14476 Voltage and Current

Teacher's Guide

Voltage and Current

Time Allocation:

To prepare this product for an experimental trial should take less than twenty minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.

Feedback:

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.

Introduction

This investigation explores the effects of varying voltage on a few common components in simple, direct current circuits: how a standard 6V light bulb varies in brightness, temperature, and color at different voltages, and the varying intensity and blinking rate in a 2.5V "blinky" bulb. How the changes in voltage and circuit polarity affect the operation and intensity of an LED are also investigated.

The study of DC circuits can be extended with the optional activity, which utilizes the LED and additional materials from the classroom. The investigation introduces simple circuit diagrams and voltage drop; students graph collected data to recognize the relationship between current and voltage.

Objective

Students will explore direct current circuits by using uncommon pathways in dealing with common DC components.

Materials Included in the Kit

5 Battery Holders for four AA batteries
5 Battery Snap Connectors
5 LEDs
5 Bulbs, 6V
5 Blinky Bulbs, 2.5V
5 Bulb Holders
15 Shunts
20 Leads with alligator clips
5 Diffraction Gratings

Materials Needed but Not Provided

20 AA Batteries
Aluminum Foil
1 Multimeter (Optional)
1 100Ω, 1W Potentiometer (Optional)

Materials Needed per Lab Group

1 Battery Holder for four AA batteries
4 AA Batteries
1 Battery Snap Connector
1 LEDs
1 Bulb 6V
1 Blinky Bulb 2.5V
1 Bulb Holder
3 Shunts
4 Leads with alligator clips
1 Diffraction Grating

Shared Materials

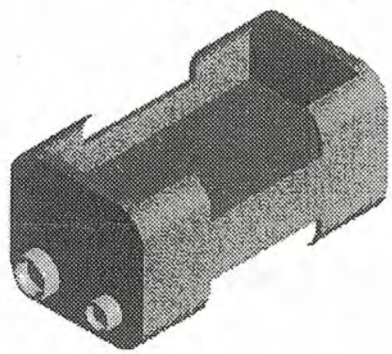
Aluminum Foil
1 Multimeter (Optional)
1 100Ω, 1W Potentiometer (Optional)

Procedure

Note: *Since many of the parts are very small, it is suggested that all materials be kept in the enclosed zippered storage bag until actually needed, then returned to the bag when no longer needed. Read the instructions completely before beginning any activity to ensure that components will be used appropriately and will be available for each of the activities described. The first investigation requires no additional materials, but lab groups may wish to compare results and share optional equipment if used.*

1. Place four AA batteries in the battery holder (Figure 1), snap the battery connector to it, and connect the bulb socket in series using the alligator clip leads.

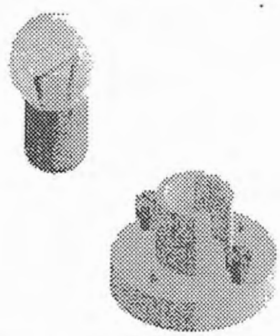
Figure 1



2. Screw the 6V DC bulb into the socket (Figure 2); the bulb should shine brightly. Does it matter which way the bulb is connected?

   Note: *Do not use the blinky bulb at this point.*

Figure 2



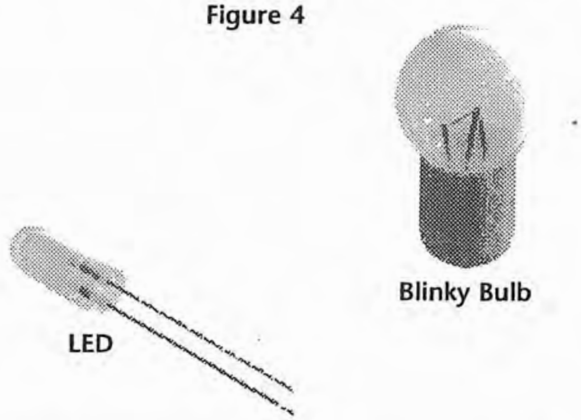
3. An interesting parallel activity at this point would be to look at the bright bulb through the diffraction grating or with a simple spectroscope. Hold the grating close to your eye and within about 5cm of the bulb. A dark background will make it easier to see there are two spectral images, one on each side of the bulb. The various colors seen are being transmitted by the hot filament of the bulb.

4. Remove the batteries one at a time and replace them with the tubular shunts (Figure 3); note the brightness of the bulb and the spectrum observed through the diffraction grating. As the voltage is reduced, both the brightness and the extent of the spectrum are reduced. What is the most persistent color? By sequentially replacing the batteries with the aluminum tubular "shunts", the output voltage becomes 4.5V DC, 3V DC, and 1.5V DC. These voltages are approximate since the output depends on battery condition and the attached load.

Figure 3

5. Disconnect the socket and replace of the standard bulb with the blinky bulb. The blinky bulb appears to have something extra inside compared with the other bulb (Figure 4); it is a thermal switch. It looks as though there are three vertical elements in the bulb, but only two of these are connected to the base of the bulb. One is connected to one end of the filament, and the other is connected to the bimetallic strip inside the bulb. This serves as the initial current path, but as the strip heats up, the two metals of which it is composed expand at different rates which makes the strip bend. As the strip bends away, it breaks the connection with the other end of the filament, and the filament is turned off allowing the strip to cool again until it can make contact as before. The cycle repeats at a rate that depends on how rapidly the bimetallic strip is heated.

Figure 4



6. Place two batteries and two shunts in the battery holder and connect it to the socket as before. Notice that the bulb will light up for a time, then turn off for a time, and then repeat the cycle.

   Note: *Do not attempt to power the blinky using four batteries! This will burn out the bulb!*

7. It is interesting to time the blinky bulb after it has been going for a while, and then time it again after the changes have been made. It is useful to use some kind of timer, such as a stopwatch, and count a large number of flashes. Divide the total time by the number of flashes to get the average flash duration.
8. What happens if the top of the bulb is covered by reflective foil? This may increase the temperature in the bulb. Can you think of a way of cooling the bulb without cracking the glass or getting the socket wet to see if this changes the cycle time of the blinky bulb? What happens if one of the two batteries is replaced by a shunt?
9. With only one battery in the holder, and the rest of the positions occupied by tubular shunts, connect the LED (Figure 4) using alligator clips. The two leads will be separated slightly, and the slightly longer one will be the anode (+) and the other the cathode (–). Does it matter which way the LED is connected? It is a diode, which means that electrical current will pass through it in only one direction. Does it glow dimly? Does it glow at all?
10. Now replace one of the shunts with a battery and see what two batteries in series will do. Again, does it matter which way the connection to the LED is made? What color do you see? What does it look like through the diffraction grating when you look straight down on the rounded top? This is a green LED, but is it transmitting only green?
11. For the next part, you will be operating the LED beyond its design voltage. If you connect the LED briefly, it should not be destroyed. Remove one more shunt and replace it with a battery. Remember, keep this connection only briefly! Now there are three batteries in series. Again, look at the apparent color of the LED. Does it now look yellow? What does the spectrum look like through the diffraction grating as you look down on the rounded top of the LED?

    Note: *There is no need to connect the LED to four batteries in the series. This might damage the LED and it does not seem to change the spectrum further.*

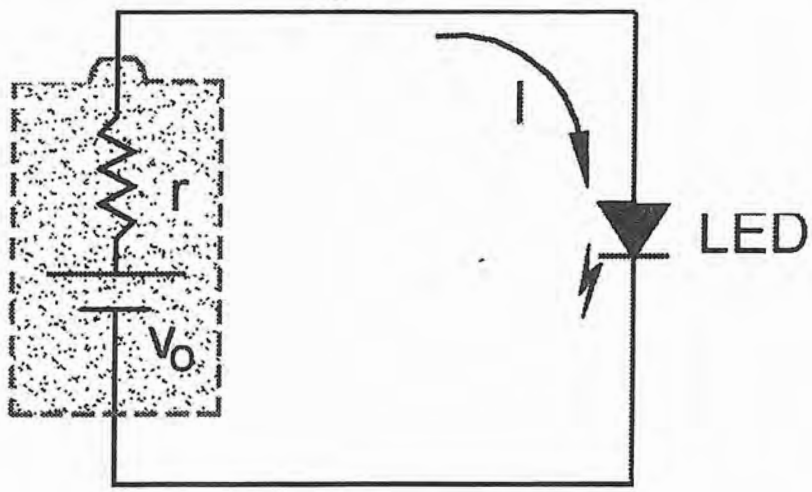
12. Summarize your findings at this point in your investigation of batteries, bulbs, and LEDs as you work your way to an understanding of voltage and currents.

Additional Investigations

Originally, a diode was a vacuum tube that could conduct a flow of electrons in only one direction. As semiconducting materials became available, this was the first circuit element to be updated; now virtually all conversions of AC to DC are accomplished with solid-state diodes. By reducing power needs, light-emitting diodes (LEDs) permit cooler operation and greatly improved efficiency. LEDs are rapidly gaining ground in commercial applications. Instead of frequently replacing the red, yellow, and green lamps in traffic lights, municipalities are beginning to install devices that look and operate the same way, except that the face is made up of many LEDs. These are expected to last some 100,000 hours, or about 10 years. The LED can take more physical shock, survive temperature extremes, and switch on and off extremely rapidly compared with conventional lamps. They are 10 to 50 times more efficient, are 90% less costly to operate, and are now available even in white, along with many very vibrant colors. Many new applications are coming on line each day in aviation because LEDs can conform to very unusual requirements of physical design and operating environment. LEDs are even showing up in safelights for use in photographic darkrooms.

Typically, the internal structure of an LED sets a limit on the amount of current it can safely pass, so it is often driven through a carefully selected protective resistor. For our purposes, and within these limits, the internal resistance of the batteries (Figure 5) seems to be enough. The symbol for the diode includes an arrow to show the direction of current flow, and often a lightning bolt to indicate that it actually emits light. Sometimes that light is not visible to the human eye, for instance in remote control devices for a television or computer printer. The diode voltage ranges from about 0.5V to 2V, depending on the particular choice of semiconducting material used in its manufacture.

Figure 5



Voltage Drop

There is a characteristic difference in potential of about 1.5V between the terminals of an individual AA cell, represented by V_0 (Figure 5). The battery will exhibit a change in voltage when it is connected to an actual circuit because of the internal resistance, represented by "r" (Figure 5). The voltage drop can be calculated using Ohm's Law.

$$V_{drop} = I \times r$$

where V_{drop} = *voltage drop in volts (V)*

I = *current in amperes (A)*

r = *internal resistance in ohms (Ω)*

The terminal voltage would be reduced by the voltage drop across the internal resistance. The voltage at the battery terminals drop to ($V_0 - V_{drop}$).

By rearranging the equation for finding the voltage drop, it's possible to calculate the internal resistance of a battery.

Example: If a circuit with a light bulb draws a current of 200mA (0.22A), and the voltage drop across the battery is 0.12V, what is the internal resistance?

$$V_{drop} = I \times r$$

$$\frac{V_{drop}}{I} = r$$

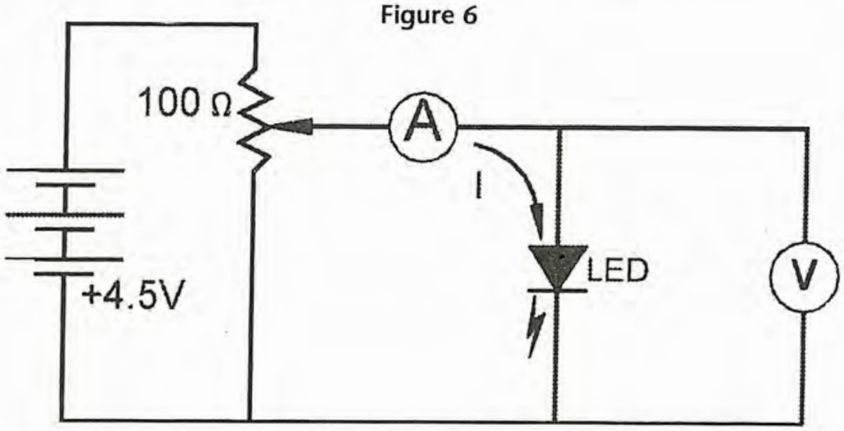
$$r = \frac{0.12V}{0.22A}$$

$$r = 0.55\Omega$$

Relationship Between Voltage and Current

Examine the circuit in Figure 6. Notice that a potentiometer is set up as a voltage divider, which is one of the most fundamental circuit components; it is built like a resistor with a slider on its back so that it can touch any place along the resistor. Most often the voltage divider is controlled by turning a knob, but sliding levers are also common. Some potentiometers vary the voltage logarithmically, such as in audio equipment. For this investigation, the potentiometer should have a "linear taper" so that the middle is 50% of the total resistance, the middle of the first half is 25%, and so forth. As you turn or slide the control from one end to the other, the voltage applied to the rest of the circuit goes from 0V at the bottom to 4.5V at the top (Figure 6). One or more multimeters, when connected appropriately, can aid in sampling the voltage and current in simple circuits. Use the meter's instruction book to become familiar with the selection and reading of analog scales or the interpretation of digital displays. Determine the relationship between current and voltage by constructing the circuit shown in Figure 6 and gathering data to create an IV graph.

Figure 6



Procedure

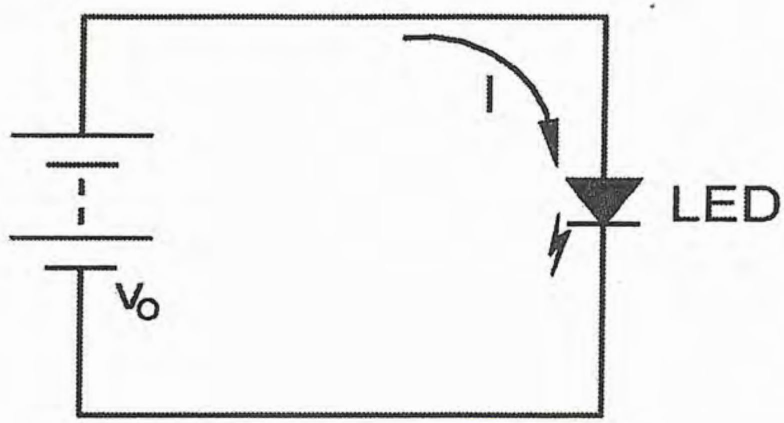
Note: *Students should work independently wherever possible.*

1. Insert three batteries and one shunt into the battery holder.
2. Connect the potentiometer to the battery holder.
3. Connect one multimeter to the output from the potentiometer. This meter will be used to measure the current and should be set in the milliamp range.
4. Connect one lead of the LED to the output from the first multimeter and complete the circuit by connecting the other lead to the battery.
5. Set up the second multimeter to read the voltage across the LED.
6. Adjust the potentiometer so that the voltage reads 0 on the second meter, then record the current from the first meter.
7. Adjust the potentiometer to increase the voltage to 0.5V and record the current.
8. Continue increasing the voltage in 0.5V increments and record the current for each.
9. Create an IV plot by graphing the data you have collected.

Drawing Circuit Diagrams

You saw circuit diagrams in the exercises above; now let's explore the diagrams in more detail. Figure 7 shows, in symbols, the circuit you made to investigate the light characteristics of the LED. Symbols should always be easier to draw than the actual device, since the symbol is intended to be a form of "shorthand". Notice that the number of batteries is not stated. In this situation, voltage is usually written near the battery symbols, or the proper number of symbols is used to show just how many batteries are hooked up. In this kind of circuit diagram, there is no mention of the shunts nor is there a picture of the battery holder. The symbol for the LED includes an arrow to show the direction of current flow, and often a lightning bolt to indicate that it actually emits light. Notice that there is no switch in the circuit; there was no need for one, since it was possible to remove a shunt or battery, or disconnect a clip lead, to break the circuit.

Figure 7



Procedure

1. Invent a symbol for the ordinary light bulb and draw a circuit diagram for each of the situations you investigated.

   Note: *You would not need to make a symbol for the socket unless you wanted to.*

2. Draw the circuit from the first investigation of the LED. Add a protective resistor for the LED in the circuit. Where is the best place to put it?
3. Redraw Figure 7. Where would you connect the ammeter if you wanted to read the current through the LED only and not the sum of the LED and voltmeter currents? (For a digital meter, this might not make a big difference, but an analog voltmeter might draw approximately 50 microamps at full scale while reading 5V.)
4. Make a circuit diagram that is not pictured anywhere in these instructions. The only new symbol you would need to draw is that of a switch. The standard symbol uses a short arrow and pictures it as swinging like a gate from the back side. Small circles show the places that the arrow "gate" can park. With this in mind, make a diagram of a blinky bulb circuit. The bulb filament could be represented as a resistor.