Line Following Robot

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Now that you have learned about electricity and resistors, you are ready to start working on your line following robot. The robot you are going to build is described in detail in "Robot Building for Beginners," written by David Cook. The line following robot has several circuits that work together to control two motors, one connected to each wheel of the robot. The robot has only two wheels. The front of the robot slides along the floor as it moves. When both motors are on, both wheels turn, and the robot moves forward in a straight line. The robot turns right by powering only the left wheel and turns left by powering only the right wheel. That is the steering mechanism of the robot. The robot has photoresistors to detect a line on the floor. The photoresistors are connected to an integrated circuit (IC). The IC is a simple logic device that controls the motors of the robot. However, the IC is not able to provide enough current to the motors to run them directly. Instead, the IC controls two transistors. The transistors act like switches. The IC turns the transistors on and off. When a transistor is on, current flows to its attached motor and the wheel turns.

You will complete several lessons. Each lesson will cover a specific circuit of the robot. As you assemble each circuit, you will test it and learn how it works. Along the way you will learn more about electronics. You will assemble each circuit on a breadboard. This kind of work is called **prototyping** and is a way to temporarily connect electronic components together for testing purposes. After you have completed all the lessons, and understand each circuit of the robot, you will assemble a complete robot. To assemble the complete robot, you will need to solder the electronic components together. However, as you build each circuit on a breadboard, you don't need to do any soldering. You simply push the wires of the component into the sockets (holes) of the breadboard. If you make a mistake in connecting components, it is easily corrected on the breadboard. You will learn how to solder in the last lesson, when you assemble the complete robot.

Here is a list of the lessons:

1. **Power circuit** – in this circuit you will learn about LEDs (light emitting diodes). The circuit contains a 9 volt battery, a switch, a resistor and a LED. The power circuit is designed to provide power to the robot. The switch turns the power on and off (just like turning a light on or off in your house by using a wall switch). When power is turned on by the switch, current flows through a resistor and then through the red LED. The glowing red LED indicates that the robot is turned on. The resistor controls the amount of current that flows through the LED to prevent damage to the LED.
2. **Photoresistor circuit** - photoresistors are a type of variable resistor and you will learn about variable resistors in this lesson. When light shines on a photoresistor, it changes resistance. When light reflects off a light-colored floor, more light shines on the photoresistor than when light reflects off a dark-colored line on the floor. Photoresistors can be used to measure

amounts of light. That characteristic can be used to detect a dark line on a light floor or a light line on a dark floor.

3. **IC circuit** – the robot uses a logic chip called a voltage comparator, which is an integrated circuit (IC). As the photoresistors change resistance, they supply a variable amount of voltage to the IC. The IC chip compares the voltages supplied by two sets of photoresistors to decide where the line is under the robot. If the line is not centered under the robot, then the two sets of photoresistors will supply different amounts of voltage to the IC. The IC compares the voltages and decides which wheel on the robot should turn and which one should not, to steer the robot in a way that centers the line under the robot. In this lesson you will assemble the IC circuit and learn how the voltage comparator steers the robot to keep the line centered underneath it.
4. **Transistors as switches** – in this lesson you will learn about transistors. Transistors are a common type of semiconductor (LEDs are also semiconductors). Integrated circuits (ICs) contain many transistors, diodes, resistors, and other parts, all incorporated into one package. Integrated circuits are common components of most electronic devices. Therefore, transistors are important in nearly all electronic devices. In this lesson you will learn about individual transistors that are not combined into integrated circuits. A transistor can be used as a kind of electronic switch, to turn something on or off. In the case of our robot, the transistors are used to switch the motors on and off. A large transistor can supply a relatively large amount of electrical power to a motor in the robot when a relatively weak electrical signal is received from the IC. In general, ICs don't handle much electrical power due to the tiny size of the parts inside it. In contrast, an individual transistor is usually much larger than one in an IC, and is able to handle much more electrical power. That is why large, individual transistors are used to turn power on and off to the motors in the robot.
5. **DC motors** – your robot will utilize two motors designed to run on direct current (DC). In this lesson you will learn about DC motors.
6. **Assembling the complete robot** – after you have completed lessons one through five, you will understand all of the circuits of the robot. It is now time to assemble a complete robot, make adjustments of its control circuits, and test its ability to follow a line on the floor. You will need to learn how to solder to assemble the robot and you will learn that skill in this lesson.

Lesson 1 – Power circuit

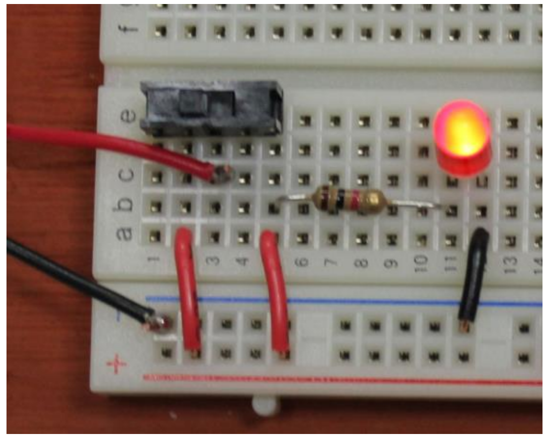

Figure 1. Breadboard with complete power circuit

In this lesson you will learn how to prototype an electronic circuit using a breadboard. When engineers are working on the design of a new electronic device, they will often build prototypes to test the design before actually building the device. The breadboard provides an easy way to build a temporary circuit for testing purposes.

Figure 1 shows the power circuit on a breadboard, as it will appear when you finish this lesson. The circuit contains a 9 volt battery (which is not visible in Figure 1 but you can see the red and black battery wires on the left side of the photo), two red wire connectors, one black wire connector, a single pole double throw switch (abbreviated as SPDT), a 1,000 ohm resistor, and a red LED. You should notice that the breadboard has many holes. Wires of electronic components are inserted into the holes. Figure 2 is a close-up view of the red LED inserted into the breadboard. The LED has two wires and each one is inserted into a hole in the breadboard. Groups of holes are connected to each other inside the breadboard, which provides the method of connecting components together. Now go to the next page to learn more about the breadboard.

Figure 2. Red LED inserted into breadboard

Figure 3 shows one section of the breadboard. There are 30 rows of holes in the middle. Each row is divided into two groups of five holes each. On the left and right sides there are two columns, each containing 25 holes.

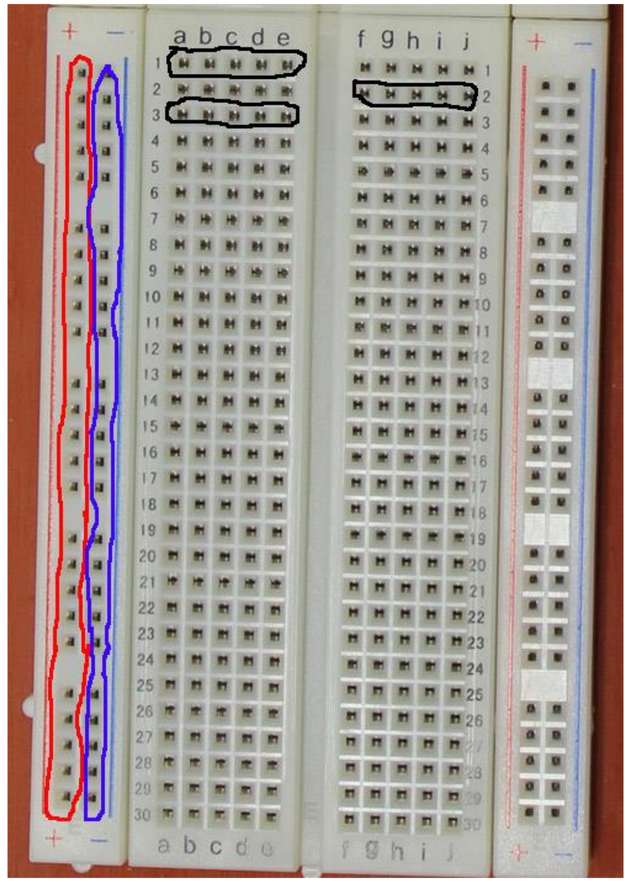

Figure 3. One section of the breadboard

Let's start with the holes on the left and right. These holes are called the power bus. The power bus is used to connect power from the battery to the electronic components. Notice at the top and bottom of the breadboard section there are red-colored plus symbols and blue-colored minus symbols. All of the holes in each column marked by a plus symbol are connected to each other (I have drawn a red line around the column on the left). When you attach a red wire from the plus terminal of the battery to one of the holes in a plus column, all holes of the column will provide a connection to the plus side of the battery. In the same way, when you attach a black wire to the negative terminal of the battery and insert the other end of the wire into a hole in a column marked with the minus symbol, all holes in that column will be connected to the minus terminal of the battery. The power bus on the left is not connected to the power bus on the right. You must connect the battery to both power buses if you want to use both of them to power components on the breadboard.

Now let us take a look at the rows of holes on the breadboard. I have drawn black lines around three groups of holes near the top of the breadboard. All wires inserted into holes of a group will be connected together. For example, let's take the group of five holes at the top just left of center, row number one, holes under the columns marked a, b, c, d and e. Suppose we insert a wire into each hole of row number one, marked a, b, c, d and e. All five of those wires will be connected to each other inside the breadboard. If we insert a wire into the hole in row number one under the letter f, that wire will not be connected to the other five wires because it is in a different group. If we insert a wire into the hole in row number two, under the letter a, that wire will not be connected to the five wires in row one, a, b, c, d and e, because it is also in a different group. This may be a little confusing now but with a little practice and help you will be able to understand exactly how the breadboard works.

Electronic components of the power circuit

Figure 4. Red LED. The short wire is the cathode and long wire is the anode

Figure 5. Red LED inserted in the breadboard. The flat side of the LED on the left marks the side with the cathode wire. The cathode must be connected to the negative side of the battery.

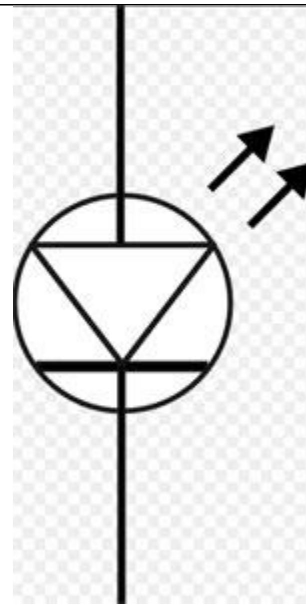

Figure 6. Symbol for an LED

You have learned about conductors and insulators in a previous lesson. In this lesson and the following ones, you will learn about semiconductors. The name suggests that semiconductors allow the flow of current but less than conductors. Well, it is a little more complicated than that, as you will learn in these lessons. The LED that you will use in the power circuit is a semiconductor.

The LED (light emitting diode) is a special type of diode that emits light. Diodes are semiconductors that allow current to flow only in one direction. The symbol for a diode is an arrow pointing to a horizontal line (see Figure 6). The arrow indicates the direction in which current is allowed to flow.

The LED must be connected to the circuit with the proper "polarity" in order for the LED to pass current and glow. The two wires of the diode are named **anode** and **cathode**. The cathode is usually a shorter wire (see Figure 4). The cathode may also be marked by a notch or flattened side of the LED (see Figure 5). The cathode must be connected to the negative power bus and the anode must be connected to the positive power bus. However, an LED must not be connected directly to the positive power bus because the battery will supply too much current and ruin the LED. To protect the LED, a resistor of a proper resistance must be connected in series with the LED to reduce the current flow through the LED to a safe level.

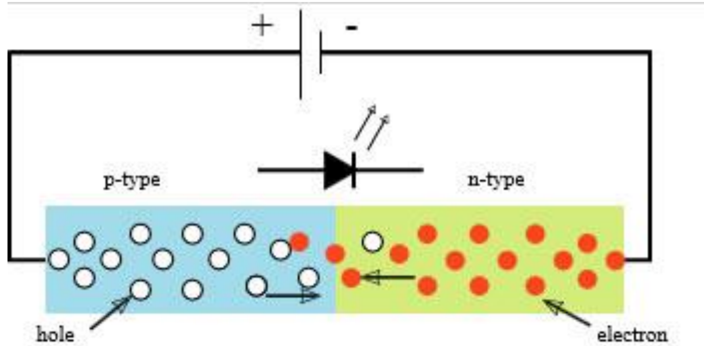

Figure 7. Diagram of a LED

I think you might like to learn how LEDs work, so let's go over that now.

A number of different semiconducting compounds can be used to manufacture LEDs (a compound is a mixture of at least two different kinds of atoms). A particular mix of atoms will result in a specific color of light emitted from the LED. Aluminum, gallium and arsenic (aluminum-gallium-arsenide [AlGaAs]) is one compound that can be used for red LEDs. Semiconductors are poor conductors of electricity in the pure state. However, by adding very small amounts of other kinds of atoms, the conductive property of a semiconductor can be increased. Depending on the atoms added, the material can be classified as **p-type** (positive) or **n-type** (negative) semiconducting material. The atoms of the n-type have some electrons that are easily separated from the atoms. The p-type material can be said to have a **shortage** of electrons. We can represent that shortage as "holes."

When p-type and n-type materials are connected to form a **junction** (as in the middle of the diagram in Figure 7), and are properly connected to a DC power source, electrons can flow from the n-type material a short distance into the p-type material and holes can flow from the p-type material a short distance into the n-type material (see Figure 7). The major charge carrier in the p-type material is the hole and the major charge carrier in the n-type is the electron. When a hole moves into the n-type material, an electron will fill the hole and by the same token, a hole will accept an electron when the electron moves into the p-type material. Free electrons are injected into the n-type material by the power source but they do not travel through the p-type material to any significant extent. Instead, at the connection of the positive terminal of the power source to the p-type material, electrons are collected from the p-type material, which in turn forms new holes by the loss of electrons. Then the holes travel to the junction zone, where they accept electrons. Thus, when current is flowing through the LED, holes are flowing to the right in the p-type material in Figure 7 and electrons are flowing to the left through the n-type material. In the zone of the junction electrons and holes are "consumed" by recombination.

The cathode wire of the LED is connected to the n-type material and the anode wire of the LED is connected to the p-type material. If we reverse the connections to a battery, then current will not flow through the LED. That is the magic of a diode: current can flow only in one direction. That is why the negative side of the battery must be connected to the cathode. I will provide a detailed explanation of "reversed bias" behavior of the diode in another lesson.

When looking at Figure 7, there may seem to be something wrong. The symbol for the LED indicates that current flows from left to right. The diagram also indicates that electrons flow from right to left, the opposite direction. Try to remember back to the first lesson on electricity. It is a convention that diagrams show the direction of positive charge flow. Electrons have negative charge and flow in the opposite direction from positive charge. In the case of semiconductors we do have a positive charge carrier (the hole). And notice that the holes do move from left to right, the opposite direction from the electrons.

When electrons are captured by the holes at the junction, energy is emitted in the form of light. The color of light emitted is determined by the wavelength of the light. Most LEDs emit light of a limited range of wavelengths, which results in colored light. LEDs can be designed to emit light of various colors depending on the kinds of atoms used to make the semiconductor. Aluminum-gallium-arsenide is a good material for red LEDs.

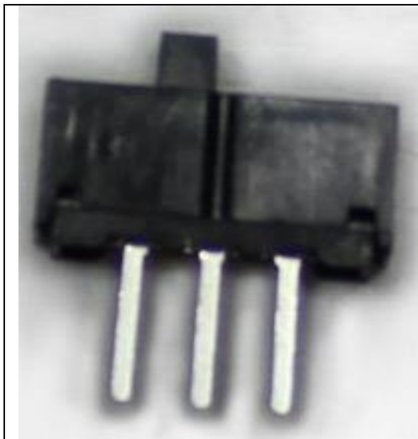

Figure 8. Single pole double throw switch (SPDT)

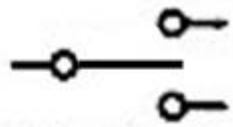

Figure 9. Symbol for a SPDT switch

You will use a single pole double throw switch (SPDT) to turn the power on and off. There are other types of switches you could use, but I happen to have this kind for you to use. You can see what the switch looks like in a close-up view in Figure 8. The switch has three metal pins that are spaced exactly to fit into the breadboard. The switch is inserted into the breadboard so that its length runs parallel to the length of the breadboard. That way, each pin will be inserted into a different row (if you inserted the switch parallel to the rows, then all three pins would be connected together in one row and the switch could not function). Notice on the top of the switch there is a square-shaped slider. When the slider is pushed to the left (like in the photo), the middle pin is connected to the left pin. When the slider is pushed to the right, the middle pin is connected to the right pin. The switch is designed to connect either the left or right pin to the center pin.

You have already learned about resistors in a previous lesson. Now you have learned something about all of the components that will be used in the power circuit. Let us now take a look again at the circuit on a breadboard on the next page.

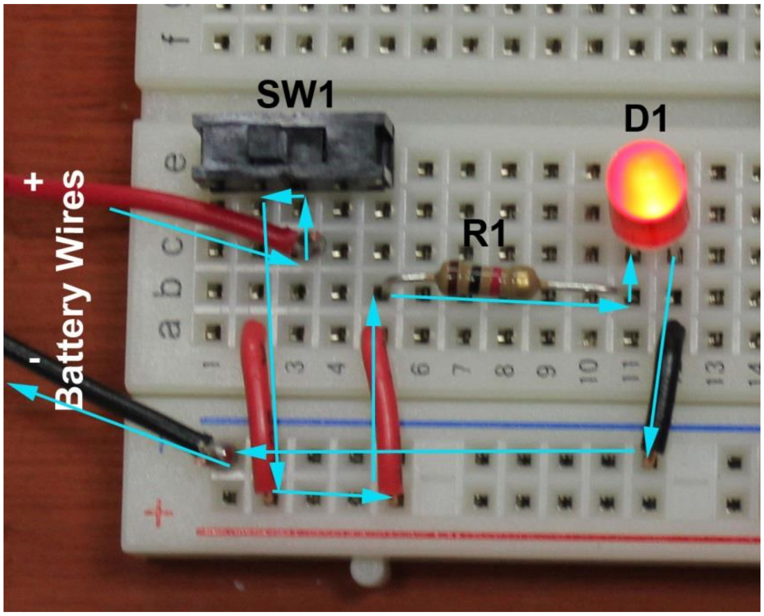

Figure 10. Power circuit on breadboard. Blue lines trace the flow of current. SW1 is the SPDT switch, R1 is the 1,000 ohm resistor and D1 is the red LED.

In Figure 10 the battery wires are on the left. Remember that the color red is used for the positive side of the battery and black for the negative side. The red wire from the battery is connected in row 3 to hole c. The middle pin of the switch is also connected in row 3, to hole e (you can't see the switch pins and will just have to trust that I am correct!). Therefore, the red wire from the battery is connected to the middle pin of the switch. The left pin of the switch is connected in row 2 to hole e. Also notice that there is a red wire connected in row 2 to hole a. The other end of that wire is connected to a hole of the positive power bus. Therefore, after current flows through the switch, it is delivered to the positive power bus at the bottom of the breadboard. Any other wire connected to any hole of the bottom, positive power bus will also be connected to the positive terminal of the battery when the switch is closed (on). Notice that there is another red wire connected in row 5 to hole a and also to the positive power bus. One end of resistor R1 is also connected in row 5 to hole b. Therefore, the resistor is connected to the positive power bus through the short red wire which is also connected in row 5. The other end of the resistor is connected in row 11 to hole b. The anode of the LED D1 is also connected in row 11 to hole c, which means that it is also connected to the resistor wire in hole b, row 11. The cathode wire of LED D1 is connected in row 12 to hole c. There is also a black wire connected to row 12 at hole a. This wire connects to the negative power bus. Notice also that the black wire of the battery is connected to the bottom negative power bus. Therefore, the cathode of the LED D1 is connected to the negative terminal of the battery. This completes our circuit. When the switch is closed (on), current flows from the positive terminal of the battery through the switch to the positive power bus, then through resistor R1, then through LED D1, and then returns to the battery by way of the negative power bus. If we continue to build additional circuits on the breadboard, using the positive and negative power bus at the bottom of the breadboard, then all of those circuits will be controlled by switch SW1. When the LED is glowing with red light, we know that power is being delivered to all circuits connected to the bottom power bus. That is why we call this circuit the power circuit.

Since all current will flow through SW1, we must be careful not to exceed the current limit of the switch, which is 200 milliamps. We must keep this in mind as we add more circuits to our breadboard.

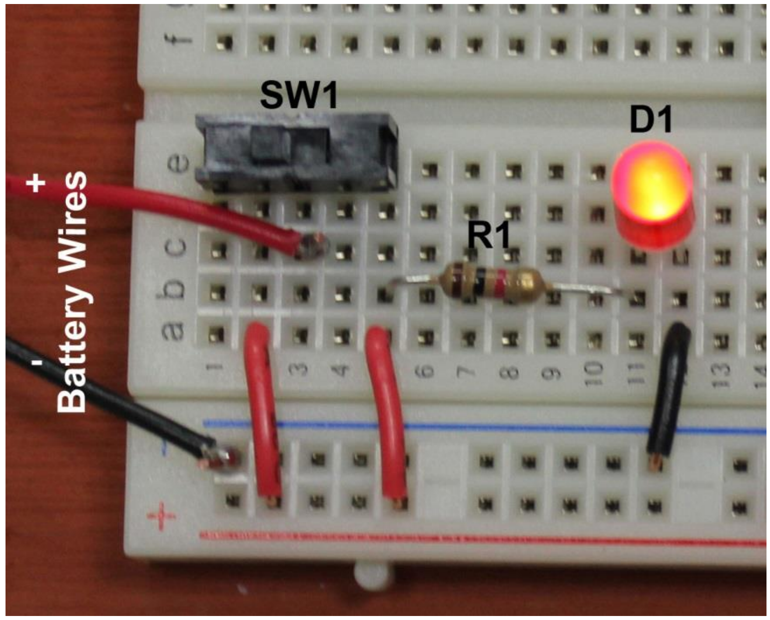

Figure 11. Power circuit on breadboard.

You will now assemble the power circuit on your breadboard. Use the photo in Figure 11 to help with the assembly.

1. Insert the switch in column e of the board, at the left end, as seen in the photo.
2. I have prepared wire jumpers for you to use on the board. Using one of the short red wires, connect one end into a hole in the same row that contains the left pin of the switch. Connect the other end of that wire to a hole in the positive power bus.
3. Using another short red wire, connect one end into a hole of the row that is the next row right of the row containing the right pin of the switch. Connect the other end of that wire to the positive power bus.
4. Connect one end of the resistor into a hole in the row that also contains the red wire you inserted in step 3. Connect the other end of the resistor into a row that is not yet used.
5. Connect the anode (the longer wire) of the LED into the same row that contains only the resistor. At the same time, you should connect the cathode of the LED into the row next right of the row that contains the anode.
6. Connect the short black wire to a hole in the same row that contains the cathode of the LED. Connect the other end of that wire to the negative power bus. **Before doing the next steps, make sure the battery is not inserted in the battery holder.**
7. Connect the black battery wire to the negative power bus.
8. Connect the red battery wire to the same row that contains the middle pin of the switch.
9. **Ask an adult to check your circuit.**
10. Now insert the 9 volt battery into the holder (ask for help if you need it).
11. Is the LED glowing? If no, then push the switch slider to the other side. The LED should be on when the switch is in one position and off when in the other position. If not, then you need to check your circuit for wiring errors.

Now let us look at the circuit in schematic form. The positive terminal of the battery is connected to the middle pin of the switch. The left pin of the switch is connected to one side of the resistor. The other side of the resistor is connected to the anode of the LED (D1). Remember that the anode must be connected to the circuit on the positive side. The cathode of the LED is connected to the negative terminal of the battery.

In this circuit the wires and switch contain very little resistance to the flow of current. Therefore, the only components of the circuit that consume power are the resistor and the LED.

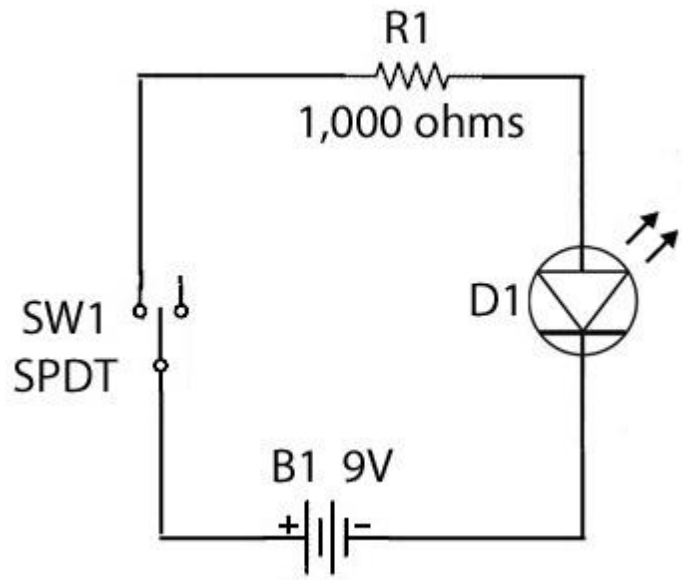

Figure 12. Diagram of power circuit

The typical forward voltage drop for the LED you have used should be about 2 volts.
What if we just connected the LED to the battery without the resistor? What would be the voltage drop across the LED? The voltage drop would be the same as the voltage supplied by the battery, about 9 volts. Nine volts is much more than the 2 volts specified for the LED. If we don't add a resistor into the circuit, then an excessive amount of power will be applied to the LED and it will burn out and be ruined.

The resistor R1 and LED D1 are in series in this circuit. That is, the current flows first through the resistor and then through the LED. The resistor controls the amount of current flowing through the circuit so that the LED will not be damaged.

In the resistor lesson you learned how to use Ohm's Law to calculate the current flow through a circuit given the voltage and resistance of the circuit. We can measure the total voltage drop in the power circuit with a meter. We **cannot** measure the total resistance of the circuit with the meter because it is not possible to measure the resistance of the LED with the meter.

Without knowing the resistance of the LED, how can we design the circuit to protect the LED? First we need to know how much current the LED can withstand. That information is available on the datasheet supplied with the LED. The maximum current your LED can withstand is 20 milliamps. But it is not always a good idea to run a LED or any other electronic component at the maximum current value. To be safe, we should select a fraction of the maximum value. Let us choose a value about one half the maximum value as a safe value. That would be 10 milliamps. Now we can ask the question: how much resistance is required for resistor R1 to limit current flow in the power circuit to 10 milliamps? In order to use Ohm's Law, we need to know the voltage drop across the resistor. Remember that the LED has a forward voltage drop of 2 volts. The total voltage drop of the circuit will be the voltage supplied by the battery. My fresh battery supplies 9.6 volts. We calculate the voltage drop across the resistor as total voltage drop minus voltage drop of the LED:

9.6 volts total drop – 2 volts for LED = 7.6 volts drop across R1

We now know the voltage drop across R1 and the current desired (10 milliamps) and can calculate the resistance needed for R1:

Current = Voltage/Resistance

Or

Resistance = Voltage/Current

Resistance of R1 = 7.6 volts/0.010 amps = 760 ohms

If we use a 760 ohm resistor for R1, then the current flow through the LED will be 10 milliamps. I don't happen to have a 760 ohm resistor, but I do have a 1,000 ohm resistor. If I use the 1,000 ohm resistor I should be extra safe because the LED will have a little less than 10 milliamps of current flow. Let's calculate that out.

Current = Voltage/Resistance

Current = 7.6 volts/1,000 ohms = 7.6 milliamps

Now you will make some measurements with the meter.

Measured resistance of resistor R1:

1. Disconnect the battery from the breadboard. This is a safety measure to protect your meter from damage when making a resistance measurement.
2. Set the dial on the meter to measure resistance.
3. Touch one probe of the meter to one of the wires of the resistor and the other probe to the other wire of the resistor.
4. Record the resistance value in ohms displayed on the meter

The measured resistance of R1 is __________________ ohms

Now reconnect the battery to the breadboard.

Measured voltage drop across the resistor R1:

1. Turn the power on if it is off. The LED should be glowing.
2. Set the meter to read DC volts (VDC or 20 volts DC, depending on your meter).
3. Touch the red probe of the meter to the wire on the positive side of the resistor and the black probe to the negative side of the resistor.
4. Record the voltage drop displayed on the meter

The measured voltage drop across R1 is _________________ volts

Measured voltage drop across LED D1:

1. Turn the power on if it is off
2. Set the meter to read DC volts
3. Touch the red probe to the anode of the LED and the black probe to the cathode of the LED
4. Record the voltage drop displayed on the meter

The measured voltage drop across LED D1 is _________________ volts

Measured total voltage drop for the power circuit:

1. Turn the power on if it is off
2. Set the meter to read DC volts
3. Touch the red probe to the red wire of the battery (where it connects to the breadboard) and touch the black probe to the black wire of the battery (where it connects to the breadboard).
4. Record the voltage drop for the power circuit

The measured total voltage drop for the power circuit is _______________ volts

Now sum the voltage drop of the resistor and LED and compare it to the measured total voltage drop for the power circuit: ______________ volts R1 + ________________ volts LED = __________ volts total

Your measured and calculated values for total voltage drop in the circuit should be the same or very similar values. If not, please check your work for errors.

Measured current for the power circuit:

1. You must be careful to follow these directions carefully because it is easy to damage the meter if you make an error in making this measurement. Turn on the power if it is off. The red LED should be glowing.
2. Remove the black battery wire from the breadboard, making sure the end of the wire does not touch any other wire on the breadboard.
3. Set the meter to read DC current (mA or 200 mA DC, depending on your meter)
4. Touch the red probe of the meter to the black wire that is connected to the cathode of the LED (you can pull this black wire out of the hole in the negative power bus a little so that you can touch the bare wire with the probe).
5. Touch the black probe to the black battery wire. If the probes are connected properly, then current will flow in the circuit. The LED will glow and the meter will display the amount of current.
6. Record the value of the current displayed on the meter _________________ milliamps

7. Remove the meter probes from the circuit, turn the meter off, and reconnect the black battery wire to the negative power bus of the breadboard. Also push the other black wire all the way back into the breadboard.

I believe you would agree that the red LED in the power circuit is bright enough to serve as an indicator that the power is on in your circuit. What would happen if you used a higher resistance for R1? A higher resistance would result in less current flowing through the LED. As the current flow is reduced, the LED emits less and less light. At some point the amount of light emitted by the LED will be so low that it can’t be seen, except in a dark room. In deciding on the amount of current that should flow in the LED when you are the designer of the circuit, you must first decide on the maximum safe level to allow so that the LED will not be damaged. An engineer must also try to reduce the amount of current used in a device as much as possible, especially if the device is powered by a battery. The engineer wants the device to be efficient in power usage. The more current your robot uses, the less time it will run before the battery becomes discharged.

You have now completed the lesson on the power circuit. In this lesson you learned about a new electronic component, the LED. You also learned how to use a breadboard to build a prototype circuit. You will continue to use the breadboard in the following lessons to test additional circuits contained in the line following robot. In the next lesson you will learn about variable resistors, especially the photoresistor.