

CALIFORNIA STATE UNIVERSITY
LOS ANGELES

Department of Electrical and Computer Engineering

EE-2449 Digital Logic Lab

EXPERIMENT 1
INTRODUCTION TO ELECTRIC CIRCUITS

Required hardware and tools: Breadboard with test circuitry, 15 K Ω (Kilohm) resistor (brown-green-orange), 2.2 K Ω resistor (red-red-red), 330 Ω resistor (orange-orange-brown), 2 green LEDs, 2N4124 NPN Silicon Transistor, AL 21649 pushbutton switch, breadboard wires, and logic probe.

Resistor Color Code Conversion Calculator: To help you determine the value of resistors, you can use this calculator: <http://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code-4-band>. Notice that from 2 (red) through 7 (violet) the colors are arranged in the order they appear in a rainbow (ROYGBV), making it easy to remember numbers in this range.

Note: While conducting the experiment you should record the circuit diagrams of circuits you are building, record observations from experimenting with the circuits, and record your answers to the questions throughout the experiment in your lab journal (a composition book). If you have not had a chance to purchase the composition book, for the first experiment you can use a piece of paper that you will paste into your lab journal. Every section that requires you to build a circuit and test it has an asterisk (*). For those sections, demonstrate the working circuit to your lab instructor. They will sign off on your experiment. You can often build multiple circuits or variations before getting a sign off and then demonstrate the various versions of the circuit together to your instructor.

1.1 Simply defined, an electric circuit is a closed loop where through which charges (electrons) can continually flow. Electric circuits can be analog or digital. Analog circuits operate on continuous signals whereas digital circuits operate on discrete, usually binary, signals. Binary signals have two discrete values or logic levels: a high value of 5V (volts) in this lab represents logic one and a low value (0V or ground) represents a logic zero. Fundamental components in analog circuits are resistors, capacitors, inductors, diodes, transistors, and operational amplifiers. Fundamental components in digital circuits are transistors, logic gates, and integrated circuits (ICs). ICs are a combination of logic gates that are integrated to implement simple digital circuits like counters and decoders and more complex digital systems like microprocessors and microcontrollers. As you'll discover in this experiment, all digital components are actually analog circuits underneath.

Many circuits will have both analog and digital components such as in embedded systems which may have analog inputs such as sensors and analog outputs such as output voltages that control motor speed and a digital microcontroller programmed to control the system.

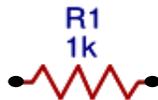
In this experiment, you will be introduced to the basics of voltage, current, and resistance which are the building blocks of any electric circuit. You will also discover how transistors work as electrical switches and see how they can be combined to build digital components known as logic gates.

1.2 Electricity is the movement and interaction of electrons which are charged particles. Voltage is a measure of the potential difference in charge between two points in an electric field. Voltage is measured in volts (V) which is a measure of the energy per unit charge. So a battery that is a source of energy (electrons) will have a potential difference in charge between its two terminals. For example a 9V battery would supply 9 Joules of electric potential energy per every 1 Coulomb of charge which moves between its negative and positive terminals. Current, measured in amperes (A), is the rate at which electric charge flows past a point in a circuit. When a load is connected to the positive and negative terminals of a battery, an electric circuit will be formed and current will flow within the battery from its negative terminal to its positive terminal, then through the load and back to the negative terminal. A load in a circuit is an electrical component containing resistance, which dissipates energy as heat; examples are the appliances and lights in your home. Resistance is measured in Ohms (Ω). **Ohm's Law** defines the relationship between voltage, current, and resistance.

$$V = IR \quad (\text{Eq. 1.1})$$

Here **V** represents the voltage, **I** represents the current, and **R** represents the resistance.

While all electrical components, including wires, have some level of resistance, *resistors* are manufactured components with specific ohmic values designed to control the amount of current flowing through a circuit. They are passive components that consume power. Resistors have two terminals (end-points) and are represented by a zig-zag line such as:



Here R1 refers to a specific resistor in a circuit, and 1K is an abbreviation of $1K\Omega$ (or 1×10^3 Ohms) which is the value of the resistor. Resistors are manufactured to provide various values of resistance and, as mentioned earlier, are color-coded to indicate those values.

Figure 1.1 below shows a simple electric circuit with a power source (voltage supply) and a resistor connected together using wires. The power source provides electric energy to the load, which in this case is the resistor. The power source could be a battery or a power supply such as the adjustable DC (direct current) power supply that we will be using in this lab. The power supply converts AC (alternating current) voltage from the wall outlet to an adjustable DC voltage.

The energy for the AC power source could come from many different sources including wind, solar, fossil fuels (coal, oil, natural gas), hydrogen, hydroelectric (water), and nuclear. The DC power supply is regulated to provide a constant voltage or current. In our lab, we will be using TTL (transistor-transistor-logic) chips which typically use a 5V voltage supply. TTL logic treats input voltage levels in the range 0V to 0.8V as logic zero and levels in the range 2V to 5V as logic one.

In the circuit of Figure 1.1, current (I) flows through the resistor as shown. To determine how much current will flow, we can use Ohm's Law.

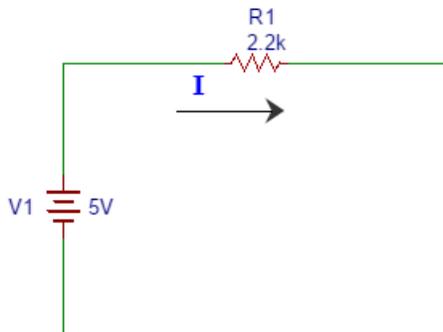


Figure 1.1. Simple electric circuit with power supply (V1) and resistor (R1)

Aside: The source of energy in a battery is a chemical reaction. Batteries provide a relatively constant voltage level. AA, AAA, C, and D alkaline batteries have an average voltage output of 1.5 V (other types like NiMH output 1.2 V). For a mobile power supply for this course to use at home, you can buy an inexpensive battery holder (maybe < \$2) at an electronic supply store or online. Pick one that holds 4 AA batteries ($4 \times 1.5 = 6V$) and has wire leads to insert into the power terminals of your breadboard.

Use Ohm's Law to compute the current in the circuit of Figure 1.1. Place your result in your lab journal.

1.3a You could build the circuit in Figure 1.1 and confirm your computation by measuring the current using a multimeter (you will do this type of measurement in your EE 2049 lab). For this course, we just want to gain a basic understanding of electric circuits before delving into digital logic circuits. Rather than measure the current, we want to observe the effect of varying the resistance on another load, namely an LED (light emitting diode).

A diode is an electrical component built from semiconductor material that only allows current to flow through it in one direction. In an LED, when the current flows through the diode, light is emitted¹. LEDs are designed to emit light of a specific wavelength (color) depending on the material that the LED is made from. LEDs are non-ohmic devices (they do not follow Ohm's Law). There will be a voltage drop (called the forward bias voltage) across the LED when it is on. The voltage drop is dependent on what wavelength the LED is designed to emit (e.g., the color of the LED). For the green LED we are using in this experiment, we will assume the voltage drop is 2.1V.

Figure 1.2 (below) shows a circuit diagram with a resistor and LED. Resistors are used to control the amount of current flowing through the LED. If the circuit were connected without the resistor, the LED would be over-driven; it would light brightly for a while and then burn out.

¹ If you want to learn more about LEDs, there are many useful resources online. Here is a nice explanation of how they work (<http://www.explainthatstuff.com/diodes.html>). You'll learn more about them in EE 3700.

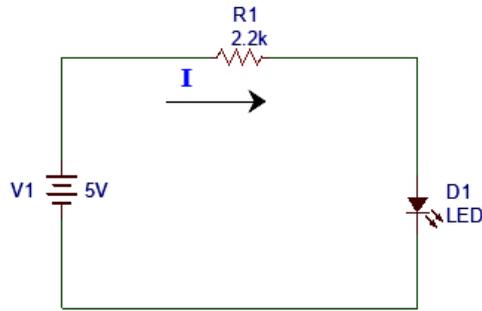


Figure 1.2. Simple electric circuit with resistor and LED.

In Figure 1.1, the voltage across the resistor was equal to the full supply voltage (ignoring any voltage drops due to the resistance in the wires) so $V_R = 5V$. But in Figure 1.2, the 5V is divided between R1 and the LED. Assuming a 2.1V drop across the LED, the voltage across the resistor is thus $V_R = 5V - 2.1V = 2.9V$. For this circuit, compute the current flow I around the loop.

As you did in part 1.2, draw the circuit in your lab journal (or on a piece of paper that you'll paste in your lab journal later). Include the value of current calculated for the 2.2K Ω resistor and also for a 330 Ω and a 15K Ω resistor. Show all calculations.

Question: Assuming that the maximum current through the LED is 20mA and the voltage drop across the LED is 2.1V, compute the smallest value for R_1 that can be used without damaging the LED. Include question and your answer in your lab journal.

1.3b* (* = lab work)

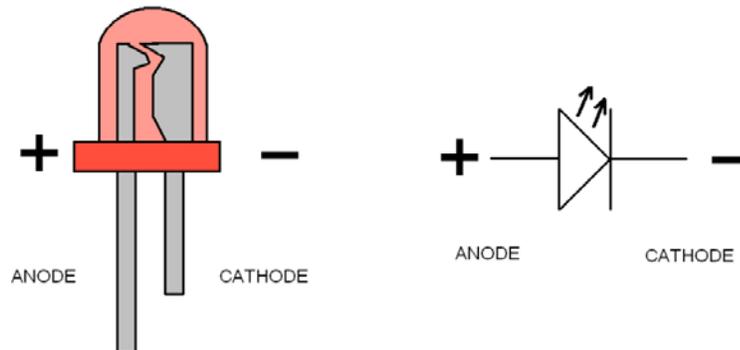


Figure 1.3. LED terminals. The anode (+) terminal has the longer lead and the cathode (-) terminal has the shorter lead.

Build the circuit shown in Figure 1.2 on the breadboard. While the orientation of a resistor in a circuit does not matter (current can flow in either direction through a resistor), current can only flow in one direction in an LED, from the anode (positive terminal) to the cathode (negative terminal). Figure 1.3 shows how to determine which is the anode (longer lead/wire) and which is the cathode (shorter lead). Figure 1.4 (below) shows how to connect the components.

Note that on your breadboard, the five holes along each row are internally connected. Also note that there are two buses running vertically along each section of the board. The red bus has been wired to connect to the positive terminal of the breadboard, which, in turn, is connected to the positive terminal of the power supply (5V). Similarly, the blue bus has been wired to connect to the negative terminal of the breadboard which, in turn, is connected to the ground terminal of the power supply (0V).

First wire up your circuit and then connect the negative (ground) terminal of the DC power supply to the breadboard's negative terminal's banana "jack" (opposite of banana plug). Likewise, connect the positive terminal of the power supply to the breadboard's positive terminal's jack. Turn on the power supply and adjust the supply voltage to 5V.

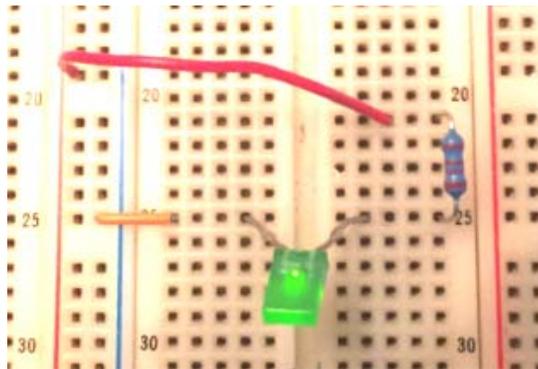


Figure 1.4. Example of how to build the circuit from Figure 1.2 on your breadboard.

Vary the values of R and observe the brightness of the LED. Fill in Table 1.3 and enter it in your journal.

Table 1.3. As you vary the values of R , record your observations of the brightness of the LED.

R	Observations on LED Brightness
2.2K Ω	
330 Ω	
15K Ω	

Questions:

- What is the relationship between the amount of current flowing through the LED and the brightness of the LED?
- Now vary the supply voltage from 0V to 5V and record your observations. At what voltage level does the LED seem to turn off?

1.4* Oftentimes circuits are controlled by a switch. Think about the lights and appliances in your house. In the circuit you built in the previous section (Figure 1.4), you could manually turn the LED off by removing one of the circuit's wires to create an open circuit (current cannot flow through an open circuit) and then replacing it to close the circuit and turn the LED on. But creating an open or closed circuit using a switch is far more efficient.

Figure 1.5 shows an example of a pushbutton switch different from the ones in the test-circuit. This one has 3 leads. When the switch is not depressed (normal condition) the center lead is internally connected to the right-hand lead (the upper contact). When the button is depressed, the center lead connects to the left-hand lead (the lower contact). We can use this to control the circuit in Fig. 1-6 as described below.

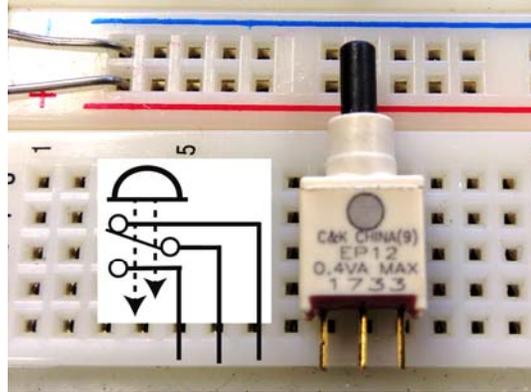


Figure 1.5. The pushbutton switch to be used in the circuit of Fig. 1-6.

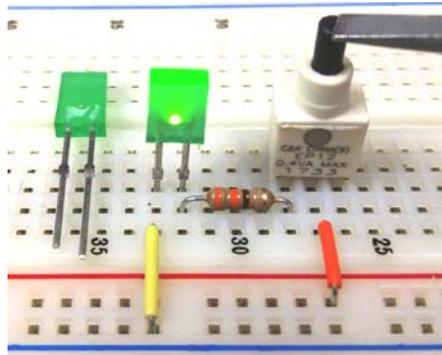


Figure 1.6. Simple resistor-LED circuit with a pushbutton switch to turn on and off the LED.

Build the circuit shown in Figure 1.6, which is just Figure 1.4 with the switch of Fig. 1-5 added. The resistor's value here is 330 ohms. A screwdriver is shown depressing the switch, thereby internally connecting the switch's center and left-hand leads. This allows current to flow up from the 5V (red) bus to the center lead and out the left-hand lead to the resistor. Current then flows through the resistor into the LED's anode and out of its cathode (thus turning it on) down to the ground (blue) bus. The resistor prevents excess current from flowing through the LED.

The LED's leads are not of equal length (as the one at the left illustrates). The longer one connects to the LED's anode and must be inserted next to the resistor. If you reverse the leads, current can't flow; an LED is a diode and can only conduct in one direction.

Press and release the pushbutton switch and record your observations.

1.5 There are times when you want to control a circuit automatically rather manually. Consider your air conditioner at home. You could turn it on and off manually, or you can use a thermostat that has a sensor to measure the temperature and a control system to turn the air conditioner on or off in order to maintain a desired temperature. In this case, you need to have a switch that can be controlled electronically. Transistors are electronic switches. Figure 1.7 shows the circuit diagram for a NPN transistor.

(Note: In this experiment we want to have a basic understanding of what transistors are and how they work, but we will not be able to explore the physics behind semiconductor transistors. You will learn more about transistors in EE 2040 and EE 3700.)

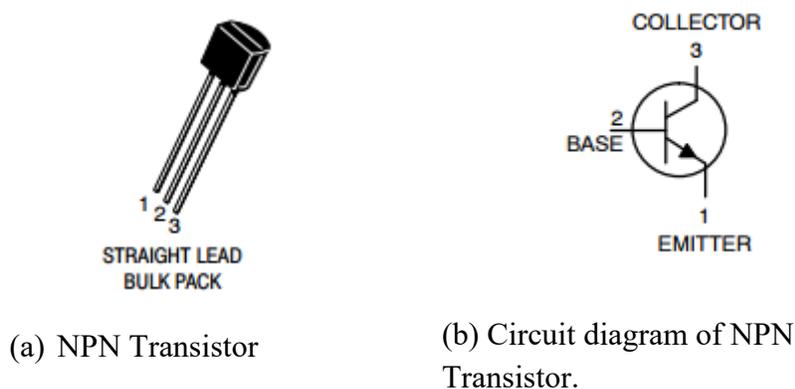


Figure 1.7. An NPN Transistor, an electronic (semiconductor) switch.

How is an NPN Transistor like a mechanical switch? The transistor is turned on when a small current flows into its base. This small current will induce a much larger current to flow from the collector to the emitter which can be used for example, to turn on an LED like the one in Figure 1.8. Conversely, when the base current is cut off, no current flows from collector to emitter and the LED is turned off.

Figure 1.8 shows how to connect the transistor to our simple resistor-LED circuit to control turning the LED on and off.

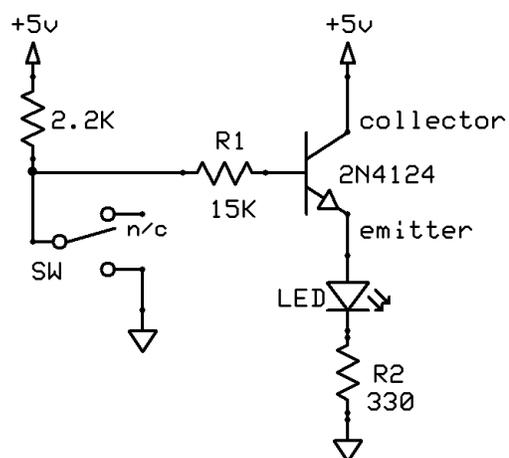


Figure 1.8. Resistor-LED circuit controlled by an NPN transistor.

1.6* Build the circuit of Figure 1.8. Record observations in your journal as you open and close the switch.

Here you will use an LED from the LED "bargraph". Each of the ten LEDs is already connected to ground through a 330 ohm resistor, as shown in Figure 1.8, so you won't need a separate LED and R2 resistor. In Figure 1.9 below left, the resistors are available in the 330 Ω Array. (You can refer to the Intro section of the lab manual, pg. 4, to see how the LEDs and resistors are connected.)

Connect the transistor's emitter directly to a bargraph LED through one of the holes circled above the bargraph. Then connect the base resistor (R1) to the output of one of the 12 toggle switches. A chip (red) with 4 of these is shown at the right in Fig. 1-9. Output holes for the switches lie above them in the diagram (those for the switch at row 62 are shown circled).

As shown in Figure 1.8, when the switch is down, the output connects to ground. When it is up, the switch is not connected (n/c) so current can flow into R1 and the base from the 5V bus through a 2.2K "pullup" resistor. The voltage drop across this resistor will be very low, so we can say that the switch output is "pulled up" to just under 5V. The real purpose of the resistor is to prevent a short-circuit from 5V directly to ground when the switch is down.

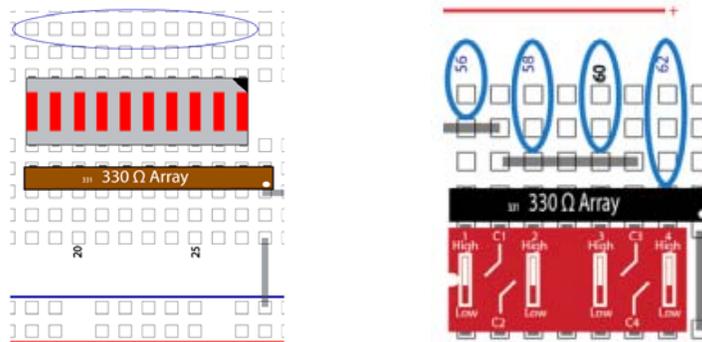


Figure 1.9. LED bargraph at left; toggle switch access diagram at right.

1.7 Transistors are the building blocks of digital logic circuits. Digital logic uses binary logic signals that are high (logic 1) and low (logic 0). Why binary? Because transistors are used as switches and so have two states. In logic, since things are true and false, we can refer to these states that way. With "positive logic", True would be considered logic 1 and False would be considered logic 0.

A simple logic function is the NOT function. If the input to the function is True (1) then the output is False (0) and vice-versa. We can describe the behavior of a logic circuit using a "truth table". The inputs to the logic function are shown on the left of the table and the corresponding outputs are shown on the right.

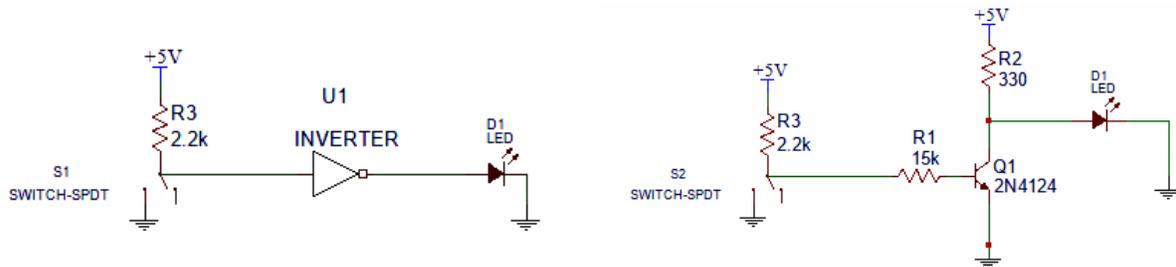
Input	Output
False	True
True	False

(a) Truth table of a NOT function.

Input	Output
0	1
1	0

(b) Truth table of a NOT function using positive logic (0 = False, 1 = True).

A NOT function (also known as an INVERTER) can be built using transistors. We refer to basic digital logic circuits as “gates”. Other basic logic functions include AND, OR, XOR, NAND, NOR, and XNOR gates. You will learn more about these in Experiment 3. Figure 1.10 shows the symbol of a NOT gate and the circuit to build it using an NPN transistor and resistors.



(a) Circuit built with an INVERTER gate.

(b) Circuit for an INVERTER function built with a discrete transistor

Figure 1.10. INVERTER circuits: with gate and with transistor.

Based on your understanding of how the transistor works, you can see how the circuit in Figure 1.10b will act as an INVERTER. It's behavior is as follows:

- When the switch is closed, input is grounded so there is no voltage across R1 and, therefore, no base current; instead all current flows down through R3 to ground. As a result, the transistor doesn't conduct and current through R2 is diverted into the LED, turning it on. Thus, when input goes low, output goes high (LED on).
- When the switch is open, current flows through R3 and R1 into the transistor base. The transistor conducts, pulling the collector voltage almost to zero (the transistor saturates). This cuts off current into the LED. Thus when input goes high (open switch), output goes low (LED off).

(Note: collector resistor R2 provides protection in two ways. (1) When switch is open, the transistor saturates and collector voltage is essentially 0V. R2 limits the current flowing from the 5V supply ($I_c = 5/R2$). But if R2 were 0, there would be excessive current flow into the collector which would likely blow the transistor. (2) When switch is closed, the transistor does not conduct and no current flows into the collector. R2 limits the current flowing into the LED which might otherwise also likely blow.)

1.8* Now that you understand more about how electric circuits work, please refer to the test circuit description and schematic in the **Introduction** section of the Lab Manual. Use your logic probe to verify that the test-circuit inputs all work properly; i.e. pushbutton switch outputs, toggle switch outputs (12), and 555 timer output. For the timer output, switch the large vertical (cylindrical) 470 μF capacitor into the timer circuit by moving the select switch toward the other capacitor. With the cylindrical one thus connected, the timer output frequency is a slow 1 Hz.

Clock output: check the timer circuit's output with the logic probe. If the timer is working, the probe's LEDs should flash red and green at 1-second intervals--easy to detect. Now, move the capacitor select switch the other way. This brings the 0.47 μF capacitor (much smaller value) into the circuit and the timer frequency jumps to 1,000 Hz. The probe LEDs again flash red and green but so rapidly that the eye can't see them flashing--they appear to be on all the time.

For the test-circuit's LED bargraph chip, check it by connecting a wire from the push-button switch to each LED in sequence. Make sure each one turns on and off.