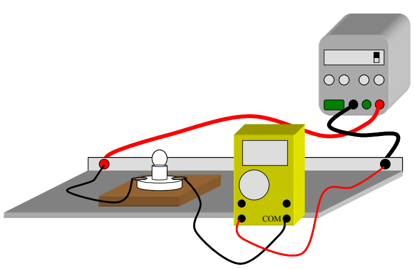

*Figure 2*: Measuring current in the wire connected to the positive terminal

- Turn on the power supply, still set at 5V, and record the reading on your multimeter in row one of *Table 1*. Note that a positive current reading means conventional current is directed into the "300 mA" terminal of the meter and out of the COM terminal. A negative current reading means conventional current is directed into the COM terminal of the meter and out of the "300 mA" terminal. Note in the final column if this result implies a clockwise or counterclockwise flow in the circuit.

| Wire | Current (mA) | Direction (CW or CCW) |
|---|---|---|
| Positive terminal to bulb | | |
| Negative terminal to bulb | | |

*Table 1*

- Turn off the power supply, disconnect the multimeter, and construct the circuit shown in *Figure 3* to measure the current in the other wire. Pay careful attention to the orientation of the meter.



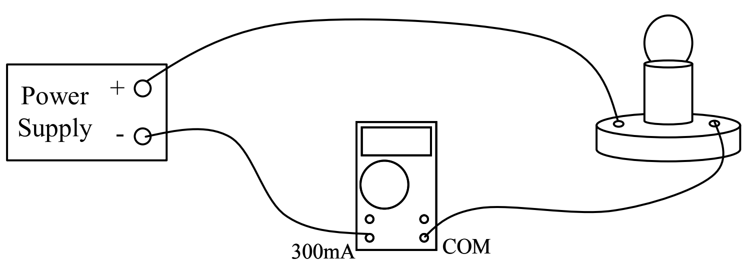




*Figure 3*: Measuring current in the wire connected to the negative terminal

- Turn on the power supply and record the current in row two of *Table 1*. Also note the direction.

**Conclusion**

Consider whether these two current measurements indicate the same of different current is in the two wires. (Note: Some slight variation in the last one or two digits of the meter reading is to be expected. What you are looking for is significant differences, say greater than five or ten percent, between the two readings. If no significant differences are noted, you can conclude that the two measurements in fact agree.)

Is current in each wire the same or different?

Was your prediction correct? If not, modify your model of current on page 3 so it is consistent with your observations.

# 2. A slightly more complicated circuit

**Introduction**

The circuit shown in *Figure 4(b)* is called a *series* circuit because the two bulbs are connected one after the other rather than side by side. How will this circuit behave as compared to the single bulb circuit that you just investigated and shown in *Figure 4(a)*? In particular, for the same power supply voltage (5V), will the current in the two-bulb series circuit be the same as in the one-bulb circuit, or not? Will the first bulb somehow "use-up" some of the current so the second bulb gets less, or will the current through both bulbs be the same?

**Prediction**

Based on your results from the previous section draw three arrows alongside each wire in *Figure 4(a)* that correctly illustrates current in this circuit. If your earlier prediction was correct, this will be the same as before, but if your earlier prediction was incorrect, modify the arrows so they are consistent with your experimental results. As before, let the direction of the arrows indicate the current's direction and the relative lengths of arrows depict the current's strength.

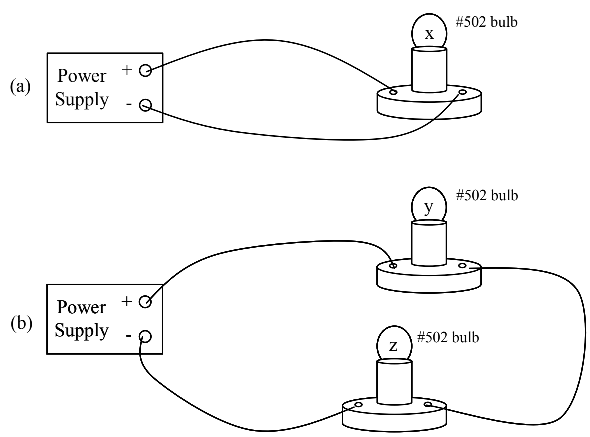



*Figure 4*: Comparing a one and two bulb circuits

In a similar fashion draw three arrows alongside each of the three wires in *Figure 4(b)* to depict your prediction as to how current behaves in this circuit. In particular, these nine arrows should reflect two different comparisons. Firstly, arrow lengths should reflect how you think the current strength changes from one wire to the next within this circuit. Secondly, the arrow lengths should also reflect how you think the current in this circuit compares to the current in the single bulb circuit.

**Procedure**

This time we will use bulb brightness, rather than the multimeter, as a measure of current. For *identical* bulbs, and they must be identical, if one bulb is brighter than another it has greater current through its filament.

- As a reminder, reconstruct the single bulb circuit, without the multimeter. Turn the power supply on, still set at 5V, look at the lit bulb, and remember how bright it is.
- Now construct the two bulb circuit of *Figure 4(b)*. Turn the power supply on, still set at 5V, and look at the bulbs.
- Based on your observations rank the three bulbs (notice that each is assigned a letter in *Figure 4* from brightest (1) to least bright (3) in *Table 2* below. If any of the bulbs have the same brightness give them the same ranking. Also rank the current in each bulb's filament from most current (1) to least current (3). If any of the bulbs have the same current give them the same ranking.

| Bulb | Brightness Rank | Current Rank |
|---|---|---|
| x | | |
| y | | |
| z | | |

*Table 2*

**Conclusions**

Infer from these observations how current behaves through the entire circuit, and how current in the two bulb circuit compares to current in the one bulb circuit. Was your prediction, as depicted by the arrows you drew in *Figure 4*, correct? If not, use a different colored pen or pencil and draw a new set of arrows on *Figure 4* that is consistent with your observations and describe in writing the modifications you had to make.

# 3. Potential differences in a series circuit

**Introduction**

You should be starting to develop an accurate model of how current in a series circuit behaves, but what about potential difference? The power supply develops a potential difference of 5.0 Volts across its terminals. In a circuit consisting of only a single bulb, this potential difference is dropped across the terminals of the bulb, but what about in a circuit consisting of two or more bulbs in series? In this section you will investigate this question.

**Prediction**

In writing predict what you expect to find for the potential difference dropped across each bulb. In particular will the potential difference across each bulb be 5 Volts, since that's what the power supply is set at, or will it be something else? Be specific.

*Prediction:*

**Procedure**

- Draw a circuit diagram in the box below to show how you will use the multimeter, configured to measure voltage, to measure the potential drop across one of the bulbs in a two bulb circuit. Use only the symbols shown in *Figure 5*. (The symbols VΩ and COM are the labels on your multimeter for the two sockets where you connect the meter's probes when measuring potential difference (V) or resistance (Ω). When measuring potential difference, as you are here, if the probe connected to the VΩ socket is placed at the point of higher potential you will obtain a positive reading from your meter.)

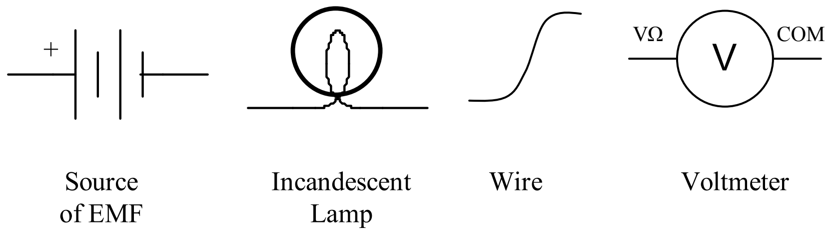



*Figure 5*: Symbols to use in circuit diagram

- Turn on the power supply, still set to 5V, and measure the potential difference across each bulb and record the results in *Table 3*. Also, use the multimeter to measure and record the potential difference across the terminals of the power supply.

| Measured Across… | Potential Difference (V) |
|---|---|
| Bulb 1 | |
| Bulb 2 | |
| Supply Terminals | |

*Table 3*

**Conclusion**

Based on your measurements, what is a mathematical relationship between the potential drops across the two bulbs and the supply terminals?

Speculate as to whether the mathematical relationship you just stated would hold true if the bulbs were not identical. Answer yes or no and then explain. If yes, confirm your expectations with your instructor.

If you answered no to the last question propose a more general mathematical relationship between the potential drops across the two bulbs and the supply terminals that will hold true even if the bulbs are not identical. Confirm your expectations with your instructor.

Maybe you found a small difference between the voltages dropped across each bulb. The bulbs are both model 502's. If so, speculate as to why the total supply voltage isn't split evenly.

# 4. Resistance

**Introduction**

*Resistance R* is *defined* as the ratio of the potential difference across the terminals of an electrical device to the current through it.

$$R \equiv \frac{V}{i}$$

The resistance of the bulb can be determined using the above equation. For example, you probably found, for a single #502 bulb, that a potential difference of 5 Volts resulted in a current of about 0.14 Amperes. The resistance of the bulb under these conditions, as you should confirm, is about 36 Ω (ohms). But is the resistance of the bulb always this value? Maybe filament resistance depends on the current through it. To answer that question, more data is needed.

If current through a device is measured for several different values of potential difference, and the results graphed, we can learn much about the behavior of the device. This type of measurement, which results in a graph often called an *i-V* curve, is a very common electrical measurement that is used to characterize all different types of devices and materials, including light bulbs. *Figure 6* shows several possible graphs of potential difference versus current through an electrical device.

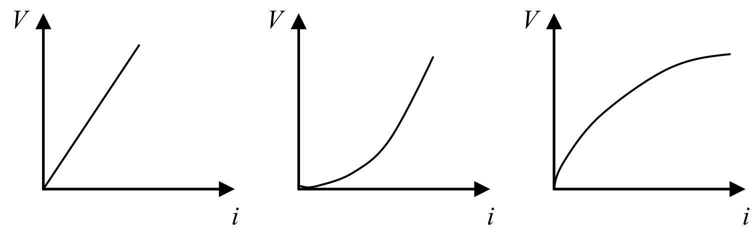



*Figure 6*: Common *i*-*V* curve types

If the graph is a straight line, then the resistance of the material, or device, is the *same* regardless of current. This is because, although *V* depends on *i*, the ratio of *V* to *i* remains constant. Such a material, or device, is said to exhibit *ohmic* behavior.

If the graph is not a straight line, the *i*-*V* curve is non-linear, which means the resistance of the material or device changes with the current. You should convince yourself that an *i*-*V* curve of Type 2 is one indicating a resistance that increases with current. An *i*-*V* curve of Type 3 is one indicating a resistance that decreases with current.

One common reason resistance changes with current is that the material or device heats up more and more as current rises. Most material properties have a temperature dependence to a greater or lesser degree.

If an *i*-*V* measurement can be undertaken in such a way that the temperature is held fixed, even as the current rises, then some other reason would be needed to explain a non-linear *i*-*V* curve. Such a material, or device, is said to exhibit *non-ohmic* behavior.

In this section you will investigate the *i*-*V* curves of two kinds of resistive devices: the bulb; and a *resistor*, something manufactured to have a particular resistance. Such resistors are ubiquitous in electronic circuits. The computer will be used to make simultaneous measurements of current and voltage and to generate *i*-*V* curves for display.

The current and voltage will be measured by two sensors called the *current probe* and *voltage probe,* respectively. The signals generated by these sensors are small and will be amplified by a *dual channel amplifier.* The two amplified signals pass from the amplifier to a general purpose data acquisition control box. The control box interfaces with the computer and software for controlling various aspects of the measurement and for displaying and analyzing the data.

**Warning: The current probe and the dual channel amplifier are easily damaged by either excessive current or excessive voltage, so great care must be taken in their use. Please be sure to observe all the operating precautions described below.**

**Procedure**

- While you assemble the circuit make sure the power supply voltage is dialed down to zero and the supply is turned off.
- Assemble the circuit shown in *Figure 7*. Make sure the current probe is connected with the correct polarity. You are now ready to investigate the resistive characteristics of the bulb.

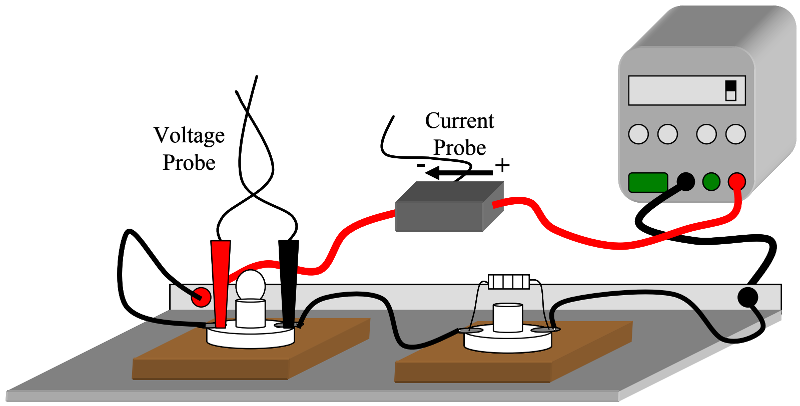



*Figure 7*: Circuit for measuring *i-V* curve of the bulb

- Start the program *Logger Pro.* Click *File* on the menu bar, select *Open*, then open the file *Simplecircuits1.cmbl*. You should see a graph of *Voltage vs. Current* displayed. If this does not happen, consult your instructor.
- After making sure the power supply is at 0 Volts, but turned on, click on the ZERO button on the tool bar to zero both sensors.
- After the sensors have been zeroed, click the *Collect* button on the tool bar. Then click the *Keep* button. This will put the first data point on your graph. Now increase the power supply voltage to 1 Volt. (Watch the voltage meter on the face of the power supply, not the voltage on the graph. These two voltages are not the same!) Again click *Keep*. Increase to 2 Volts. Click *Keep*. Continue this process, putting data points on your graph, up to and including a supply voltage of 10 Volts. Then click *Stop*. Immediately return the power supply to 0 Volts, to preserve the bulb.
- Transfer the voltage and current readings for the third, sixth and last measurements to *Table 4* and use these values to calculate the resistance of the bulb at each of those points. (You will fill in the last row later.)

| **Reading** | **Voltage (V)** | **Current (A)** | **Resistance (Ω)** |
|---|---|---|---|
| Third | | | |
| Sixth | | | |
| Last | | | |
| “Cold” resistance as measured with multimeter | | | |

*Table 4*: Bulb resistance at four different operating points

- Print a copy of your graph and submit it with your report.
- Disconnect the voltage probe leads from the bulb (but leave the bulb in the circuit) and connect them to the terminals of the resistor. Repeat the above procedure. Remember to go no higher than 10 Volts on the power supply, and turn it off as soon as you are finished.

- As before transfer the voltage and current readings for the third, sixth and last measurements to *Table 5* and use these values to calculate the resistance of the resistor at each of those points. (You will fill in the last row later.)

| Reading | Voltage (V) | Current (A) | Resistance (Ω) |
|---|---|---|---|
| Third | | | |
| Sixth | | | |
| Last | | | |
| "Cold" resistance as measured with multimeter | | | |

*Table 5*: Resistor resistance at three different operating points

- Finally, disassemble the circuit and use the resistance setting of the multimeter to directly measure the resistance of the bulb and the resistor. The multimeter drives a very small current through the devices in order to make this measurement. The current is too small to heat either device appreciably. You'll notice the bulb does not get warm enough to glow. That is why these values are referred to as "cold" resistance measurements. Record these values in the final rows of *Table 4* and *5*, respectively.

## Conclusion

Is the bulb's *i*-*V* curve linear or non-linear over the measured range of currents? State whether its resistance increases, decreases, or remains the same as current increases. If non-linear identify its Type from the possibilities in *Figure 6*.

Is the resistor's *i*-*V* curve linear or non-linear over the measured range of currents? State whether its resistance increases, decreases, or remains the same as current increases. If non-linear identify its Type from the possibilities in *Figure 6*.

The symbol *R*, for resistance, in the expression $V = iR$, is hiding a lot of good physics. *R* represents the resistance to the flow of charge, but what determines the resistance of a material? You may have already learned that for a material of length *L* and uniform cross sectional area *A* the resistance can be expressed as, $R = \rho L / A$. The symbol $\rho$ stands for a material property call its resistivity. Although this expression is an improvement, in that we see resistance depends on the shape of the material and the material itself, it still hides the microscopic details of the material's role behind the symbol $\rho$. We will go one step deeper. The resistance can also be expressed in the following way:

$$R = \underbrace{\frac{m}{e^2}}_{\text{properties of the charge carriers}} \overbrace{\frac{1}{n\,\tau}}^{\text{material properties}} \underbrace{\frac{L}{A}}_{\text{geometric properties}}$$

Here we see the origin of resistance can be divided into three parts: the geometric factors *length* and *area*, the properties of the charge carrier *mass* and *charge*, and two microscopic material parameters. The symbol $n$ stands for the *number density* of charge carriers in the material. (In a metal, this would be the density of electrons in the electron sea.) The symbol $\tau$ stands for the *mean scattering time*. It is the average time a randomly chosen charge carrier travels before it is scattered by something, in other words, deflected from its path. The deflections can be thought of as friction, impeding the flow of charge.

Referring to this expression for resistance, formulate at least one hypothesis, *based on the material parameters* in the formula, for why the resistance of the light bulb filament increased as the current through it increased.

*Hypothesis:*

Insulators and semiconductors can exhibit a temperature dependence that is opposite conductors. Their resistance *decreases* when the temperature rises. Referring to the expression for resistance above formulate at least one hypothesis, based on the material parameters in the formula, for this phenomenon.

*Hypothesis*:

We will not test these hypotheses. Discuss them with your friendly instructor if you are interested.

# 5. Designing multi-bulb circuits

**Introduction**

In this activity you will design circuits with multiple bulbs to meet certain specifications.

**Procedure**

- *Build* a circuit with four identical bulbs, that we will call A, B, C and D, such that the brightness of the bulbs ranks A = B > C = D. After you have discovered a circuit that satisfies this requirement, draw its circuit diagram in the space below.

- *Build* a circuit with four identical bulbs such that the brightness of the bulbs ranks A > B > C = D. After you have discovered a circuit that satisfies this requirement, draw its circuit diagram in the space below.