37

Electrical Resistance
Brown Out

Purpose

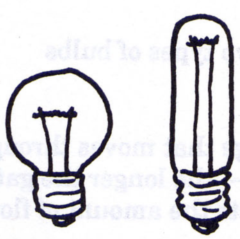
To formulate a model about electrical resistance.

Required Equipment and Supplies

CASTLE Kit (available from PASCO)
or
1 25,000 µF capacitor (20 volts non-polar)
2 #14 light bulbs (round) (no substitutions allowed!)
2 #48 light bulbs (long) (no substitutions allowed!)
2 light bulb sockets
4 alligator leads
1 4 D-cell battery holder
3 D-cells (1.5 volt)

Note: It's important to use a voltage source between 3.6 and 4.5 volts (3 D-cells) for the specified bulbs. A greater voltage is likely to burn out the bulbs—a smaller voltage is not sufficient to light them.

Discussion



The ability of a bulb or any material to impede the flow of charge is called *resistance*. Substances that offer relatively little resistance to the flow of charge are said to have "low resistance" and are called *conductors*, while substances that offer significantly greater resistance to the flow of charge are said to have "high resistance" and are called *insulators*.

When you switch on a flashlight, the maximum brightness of the bulb occurs immediately. If a capacitor is in the circuit, however, there is a noticeable delay before maximum brightness occurs. When the circuit contains a capacitor, the flow of charge through the circuit may take a noticeable time. How much time depends on the resistance of the resistor and the capacitance of the capacitor. In this activity, we will place a resistor (light bulb) between the battery and the capacitor to be charged. The glowing of the bulb indicates charge is flowing. By using bulbs of different resistances, different charging and discharging times are easily observed.

The charging times of these capacitors are noticeable and will enable you to formulate an intuitive model of electrical resistance.

Part A: Bulb Resistance and Charging/Discharging Times

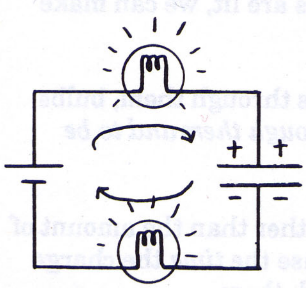


Figure 37.1

Step 1. Connect a battery consisting of 3 D-cells, two long bulbs, and a capacitor (25,000 µF) as shown in Figure 37.1 with one wire (lead) to the battery disconnected. This is an *open* circuit because the free end of the wire forms a break in the conducting path. Now *close* the circuit by connecting the lead to the battery and observe the brightness of the bulbs and the length of time they remain lit. This process is called *charging a capacitor*. The arrows on Figure 37.1 indicate the direction of *conventional current*.

Conventional current is the flow of *positive* charge. (Positive charge flowing in one direction is equivalent to negative charge flowing in the opposite direction.) Inside the capacitor are two metal plates separated by an insulating layer. Each wire you connect to the capacitor leads to one of the plates as shown in Figure 37.1. The insulating layer inside the capacitor is shown in Figure 37.1 as the gap between the plates. The plus sign indicates the accumulation of positive charge on one of the capacitor plates (the "+" side) and the minus sign indicates the depletion of positive charge from the other capacitor plate (the "–" side).

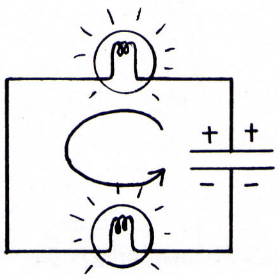


Figure 37.2

Step 2. Disconnect the leads from the battery and remove the battery from the circuit. Connect the two leads that were connected to the battery to each other as shown in Figure 37.2. Observe the brightness and the length of time the bulbs remain lit. This process is called *discharging the capacitor*. Charge and discharge the capacitor several times so you have a good qualitative sense for the *brightness* and the charging/discharging time.

Step 3. Replace the long (#48) bulbs in the circuit with round (#12) bulbs and charge the capacitor. Observe the brightness and the length of time the bulbs remain lit. As you did in Step 2, repeat several times so you have a good qualitative sense for the brightness and the charging/discharging time.

Step 4. Remove the battery from the circuit as in Step 2 and discharge the capacitor through the round bulbs. Observe the brightness and the time the bulbs remain lit. Repeat several times so you have a good qualitative sense for the brightness and the charging/discharging time.

1. Which bulbs are *brighter*—the round bulbs or long bulbs?

2. Which bulbs remain lit *longer*—the round bulbs or long bulbs?

First, let's examine the different lengths of time the two types of bulbs remain lit. Two possible explanations are:

• *Gate Model*. The bulb affects the *amount of charge* that moves through the bulb. As such, the bulb would be acting like a *gate*—the longer the gate is open, the more charge flows through it. A gate affects the amount of flow.

• *Filter Model*. The bulb affects the *rate* charge moves through it. In this model, the bulb would be acting like a *filter*—impeding the flow of charge. The rate at which charge flows would depend on the filter; some bulbs would allow charge to flow quickly while other bulbs would allow charge to flow slowly.

To account for the different lengths of time the bulbs are lit, we can make the following hypotheses.

• If bulbs affect the *amount of charge* that passes through them, bulbs that remain lit longer *allow more charge to pass through them and to be stored in the capacitor*.

• If instead, bulbs affect the *rate* charge flows rather than the amount of charge, then bulbs that remain lit longer will increase the *time* the charge flows—not the amount of charge that passes through them.

Before we test our models by experimentation, let's check our understanding.

3. If bulbs act like *gates* by affecting the amount of charge that flows, will long bulbs allow more, less, or the same amount of charge to be stored in the capacitor as round bulbs?

4. If bulbs act like *filters* by affecting the rate at which charge flows, will long bulbs allow more, less, or the same amount of charge to be stored in the capacitor as round bulbs?

5. Which idea—gate or filter—predicts that the same amount of charge is stored in the capacitor whether it is charged through long bulbs or through round bulbs?

6. Which idea—gate or filter—predicts that the amount of charge stored in the capacitor depends on the type of bulbs through which it was charged?

Step 5. To see which model is more reasonable—gate or filter—try the following experiment. Charge the capacitor through two long bulbs.

Step 6. Remove the long bulbs from their sockets and replace them with round bulbs, being careful not to accidentally discharge the capacitor. Don't discharge the capacitor yet—answer the following questions first.

7. If the same amount of charge is stored in the capacitor no matter what type of bulbs are used during charging, will discharging now through round bulbs take more, less, or the same time as it did in Step 4—when the capacitor was charged through round bulbs?

8. If, instead, a longer charging time indicates more charge is stored in the capacitor than occurs with a shorter charging time, will discharging now through round bulbs take more, less, or the same time as it did in Step 4?

Step 7. Remove the battery from the circuit and discharge the capacitor. Observe the brightness of the bulbs and the time required to discharge the capacitor. Charge and discharge the bulb several times so you have a good qualitative sense for the brightness and the charging/discharging time.

9. Is the time the bulbs remain lit longer, shorter, or the same as in Step 4?

10. Does a bulb acts like a *gate* or a *filter*? Do you think bulbs affect the *amount* of charge that flows or the *rate* charge flows? Based on your data, explain your reasoning.

Part B: Bulb Resistance and Brightness

Step 8. Let's consider the differences in bulb brightness and how they relate to our model. We can use the same models as before: either bulbs affect the amount of charge (like *gates*), or bulbs affect the rate at which charge flows (like *filters*).

Recall from Step 4 that the round bulbs were brighter than the long bulbs. Charge the capacitor through two long bulbs as shown in Figure 37.3. Using the convention described in Step 1, draw arrows on the diagram to show how charge moves in the circuit when the capacitor is charging.

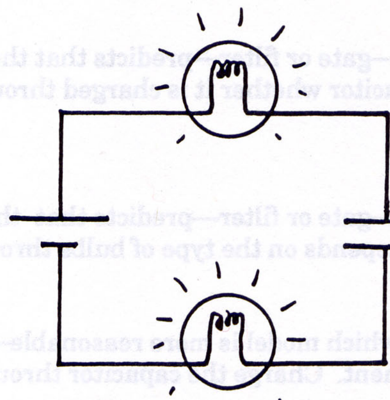


Figure 37.3

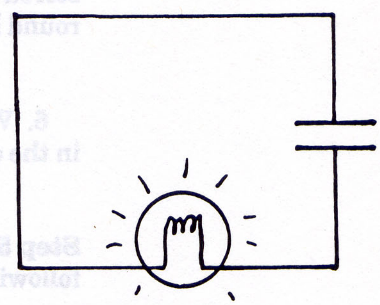


Figure 37.4

Step 9. Being careful not to discharge the capacitor, remove one bulb from from the circuit.

Step 10. Connect the leads (that went to the bulb) to each other and close the circuit to discharge the capacitor as shown in Figure 37.4. Observe the brightness of the bulb and the time required to discharge the capacitor. Draw arrows on the diagram to show the direction charge flows in the circuit as the capacitor discharges.

11. Was the single bulb more, less, or equally bright as each of the two bulbs during charging?

12. Was the discharge time of the capacitor with one bulb longer, shorter, or equal to the charging time with the two bulbs?

13. Study the arrows that indicate the direction(s) charge flows in the circuit on your diagrams. How would you compare the amount of charge that flowed through the two bulbs during charging to the amount of charge that flowed through the single bulb during discharging the capacitor?

14. Does the brightness of the single bulb during discharging of the capacitor indicate the *amount of charge* that is flowing or the *rate* at which charge is moving? Explain your reasoning.

Analysis

15. What is one use of a capacitor?

16. Is the material separating the two plates of a capacitor a conductor or an insulator? Does charge flow inside a capacitor from one plate to the other?

17. Does the *amount* of charge stored in a capacitor depend on the type of bulbs (round or long) through which it was charged? Explain.

18. Based on the results of this experiment, does the type of bulb (round or long) affect the *current* through itself?

19. Based on the results of this experiment, describe your model of a resistor in terms of the gate/filter hypotheses.

20. Would the time be longer, shorter, or the same to charge a capacitor through three identical bulbs instead of one? Explain.

21. If a capacitor is charged through three bulbs and then discharged through one bulb, will the discharge time equal the charging time? Explain. Will one bulb during discharge be brighter, dimmer, or the same brightness as the three bulbs were during charging? Explain.