Cat. No. **28-261**

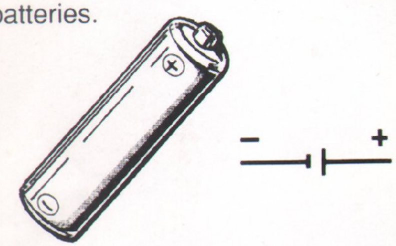
Science Fair
60 IN ONE
Electronic Project Lab
Includes everything needed to discover the exciting world of electronics
Requires 4 "AA" batteries. For ages 10 and up.
ELECTRONIC PROJECT LAB
PIEZO BUZZER
LED 1
LED 2
17 RESISTORS 18
27 CAPACITORS 28
35 TRANSISTORS 37
TRANSFORMER
BATTERIES
VARIABLE RESISTOR
SWITCH
KEY

Introduction

Your Science Fair 60–in–One Electronic Project Lab will provide you with many hours of fascinating fun. It will also introduce you to magnetism, electricity, and physics.

This manual describes 60 projects you can build with this kit.

Before you begin, be sure you have four AA batteries. Place the AA batteries in the battery holder. Refer to the plus (+) and minus (–) markings on the holder to correctly install the batteries.



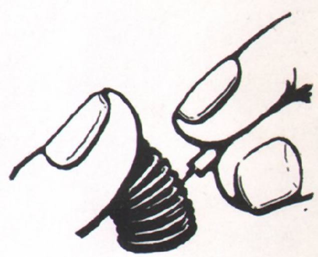
Do not ever leave the batteries in the holder when you are not using your kit.

Wiring Sequence

We provide wiring sequences for all sixty projects. The wiring sequence for Project 1 looks like this: (You get to build this circuit later.)

1–64, 2–3, 4–10, 9–43, 44–45, 46–63

The first thing you need to know to build the circuit is how to make a connection. Let's make the first connection for the first project now. The first connection in Project 1 is 1–64. This tells you to connect a wire from the terminal (spring) marked 1 to the terminal marked 64. First, locate the terminals. Then, select a wire long enough to reach between the two terminals. Finally, attach the wire. To attach a wire, bend the spring to one side with your finger and stick the wire into one of the gaps. Then, let go of the spring and it clamps the wire firmly in place.



After you connect Terminals 1 and 64, be sure the springs touch the metal part of the wire and not the plastic insulation. The project does not work if the metal part of the wires do not touch the springs. Use this method, and follow the wiring steps in this manual to build each project.

A Note to Parents and Educators

We have written and designed this 60-in-1 Electronics Lab to provide a basic practical introduction to electronics. We encourage you to supplement this introduction with further reading. Radio Shack stores sell several books that you can use for this purpose, and we have listed them below. There are also several magazines written for the electronics hobbiest that have interesting and informative articles, aimed at a novice audience. Also, check your local library, university, and bookstore for more material.

Getting Started in Electronics (Radio Shack Cat. No. 276-5003)

Basic Semiconductor Circuits (Cat. No. 276-5013)

Formulas, Tables, and Basic Circuits (Cat. No. 276-5016)

Schematic Symbols (Cat. No. 276-5017)

Optoelectronics (Cat. No. 276-5012)

Timer ICs (Cat. No. 276-5010)

Digital Logic Circuits (Cat. No. 276-5014)

Op Amps (Cat. No. 276-5011)

It is important to make the connections in the order given to prevent damage to the electronic parts.

Now, let's get started!

PARTS LIST

WIRE	YELLOW	2	3/4	IN	8	PCS
WIRE	RED	4	3/4	IN	8	PCS
WIRE	BLUE	9	1/2	IN	8	PCS
WIRE	ORANGE	11	3/4	IN	2	PCS
WIRE	YELLOW	16	1/2	FT	1	PC
EARPHONE					1	PC

Contents

1. An Electric Circuit

What is an *electric circuit*? To put it simply, an electric circuit is the path electricity follows as it flows from one place to another. But before we tell you any more, follow the wiring sequence and connect the wires for this project.

All done? Good! Now you're ready to learn.

Electric circuits, like the one you just built, are important because of the *work* the electricity does as it flows through the circuit. The work the electricity does usually results in light, heat, sound, or motion. For example:

- light from a lamp
- heat from an electric blanket
- sound from a radio or TV
- motion from a model car

When you move the switch down, the electricity flows from the *negative* (–) side of the batteries, through the resistor and the LEDs, and back to the *positive* (+) side of the battery.

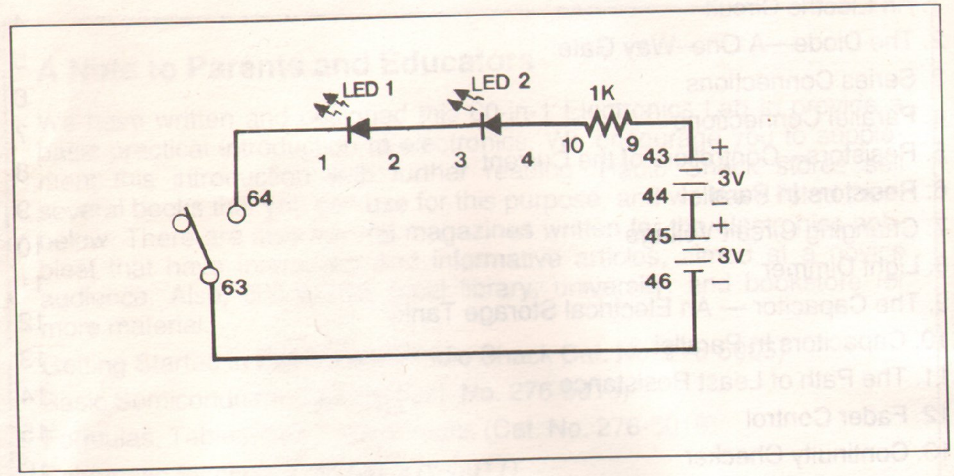
For any circuit to be complete, there must be a complete path from the negative side of the battery to the positive side. Moving the switch down connects Terminal 63 to Terminal 64. This completes the circuit and the electricity does its work—lighting the LEDs, of course. We call this a *closed circuit*.

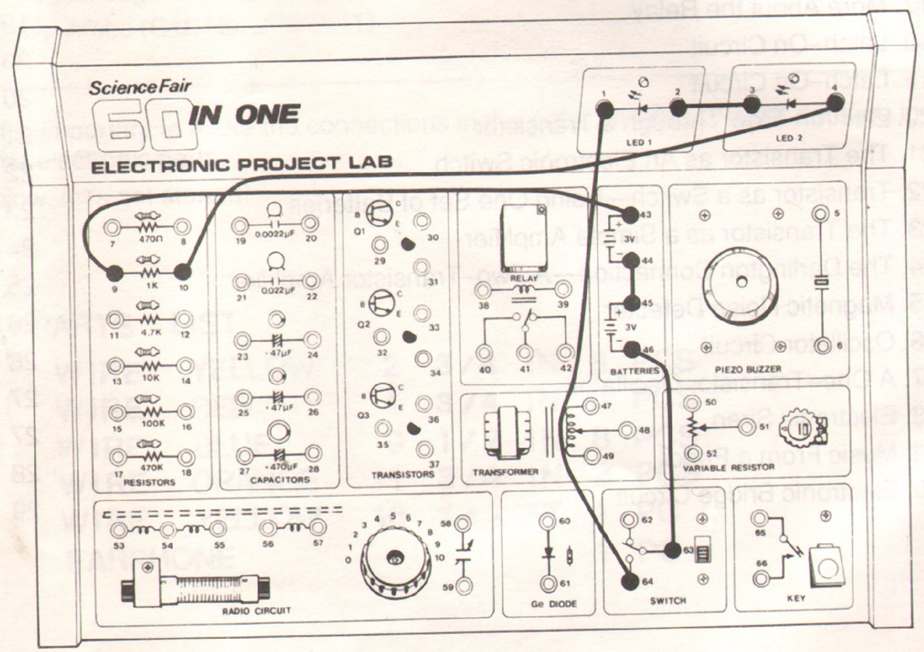
If you move the switch up, you disconnect Terminal 63 and 64 and the electricity can no longer flow, and no work is done. When the path for electricity is not complete and electricity cannot flow, we call the circuit an *open circuit*.

Now, let's change the circuit a little. Connect a wire between Terminals 63 and 64. This new wire lets the electricity take a *shortcut* around the switch. The LED stays on all the time, and the switch has no effect. When something causes electricity to take a shortcut, or causes the electricity to go where we don't want it to go, we call it a *short circuit*. Usually, a short circuit is bad because the electricity does things we don't want it to do. But don't worry—it's OK in this project.

So ... now you know what an electric circuit is. And, you know what open circuits and short circuits are. You're probably ready for the next project, but feel free to spend some more time studying this one if you want.

We'll see you at Project 2.





Wiring Sequence:
1–64, 2–3, 4–10, 9–43, 44–45, 46–63

2. The Diode—A One–Way Gate

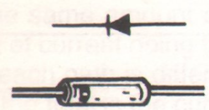
A diode is a one–way gate in a circuit. Electricity can flow one direction through a diode, but not the other direction.

Go ahead and connect the wires for this project—then, we'll explain more about how a diode affects a circuit.

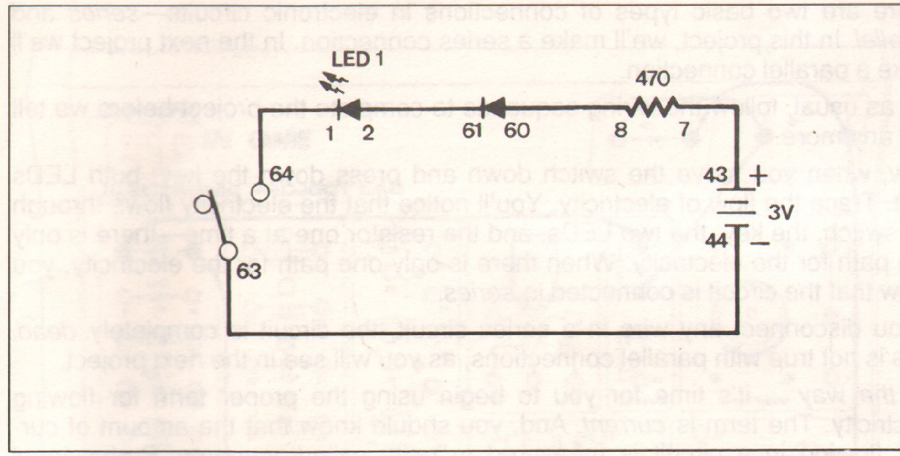
Move the switch down and the LED lights. If you trace the circuit from the batteries' negative terminal to the positive terminal, you'll see that the electricity flows to Terminal 61, through the diode, and to Terminal 60.

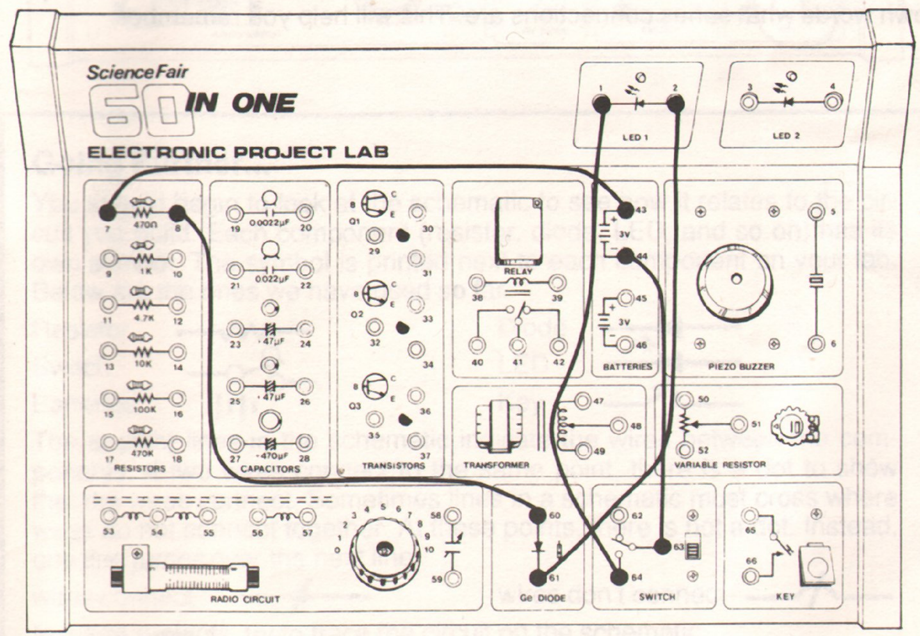
Look at the drawing of the diode and its symbol below and you'll see that electricity flows from the pointed end of the triangle to the wide end. This is the only direction electricity can flow through a diode.

SYMBOL



DIODE





Now let's see what happens when we reverse the direction the electricity flows. First, move the switch up. Then, reverse the wires that you connected to Terminals 60 and 61. Now, when you move the switch down, the LED does not light because the electricity is trying to flow the opposite direction through the diode.

Diodes are important parts of electric circuits because they can prevent electricity from going somewhere it shouldn't. We'll show you an example of this in a later project.

By the way ... how many diodes are there in this project? If you said one, you missed something. LED stands for *light–emitting* ***diode***. The LED also only lets electricity flow in one direction. The difference is that the LED produces light when electricity flows through it.

Look at the symbol next to the LED and you'll see that it is similar to the symbol for the regular diode. The arrows pointing away from the diode symbol show that the LED produces light.

Wiring Sequence
1–64, 2–61, 60–8, 7–43, 44–63

3. Series Connections

There are two basic types of connections in electronic circuits—*series* and *parallel*. In this project, we'll make a series connection. In the next project we'll make a parallel connection.

But as usual, follow the wiring sequence to complete the project before we tell you any more.

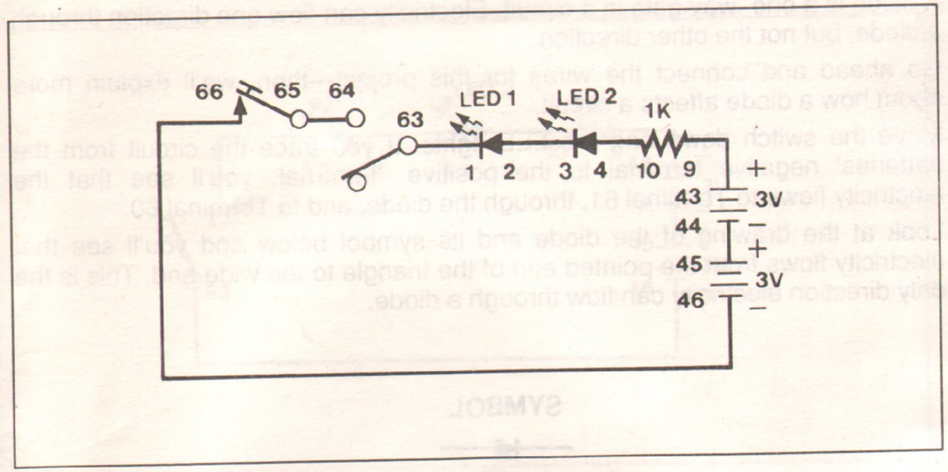
Now, when you move the switch down and press down the key, both LEDs light. Trace the flow of electricity. You'll notice that the electricity flows through the switch, the key, the two LEDs, and the resistor one at a time—there is only one path for the electricity. When there is only one path for the electricity, you know that the circuit is connected in *series*.

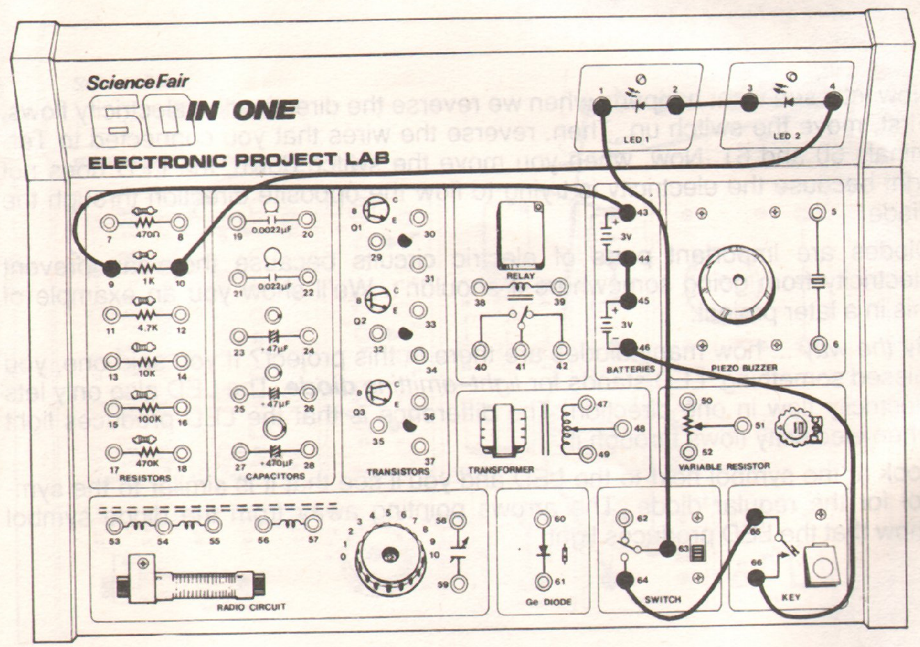
If you disconnect any wire in a series circuit, the circuit is completely *dead*. This is not true with parallel connections, as you will see in the next project.

By the way ... it's time for you to begin using the proper term for flowing electricity. The term is *current*. And, you should know that the amount of current flowing in a circuit is measured in units called *amperes*. Professional electricians and electrical engineers usually shorten the word to *amps*—so we will, too.

In a series circuit, the same amount of current flows through every component.

Before you move on to the next project, use the space below to write in your own words what series connections are. This will help you remember.





Wiring Sequence
1–63, 64–65, 2–3, 4–10, 9–43, 46–66, 44–45

4. Parallel Connections

When you connect electrical components in parallel, there is more than one path for the current (electricity). Make the connections for this project, and we'll show you how parallel connections affect a circuit.

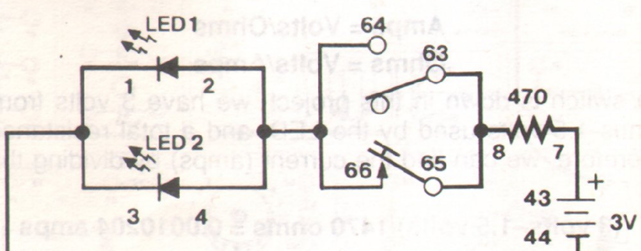
Press down the key and both LEDs light. Turn on the switch and both LEDs light, too. This means that there are two paths for current to flow through the LEDs—one through the key and one through the switch.

Trace the current through the LEDs and you'll see that there are two paths for the current here, too. To prove this, disconnect one of the LEDs and press down the key. The remaining LED still lights because there is a separate, complete path for current to each LED.

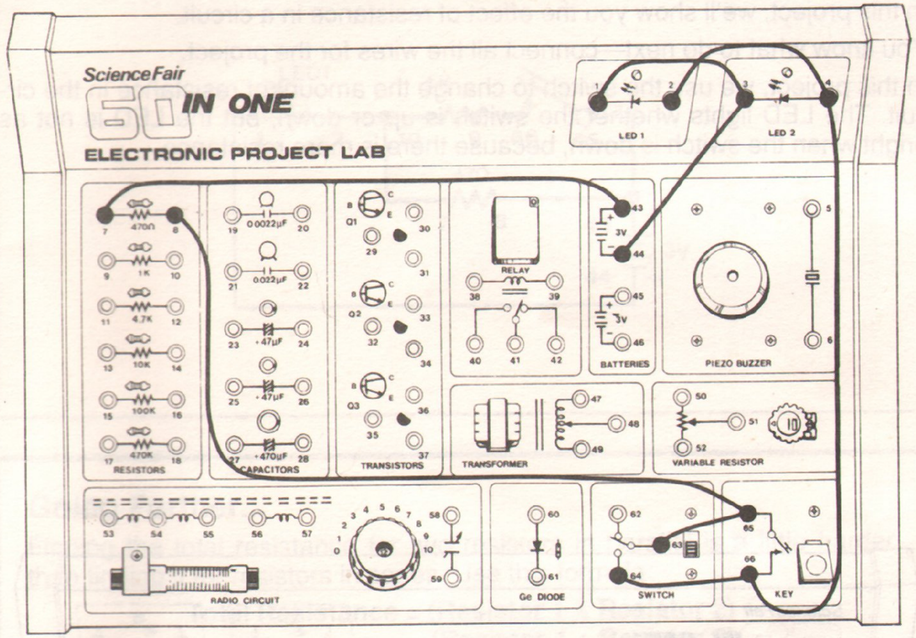
To explain the next feature of a parallel connection, we must teach you a new term—*voltage*. Voltage is the measurement of the force pushing the current through the circuit. The unit of measurement for voltage is a *volt*.

In a parallel connection, the same amount of voltage pushes current through each path. But, the amount of current going through each path is not the same, because the resistance of each path is different. If you add the current (amps) flowing through each LED, the total is the current used by the total circuit.

If you still have one of the LEDs disconnected, you can see the difference in current. Press down the key and note the brightness of the LED. Then, reconnect the other LED and press down the key again. The LEDs are not as bright, because now the current has to split into two paths, and not as much current flows through each LED.



Wiring Sequence
1–3–44, 2–4–66–64, 63–65–8, 7–43



Going Further...

You should begin to look at the schematic to see how it relates to the circuit you build. Each component (resistor, diode, LED, and so on) has its own symbol. The symbol is printed next to each component on your lab. Below are the ones we have used so far.

Resistor
Switch
Batteries
Diode
LED
Key

The straight lines in the schematic indicate the wires between the components. If two wires connect to the same point, there is a dot to show that the wires connect. Sometimes lines in a schematic must cross where wires do not connect together. At these points, there is not a dot. Instead, one line *jumps* over the next line.

wires connect
wires don't connect

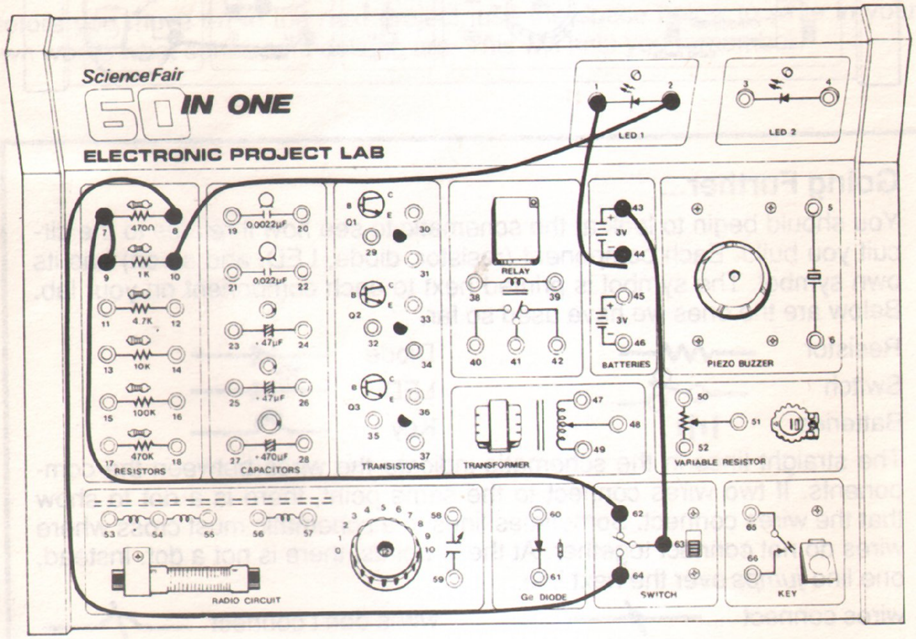
In future projects, try to trace the circuit on the schematic.

5. Resistors—Controllers of the Current

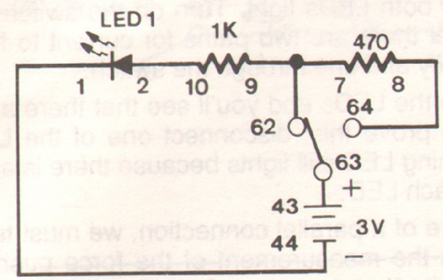
As the name suggests, resistors limit (or resist) the flow of current in a circuit. In this project, we'll show you the effect of resistance in a circuit.

You know what to do next—connect all the wires for the project.

In this project, we use the switch to change the amount of resistance in the circuit. The LED lights whether the switch is up or down, but the LED is not as bright when the switch is down, because there is more resistance.



Wiring Sequence
2–10, 9–7–62, 8–64, 63–43, 44–1



Going Further...

When resistors are connected in series, you find the total resistance by adding the values of the individual resistors. So ... what is the total resistance in the circuit when the switch is down? That's right—1470 ohms!

The LED does not have an exact resistance. Instead, it uses up a set number of volts. The LED uses 1.5 volts of electricity.

Now it's time to learn about *Ohm's law*. This law says that the voltage in a circuit is equal to the current (in amps) times the resistance (in ohms). This law can be stated in these formulas:

Volts = Amps x Ohms

Amps = Volts/Ohms

Ohms = Volts/Amps

When the switch is down in this project, we have 3 volts from the batteries, minus 1.5 volts used by the LED, and a total resistance of 1470 ohms. Therefore, we can find the current (amps) by dividing the volts by the ohms:

(3 volts–1.5 volts)/1470 ohms = 0.0010204 amps

For such small values, we usually state the current in milliamps (1/1000 of an amp) or microamps (1/1,000,000 of an amp). The current in this circuit is best stated as 1.0204 milliamps.

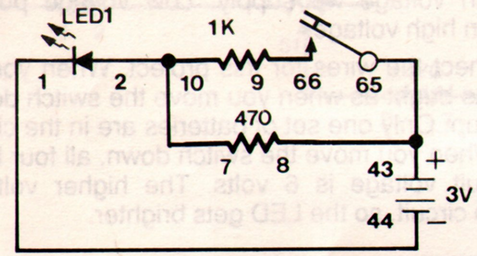
6. Resistors In Parallel

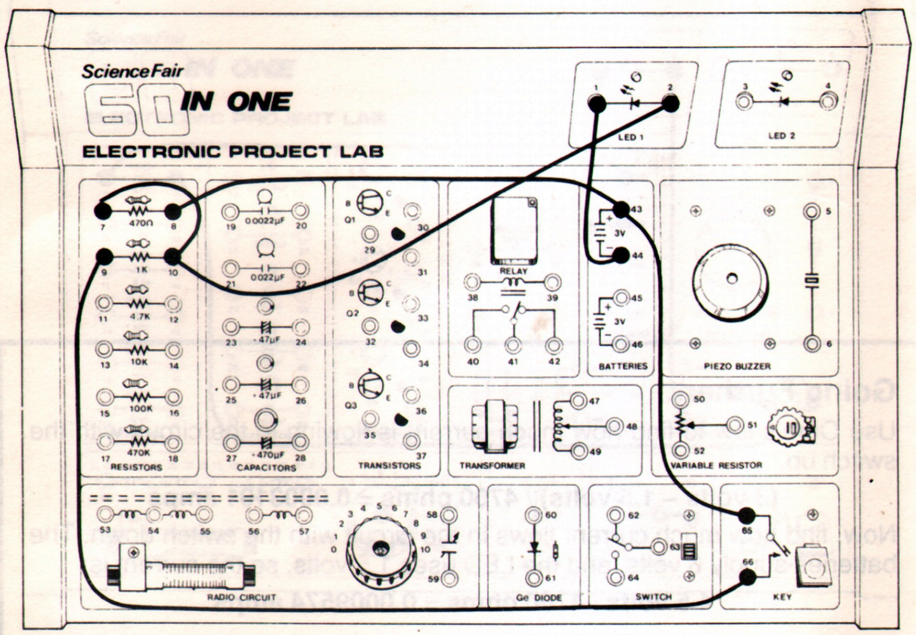
Now we'll learn more about resistors and parallel circuits. Go ahead and connect this circuit now.

In this project, we use the key to change the amount of resistance in the circuit. The LED lights whether the key is up or down. But, when you press the key, the LED gets brighter.

Trace the circuit with the key up and with the key down. When the key is up, all of the current in the circuit must flow through the 470 ohm resistor. When the key is down, some additional current goes through the 1K ohm resistor. Since more current flows through the circuit, the LED gets brighter.

When you press the key, you connect the resistors in parallel. Resistors in parallel have less resistance in the circuit than either resistor by itself.





Wiring Sequence
2–10–7, 9–66, 8–43–65, 44–1

Going Further...

Finding the total resistance for two resistors in parallel is a little harder than finding it for resistors in series. Use this formula:

Total Resistance = (Resistor 1 X Resistor 2) / (Resistor 1 + Resistor 2)

So, when you press the key, the resistance is:

(470 x 1000)/(470+1000) = (470,000/1470) = 319.72 ohms

What is the total current flowing through the circuit when you press down the key? Remember Ohm's law? We know that we have 3 volts from the batteries, 1.5 volts used by the LED, and a total resistance of 319.72 ohms. So, the current is:

(3 volts – 1.5 volts) / 319.72 ohms = 0.0046916 amps

or 4.6916 milliamps.

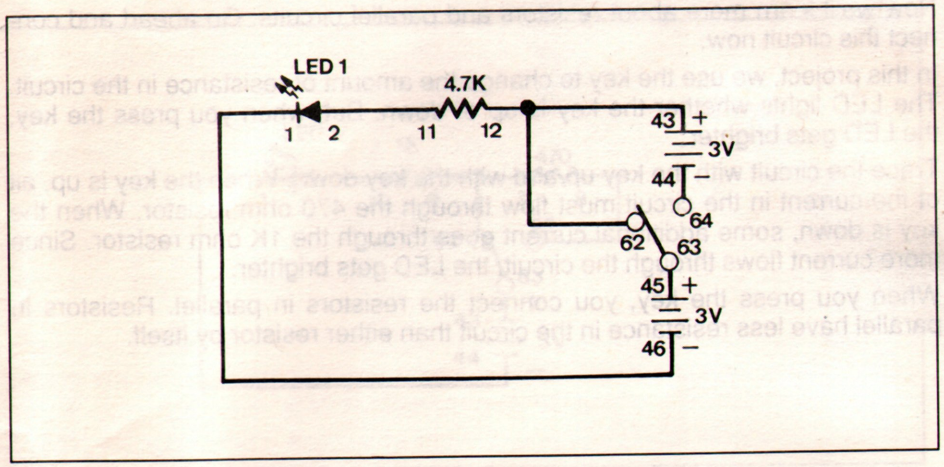
How much of the current flows through each resistor? For the 470 ohm resistor, we know that the voltage used is 3 volts minus 1.5 volts (used by the LED), or 1.5 volts used by the resistor. So the current flowing through it is 1.5 volts/470 ohms = 0.0031915.

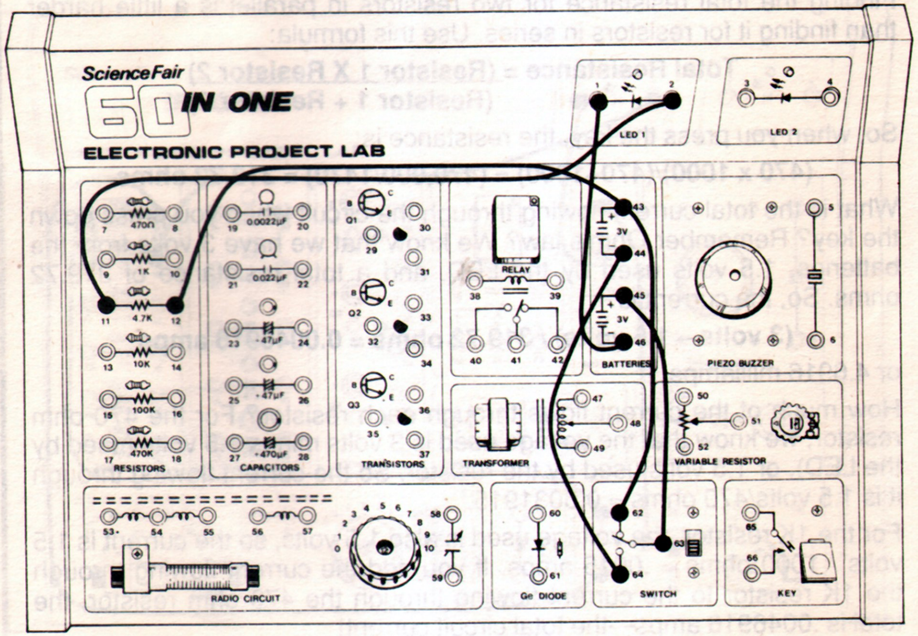
For the 1K resistor, the voltage used is also 1.5 volts, so the current is 1.5 volts / 1000 ohms = .0015 amps. If you add the current flowing through the 1K resistor to the current flowing through the 470 ohm resistor, the total is .0046916 amps—the total circuit current!

7. Changing Circuit Voltage

In the previous projects, you learned how an electric circuit provides a complete path for current, and how to adjust the amount of current flowing in the circuit by changing the resistance. Usually we control the amount of current by selecting how much voltage we supply. Low voltage pushes less current through a circuit than high voltage.

Go ahead and connect the wires for this project. When you move the switch up, the LED is not as bright as when you move the switch down. Trace the circuit with the switch up. Only one set of batteries are in the circuit, so the circuit voltage is 3 volts. When you move the switch down, all four batteries are in the circuit, so the circuit voltage is 6 volts. The higher voltage makes more electricity flow in the circuit, so the LED gets brighter.





Wiring Sequence
2–11, 12–43–62, 44–64, 63–45, 46–1

Going Further...

Use Ohm's law to find how much current is flowing in the circuit with the switch up.

(3 volts – 1.5 volts) / 4700 ohms = 0.0003191 amps

Now, find how much current flows in the circuit with the switch down. The batteries supply 6 volts, and the LED uses 1.5 volts, so the current is:

4.5 volts / 4700 ohms = 0.0009574 amps

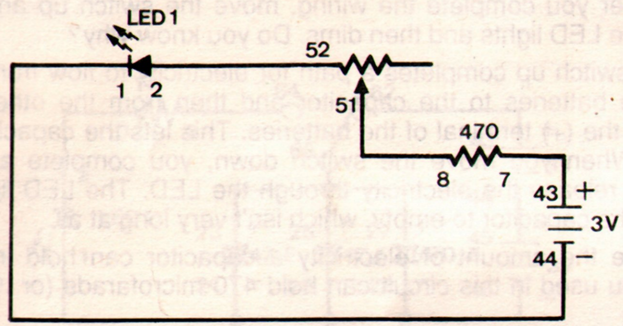
8. Light Dimmer

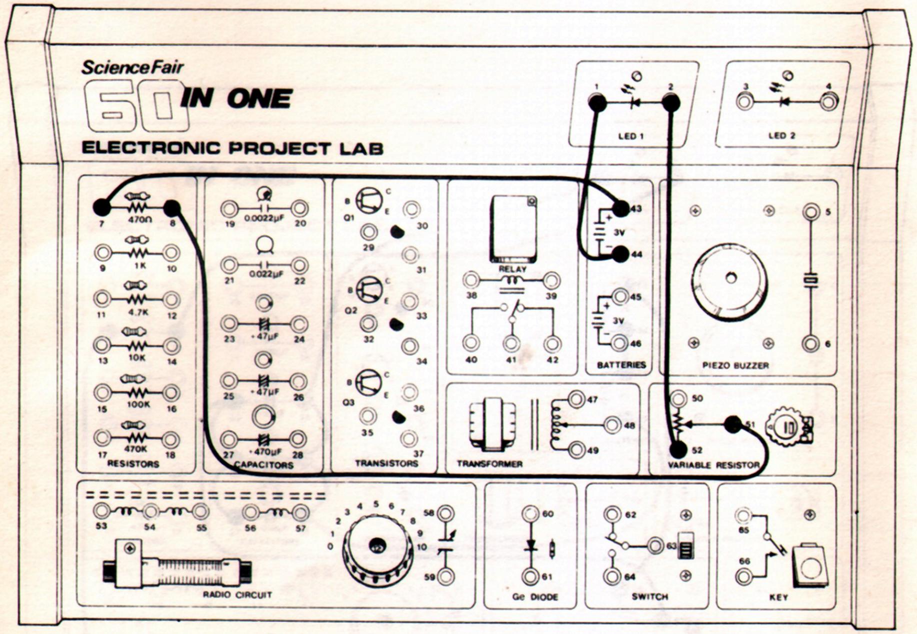
In this project, we show you another way to change circuit resistance. We use a variable resistor. You can change the variable resistor's resistance by turning its control. You can adjust the resistance of the variable resistor in this lab to anywhere between 0 and 1000 ohms.

Connect the wires. Then, we'll show you how it works.

You turn the top of the variable resistor to change its value. Go ahead and turn it counterclockwise now. The LED gets brighter. Now, turn it clockwise. The LED dims.

Variable resistors are also used as volume, and speed controls. Can you think of some other uses for a variable resistor?





Going Further...

As you turn the top of the variable resistor, a *wiper* moves across the top of a 1K ohm resistor. The wiper connects to Terminal 51, and the ends of the fixed resistor connect to Terminals 50 and 52. When you turn the wiper toward Terminal 50, there is less resistance between Terminals 51 and 50, and more resistance between Terminals 51 and 52. If you turn the control all the way toward Terminal 50, there is no resistance between Terminals 50 and 51, and there is 1K ohm resistance between Terminals 51 and 52.

Use what you have learned to answer the following questions:

What type of circuit is this (series, parallel, or a combination)?

How much resistance is in the circuit when you turn the control fully clockwise?

How much resistance is in the circuit when you turn the control fully counterclockwise?

Answers:

Series.

1470 ohms (1000 ohms + 470 ohms)

470 ohms (470 ohms + 0 ohms)

(3 volts – 1.5 volts)/(470 ohms + 500 ohms) = 1.5464 milliamps

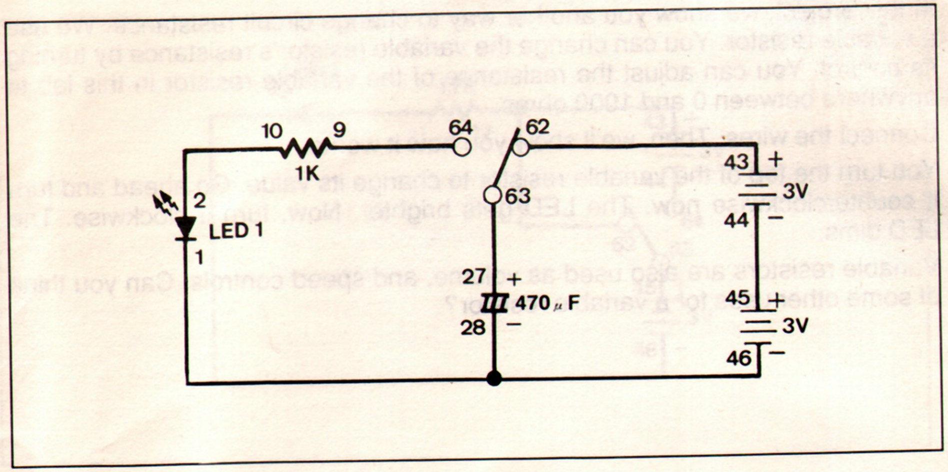
Wiring Sequence
2–52, 51–8, 7–43, 44–1

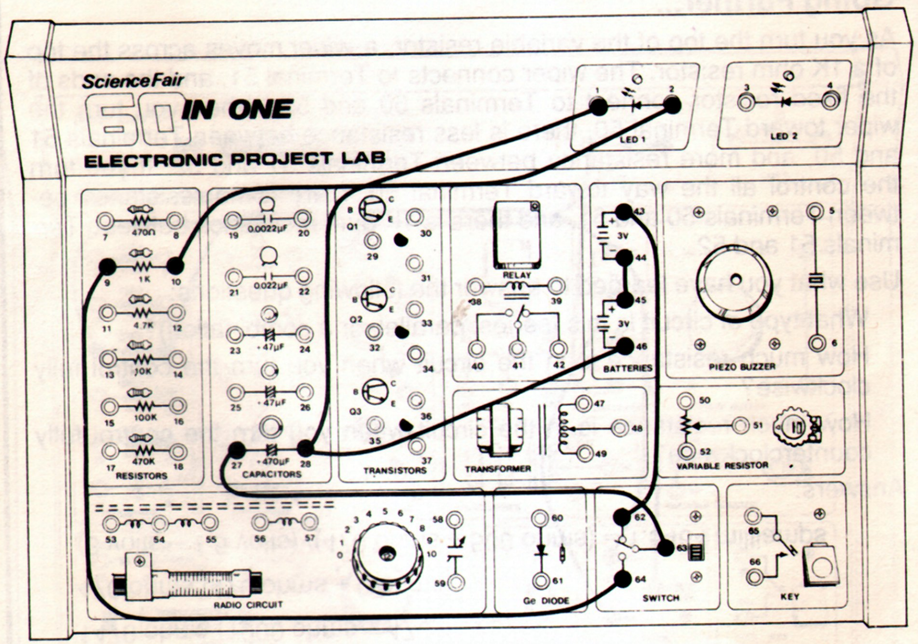
9. The Capacitor — An Electrical Storage Tank

A capacitor stores and releases electricity. This project lets you see this for yourself. After you complete the wiring, move the switch up and then down. Surprise! The LED lights and then dims. Do you know why?

Setting the switch up completes a path for electricity to flow from the (–) Terminal of the batteries to the capacitor and then from the other side of the capacitor to the (+) terminal of the batteries. This lets the capacitor *fill up* with electricity. When you move the switch down, you complete a path for the capacitor to release the electricity through the LED. The LED lights just long enough for the capacitor to empty, which isn't very long at all.

We measure the amount of electricity a capacitor can hold in *farads*. The capacitor you used in this circuit can hold 470 microfarads (or .00047 farads) of electricity.





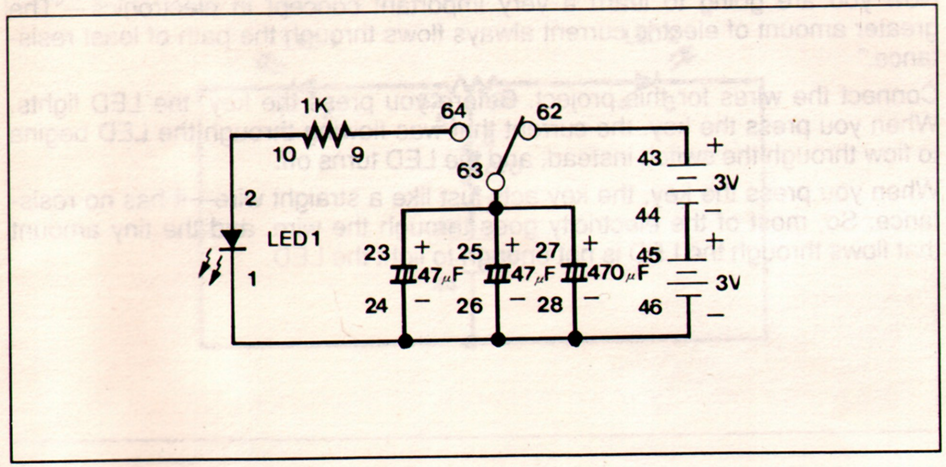
Wiring Sequence
2–10, 9–64, 63–27, 62–43, 1–28–46, 44–45

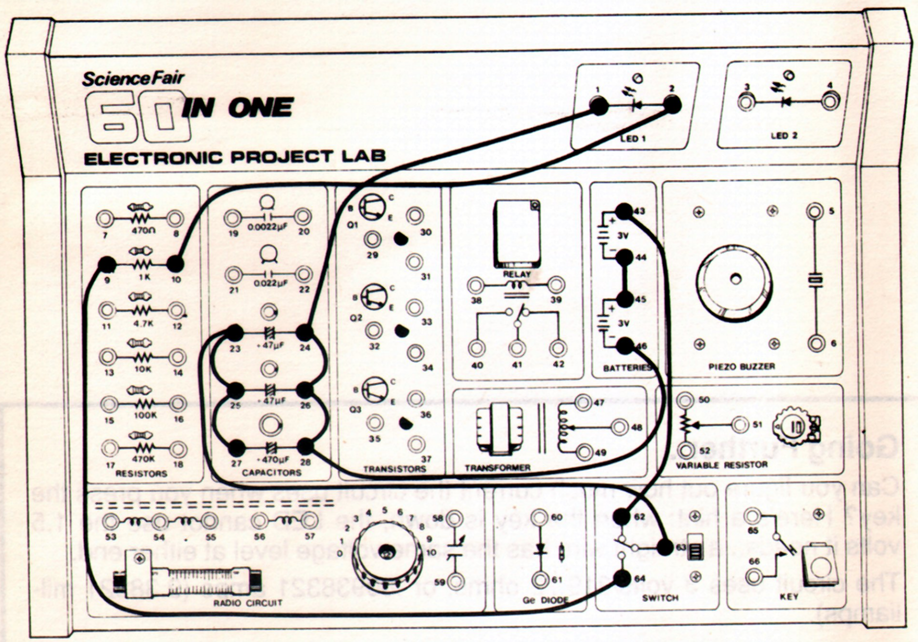
10. Capacitors In Parallel

Now, let's learn about capacitors connected in parallel. In this project, you connect three capacitors in parallel.

Remember that the unit for the amount of electricity a capacitor can hold is the farad, and one microfarad is one millionth of a farad.

Before you start wiring this project, move the switch up. Now complete the wiring. If you move the switch down, the LED lights for a short time—the time is longer than the time in Project 9, because the capacitance in this circuit is larger than the capacitance in the last project because capacitors in parallel have higher capacitance than one of the capacitors by itself.





Wiring Sequence
1–24–26–28–46, 2–10, 9–64, 62–43, 63–23–25–27, 44–45

Going Further...

When you connect capacitors in parallel, add all their capacitances to get the total circuit capacitance.

In this project, you connect one 470μF and two 47μF capacitors in parallel. The total capacitance is 564μF (470 + 47+ 47μF).

The equation is shown as follows:

$$C_{total} = C_1 + C_2 + C_3$$

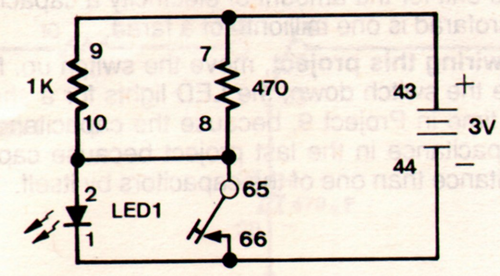
What is the total capacitance of all capacitors in your lab connected in parallel? Did you get 564.0242 μF? Great! Now let's move on to Project 11.

11. The Path of Least Resistance

Now you are going to learn a very important concept in electronics—"The greater amount of electric current always flows through the path of least resistance."

Connect the wires for this project. Before you press the key, the LED lights. When you press the key. the current that was flowing through the LED begins to flow through the switch instead, and the LED turns off.

When you press the key, the key acts just like a straight wire—it has no resistance. So, most of the electricity goes through the wire, and the tiny amount that flows through the LED is not enough to light the LED.



Going Further...

Can you figure out how much current the circuit uses when you press the key? Here's a hint: when the key is down, the LED cannot use the 1.5 volts it needs...a straight wire has the same voltage level at either end.

The circuit uses 3 volts/319.72 ohms, or .00938321 amps (9.38321 milliamps).

Wiring Sequence
1–66–44, 2–10–8–65, 9–7–43

12. Fader Control

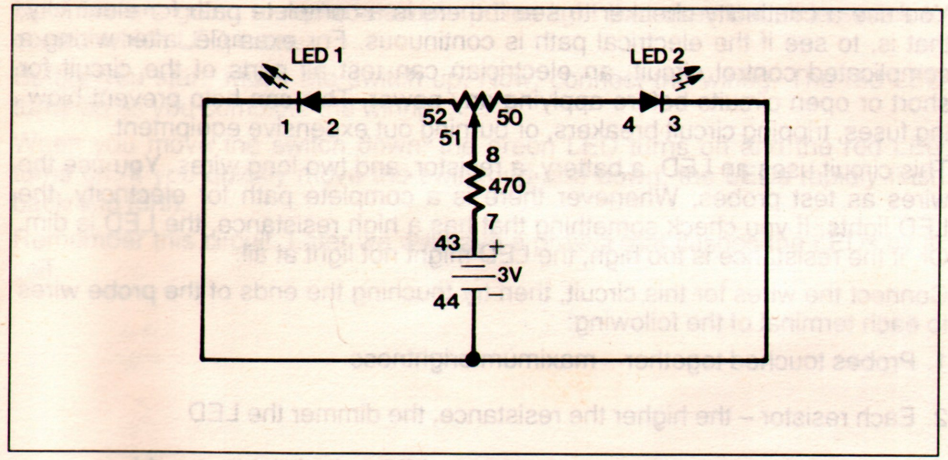
Have you ever been in a large auditorium or theater when the lights were adjusted so that different parts of the stage or auditorium became bright while other parts became dim? Well, here is a circuit that can do this kind of smooth fade. From one control, you cause one light to dim while the other light gets brighter.

Connect the wires for this project.

This project uses the variable resistor to control the current flowing to two LEDs. The variable resistor splits the current into two paths in the circuit. Remember the last project? Most of the current flows through the path of least resistance.

When you turn the control to the left, the path to the red LED has less resistance, and the path to the green LED has a higher resistance. When you turn the control to the right, the resistance in the path to the red LED gets higher as the resistance in the path to the green LED current gets lower. When you set the variable resistor to its center position, the paths' resistances are equal, resulting in equal lamp brightness.

Car stereos that have four speakers use the same kind of control. Can you think of some other ways to use this fader circuit?



Wiring Sequence
2–52, 50–4, 51–8, 7–43, 1–44–3

13. Continuity Checker

You use a continuity checker to see if there is a complete path for electricity; that is, to see if the electrical path is continuous. For example, after wiring a complicated control circuit, an electrician can test all parts of the circuit for short or open circuits before applying any power. This can help prevent blowing fuses, tripping circuit breakers, or burning out expensive equipment.

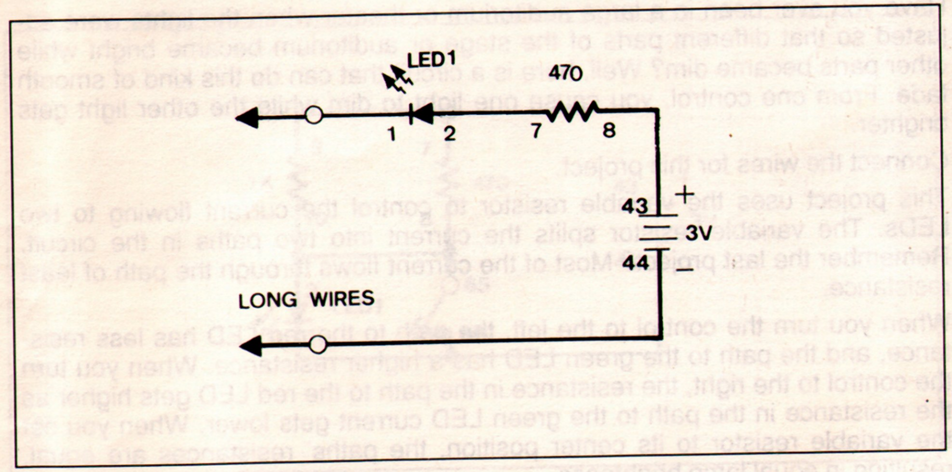
This circuit uses an LED, a battery, a resistor, and two long wires. You use the wires as test probes. Whenever there is a complete path for electricity, the LED lights. If you check something that has a high resistance, the LED is dim. Or, if the resistance is too high, the LED might not light at all.

Connect the wires for this circuit, then try touching the ends of the probe wires to each terminal of the following:

1. Probes touched together – maximum brightness
2. Each resistor – the higher the resistance, the dimmer the LED
3. Water – off (resistance is too high for the LED to be bright enough)
4. Switches – off or full brilliance, depending on switch position
5. Antenna coil (Terminals 56–57) – about full brightness
6. Antenna coil (Terminals 53–55) – near full brightness
7. Transformer (Terminals 48–49) – about medium brightness.

After checking the above items you should now have a good feeling for how you could use this continuity checker to be sure there are no breaks in an electrical circuit.

Caution: Always be sure there is no other power applied to the circuit you are testing with this tester. Other power can burn out the LED, damage the circuit, or pose a shock hazard. The low 3 volts of this circuit, of course, is safe by itself.



Wiring Sequence
2–7, 8–43, 44–Loose Wire, 1–Loose Wire

14. LEDs in Parallel

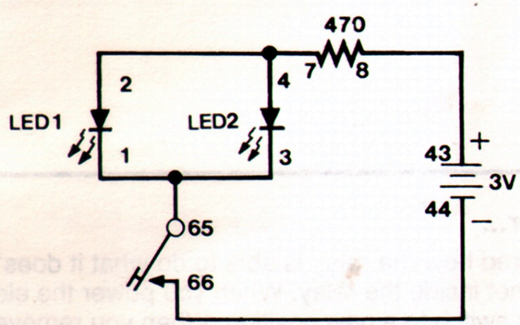
In this project, we learn more about LEDs.

Connect the wires for this circuit. Both LEDs are off when you complete the wiring. When you press the key, both LEDs light. So far, this is almost like Project 4.

Now, let's reverse the connections to red LED—by swapping the wires on Terminals 1 and 2. Now, when you press the key, only the green LED lights. This is because the red LED does not let current flow when the direction of the current is reversed.

Now swap the wires from the battery—Terminals 43 and 44. When you press the key the red LED lights and the green LED does not, because now the current is trying to flow the wrong direction through the green LED.

You could use a circuit like this to test a battery, to see which is the plus side and which is the minus side.



Wiring Sequence
2-4-7, 1-3-65, 8-43, 66-44

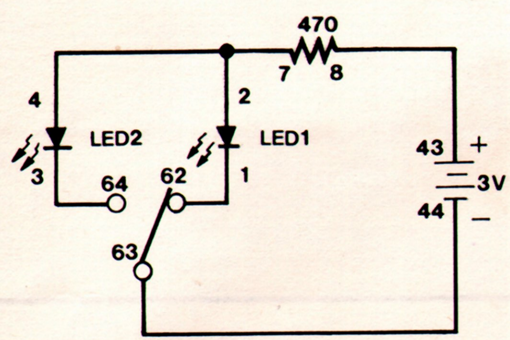
15. Red Light, Yellow Light

Now, we are going to make a simple police light that uses the slide switch to control which LED is on.

Before you start, move the switch up. Now, connect the wiring. The red LED turns on as you complete the wiring.

When you move the switch down, the green LED turns on and the red LED turns off. If you quickly move the switch up and down, the LEDs rapidly flash back and forth.

Remember this circuit. Later we will have a project that flashes the LEDs by itself.



Wiring Sequence
3-64, 1-62, 4-2-7, 8-43, 44-63

16. The Relay—An Electric Switch

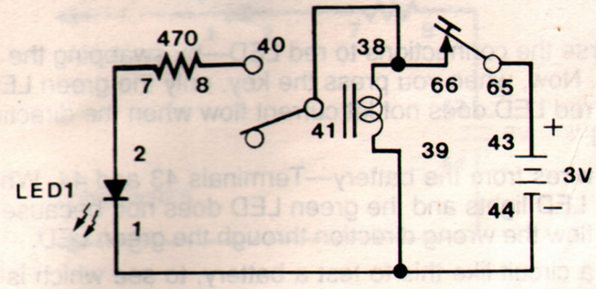
A relay is an electrically operated switch. When you apply power to its control terminals, the switch changes position. When you remove power, the switch returns to where it was before.

Terminals 38 and 39 are the control terminals for your relay. When you apply about 3 volts to these terminals, the relay activates.

Connect the wires for this project. Then, press the key. You hear a click as the relay activates, and the LED turns on. When you release the key, you hear another click as the relay releases, and the LED turns off.

Relays are often used when we need to have a low–voltage turn on a high–voltage circuit. The low voltage activates the relay. The relay can handle a higher current than most electronic devices. So, the relay can turn on high–current devices, such as the horn in your parent's car, from a low–current, such as the horn button.

Can you think of some other places we might want to use a relay?



Wiring Sequence
2–7, 8–40, 41–38–66, 65–43, 1–39–44

Going Further...

Have you wondered how the relay is able to do what it does? Well, there is an electromagnet inside the relay. When you power the electromagnet, it pulls the relay's switch to a new position. When you remove power from the electromagnet, a spring pulls the switch back to the original position.

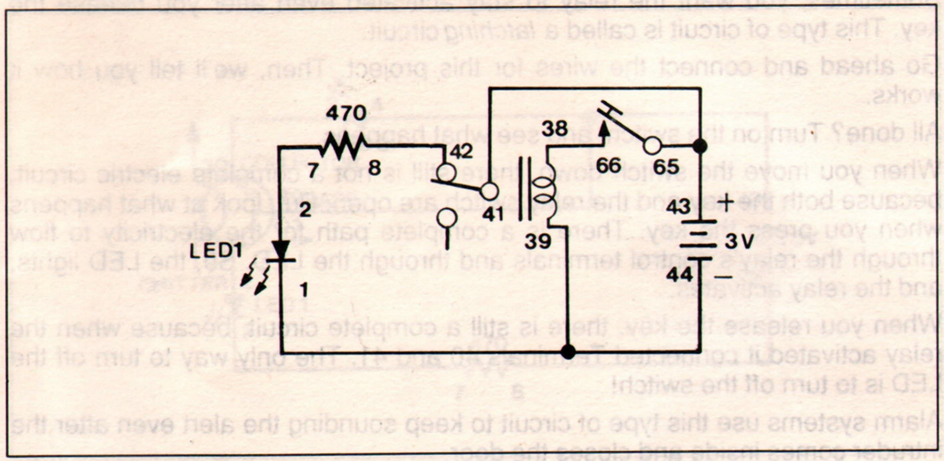
The switch in the relay is similar to the other switch in your kit, because there is always one side of the switch that is connected to the center switch terminal. Before you activate the relay, Terminals 41 and 42 are connected, and Terminals 41 and 40 are not connected. When you apply power, Terminals 40 and 41 connect, and Terminals 41 and 42 disconnect. This type of switch is called a *single–pole, double–throw* switch, and is usually abbreviated SPDT.

17. More About the Relay

In this project, we connect the relay so that it turns off the LED when you activate the relay. Go ahead and connect the wires.

Notice that the LED turns on when you complete the wiring. When you press the key, you hear the relay click and the LED turns off. When you release the key, you hear a click as the relay releases and the LED turns on again.

This type of circuit is used in a security door, where the door is normally held closed by a strong electromagnet. Pressing the button activates a relay to turn off the electromagnet so that you can open the door.



Going Further...

In the last project, we connected the LED to Terminal 40. Terminal 40 is only connected to Terminal 41 when the relay is activated. We call this Terminal the *normally open* side of the switch.

In this project, we connect the LED to Terminal 42. Terminal 42 is connected to Terminal 41 when the relay is not activated. We call Terminal 42 the *normally closed* side of the relay switch.

Can you guess what kind of switch the key is? It is a normally open switch, because normally (when you are not pressing down the key) the key is open (does not complete a circuit).

Wiring Sequence
2–7, 8–42, 41–65–43, 38–66, 1–39–44

18. Latch–On Circuit

Sometimes, you want the relay to stay activated even after you release the key. This type of circuit is called a *latching* circuit.

Go ahead and connect the wires for this project. Then, we'll tell you how it works.

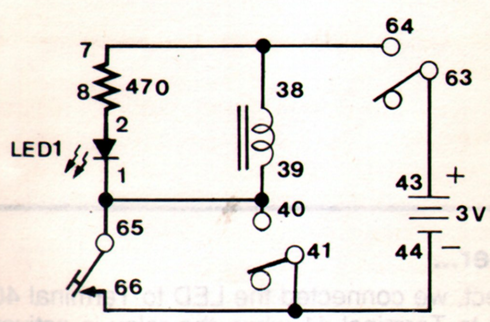
All done? Turn on the switch, and see what happens.

When you move the switch down, there still is not a complete electric circuit, because both the key and the relay switch are open. But, look at what happens when you press the key. There is a complete path for the electricity to flow through the relay's control terminals and through the LED. So, the LED lights, and the relay activates.

When you release the key, there is still a complete circuit, because when the relay activated it connected Terminals 40 and 41. The only way to turn off the LED is to turn off the switch!

Alarm systems use this type of circuit to keep sounding the alert even after the intruder comes inside and closes the door.

Ready to learn another relay circuit? Great, let's go to Project 19.



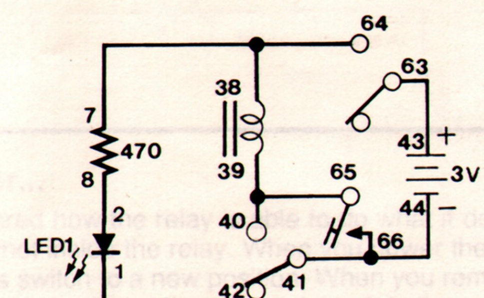
Wiring Sequence
2–8, 7–38–64, 1–65–39–40, 66–41–44, 63–43

19. Latch–Off Circuit

This project should look very familiar. It's almost like the last project. Can you guess how it works?

Go ahead and connect the wires for this project. When you complete the wiring and move the switch down, the LED turns on. When you press the key, the relay clicks and the LED turns off. Even when you release the key, the relay stays activated so the LED stays off. The only way to turn on the LED again is to turn off the switch, and then turn it back on.

Some car alarm systems use this type of circuit to turn off the ignition when the security alarm activates. That way, the car won't start until the alarm is reset by turning off the switch. Can you think of some other ways to use this circuit?



Wiring Sequence
1–42, 2–8, 7–38–64, 39–40–65, 41–66–44, 63–43

20. Electron Flow Through a Transistor

Now we are going to begin to learn about another part in your lab, the *transistor*.

This project identifies the parts of a transistor and shows how electricity (electrons) flows through the transistor. In later projects, we will show you amplifier and switch circuits that use the transistor.

The three leads on the transistor are called the base, the emitter, and the collector.

There are two paths for electricity through a transistor. One path is from the emitter to the base—the other is from the emitter to the collector.

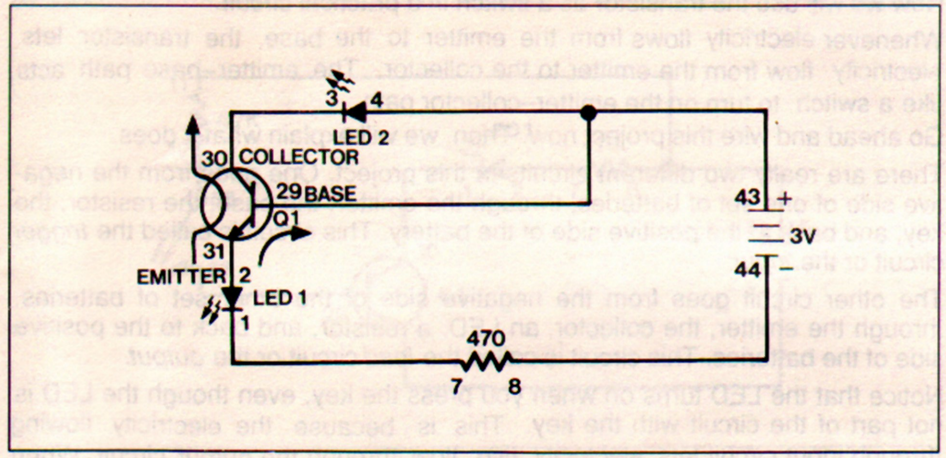
Connect the wires for this circuit now. Both LEDs lights when you connect the last wire.

Now, reverse the wires connected to Terminals 29 and 31. Notice that the LEDs does not light now, because the transistor does not let electricity flow from the base to the emitter. The transistor's paths act like diodes and only let electricity flow in one direction.

Move on to Project 21 to find out more about the transistor.

Wiring Sequence

1–7, 8-44, 2–31, 30–3, 4–29–43



Going Further...

The arrows drawn on the schematic show the direction electricity flows in this circuit. Did you notice that the small arrow that is part of the transistor points in the opposite direction of the electricity flow? The arrow part of the diode symbol also points opposite the direction of electricity flow. The reason for this is simple.

When Benjamin Franklin began his experiments with electricity, he assumed that electricity flowed from *positive* to *negative*. Since then, we have discovered the electron, and we now know that current really flows from negative to positive. Most electronic symbols follow the traditional concept of electricity flowing from positive to negative, so they *point* the wrong direction.

Also, some books refer to current flowing from positive to negative. This is sometimes an easier way to explain a simple circuit, but this book shows you the real way electrons flow in a circuit. When we refer to current or current flow in this book, we mean the measure of how much electricity is flowing in the circuit.

21. The Transistor as An Electronic Switch

Now we will use the transistor as a switch in a practical circuit.

Whenever electricity flows from the emitter to the base, the transistor lets electricity flow from the emitter to the collector. The emitter–base path acts like a switch to turn on the emitter–collector path.

Go ahead and wire this project now. Then, we will explain what it does.

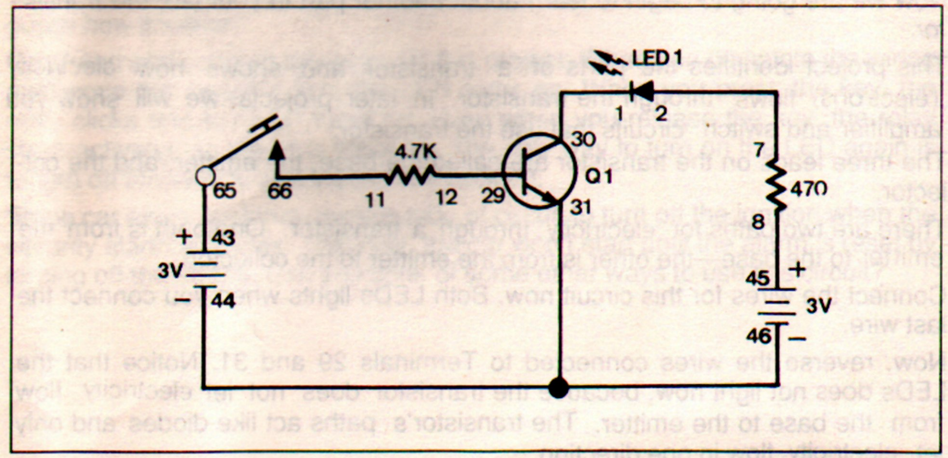
There are really two different circuits in this project. One goes from the negative side of one set of batteries, through the emitter, the base, the resistor, the key, and back to the positive side of the battery. This circuit is called the *trigger* circuit or the *input*.

The other circuit goes from the negative side of the other set of batteries, through the emitter, the collector, an LED, a resistor, and back to the positive side of the batteries. This circuit is called the *load* circuit or the *output*.

Notice that the LED turns on when you press the key, even though the LED is not part of the circuit with the key. This is because the electricity flowing through input circuit lets electricity also flow through the output circuit. When you release the key, the electricity stop flowing in the input circuit, and this stops the electricity in the output circuit.

All of the rest of the circuits in your lab use the transistor, so be sure you fully understand this circuit.

Now lets move on to Project 22, to learn a simpler way to make this same circuit.



Wiring Sequence
1–30, 2–7, 8–45, 11–66, 12–29, 31–44–46, 43–65

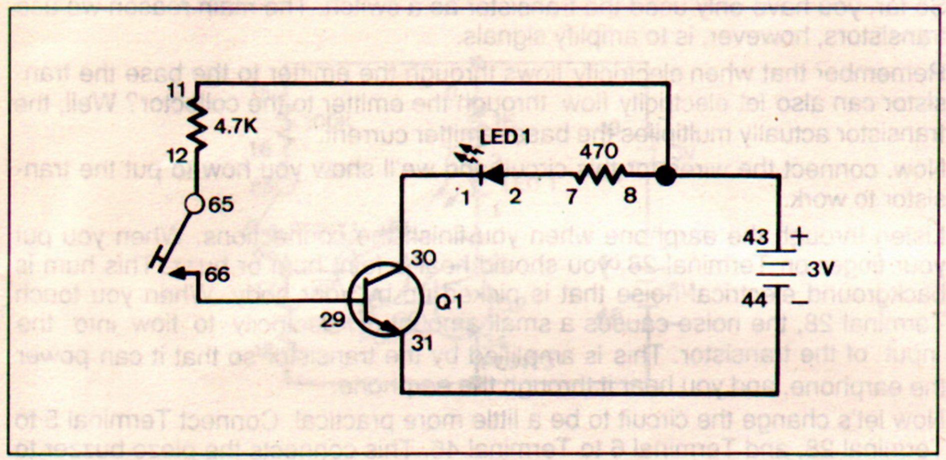
22. Transistor as a Switch—Using One Set of Batteries

In the last project, we used a separate set of batteries for the transistor's input circuit and output circuit. This project shows you how to use a single set of batteries to do the same thing.

Connect the wires for this project. When you finish, the LED is off. When you press the key, the LED lights. There are still two circuits—an input circuit and an output circuit. We've just connected the circuits to the same set of batteries.

The input circuit goes from the negative side of the battery, through the emitter to the base, through the key and the resistor, and back to the positive side of the batteries. The output circuit goes from the negative side of the battery, through the emitter to the collector, through the LED and the resistor, and back to the positive side of the batteries.

Are you ready to learn about how to use the transistor as an amplifier? Move on to the next project, and we'll show you how.



Wiring Sequence
1–30, 2–7, 8–11–43, 29–66, 31–44, 12–65

23. The Transistor as a Simple Amplifier

So far, you have only used the transistor as a switch. The main reason we use transistors, however, is to amplify signals.

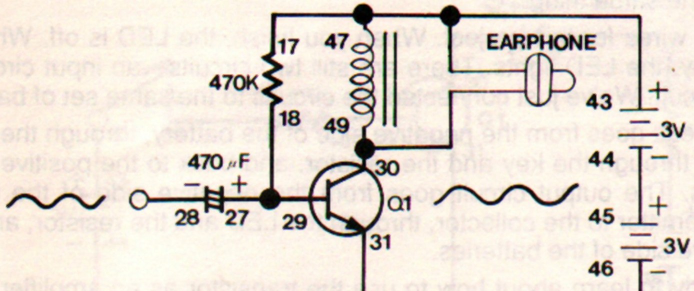
Remember that when electricity flows through the emitter to the base the transistor can also let electricity flow through the emitter to the collector? Well, the transistor actually multiplies the base–emitter current.

Now, connect the wires for this circuit and we'll show you how to put the transistor to work.

Listen through the earphone when you finish the connections. When you put your finger on Terminal 28, you should hear a faint hum or buzz. This hum is background electrical noise that is picked up by your body. When you touch Terminal 28, the noise causes a small amount of electricity to flow into the input of the transistor. This is amplified by the transistor so that it can power the earphone, and you hear it through the earphone.

Now let's change the circuit to be a little more practical. Connect Terminal 5 to Terminal 28, and Terminal 6 to Terminal 46. This connects the piezo buzzer to the input of the circuit. We can use the buzzer as a microphone.

Lightly tap the buzzer's cover. You hear the tap through the earphone! Now talk into the piezo buzzer. You should be able to hear yourself through the earphone. When you talk into or tap on the buzzer, it generates a very small electrical flow. The transistor amplifies this so that you can hear the sounds through the earphone.



Going Further...

The little wavy line next to Terminal 28 in the schematic is a *picture* of the signal you are applying to the input of the circuit. This is a very small signal.

The larger wavy line next to the earphone in the schematic shows the amplified signal. Notice that, although it is larger (bigger waves), there are the same number of waves in the input and the output signal. An amplifier should only change the height (strength) of the input, and not change the shape or the number of waves.

If the input signal is too large, the transistor distorts the input signal. We say that the transistor is *saturated*. For an amplifier to work properly, the transistor should never saturate. The following illustrate the original signal, an amplified signal, and a saturated transistor.

ORGINAL SIGNAL **AMPLIFIED SIGNAL** **SATURATED SIGNAL**

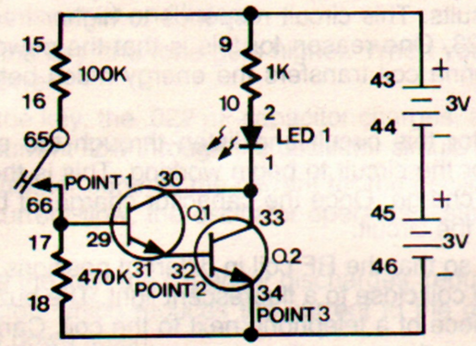
Wiring Sequence
17–43–47–EARPHONE, 18–27–29, 30–49–EARPHONE, 31–46, 44–45

24. The Darlington Connection—A Two–Transistor Amplifier

In this project, we show you how to get more amplification by using two transistors. Look at the schematic.

Connecting two transistors as shown is called a Darlington connection. The input signals current is amplified twice—once by the first transistor, then the first transistor's output current is amplified by the second transistor. We usually use Darlington connections to turn on the second transistor from a very small input.

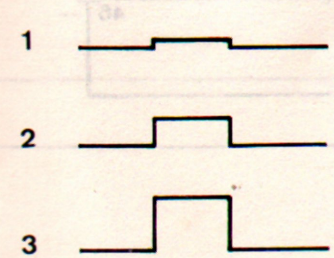
Connect the wires for this project. Then, press the key. Even though the input current for this circuit is very low, the LED still lights because of the high amplification of the Darlington connection.



Going Further...

The first transistor in this circuit is acting like an amplifier. But, when the output of the first transistor is input to the second transistor, the second transistor turns on all the way (saturates). When the second transistor saturates, it lets enough current flow to light the LED.

The diagram below illustrates the current flowing at each of the three numbered points in the schematic.



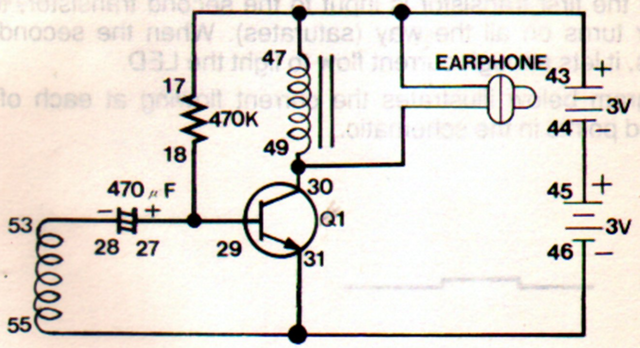
Wiring Sequence
1–30–33, 2–10, 9–15–43, 16–65, 17–29–66, 18–34–46, 31–32, 44–45

25. Magnetic Noise Detector

This circuit uses the antenna coil to detect magnetic energy. The voltage generated by the magnetic energy in the coil is amplified by the transistor so we can hear the results. This circuit responds to higher frequencies than the amplifier in Project 23. One reason for this is that the powdered iron used in the core of the antenna coil transfers the energy much better than your skin does.

Connect the wires for this circuit and listen through the earphone. It takes about 30 seconds for the circuit to begin working. This is the time it takes the 470 μF capacitor to charge. Once the capacitor charges it begins to pass the signal to the input of the circuit.

Try moving your lab so that the RF coil in different positions. Does it make the buzz louder? Put the coil close to a fluorescent light. The buzz should get even louder. Put the earpiece of a telephone next to the coil. Can you hear the dial tone? The coil picks up the magnetic pulses going to the telephone's earpiece and converts them into a small current. The transistor amplifies this current so you can hear the result.



Wiring Sequence

17–43–47–EARPHONE, 18–27–29, 28–53, 30–49–EARPHONE, 31–46–55, 44–45

26. Oscillator Circuit

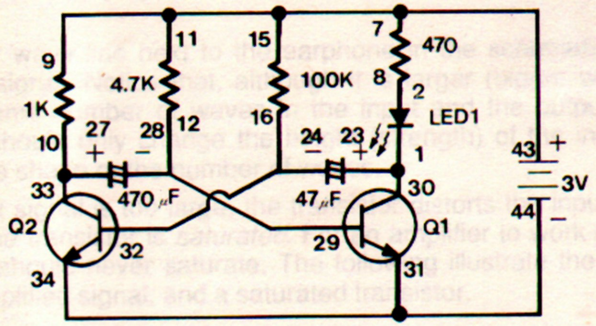
This project introduces another type of circuit—an oscillator circuit.

Connect the wires for this project now. When you connect the last wire, the LED starts blinking.

Oscillate means to move up and down, or back and forth, in a steady rhythm. We call this an oscillator circuit because the voltage to the LED moves up and down (turning the LED on and off).

A circuit like this one might be controlling the blinker in your parents' car. This is a type of oscillator called an *astable multivibrator*. It is designed so that when one transistor is on, the other is off; and they continually switch back and forth, or vibrate, from on to off.

The speed at which the LED blinks is called the *frequency*. The multivibrator's frequency is controlled by the combination of resistors and capacitors. You can replace the 100K ohm resistor with the 10K ohm resistor or 470K ohm resistor and see what happens. The oscillator speeds up when you use a smaller resistor, and slows down when you use a larger resistor.



Wiring Sequence

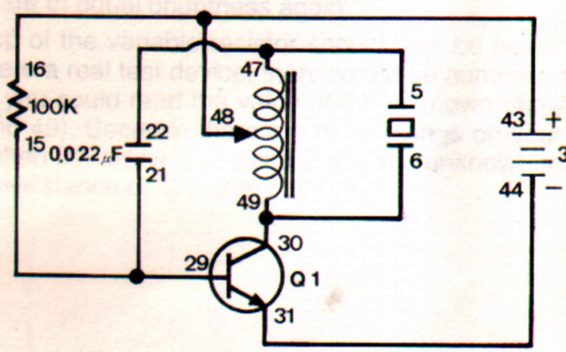
9–11–15–7–43, 10–27–33, 28–29–12, 32–24–16, 1–23–30, 2–8, 34–31–44

27. A One–Transistor Oscillator

In this project, we put together an oscillator circuit that uses a single transistor. Instead of blinking an LED, this circuit makes a noise. Connect the wires for this circuit now.

As soon as you complete the wiring, the buzzer starts sounding a tone. This type of circuit is also called an *oscillator*. The frequency of this oscillator is so fast, the piezo buzzer sounds like a continuous tone. The capacitor and resistor control how fast the transistor turns on and off.

Move the wires from the 100K resistor to the 470K resistor. The tone is now lower. The larger resistor slows the oscillator because it lets less current flow in the circuit.



Wiring Sequence
16–48–43, 15–21–29, 22–47–5, 30–49–6, 31–44

28. Electronic Siren

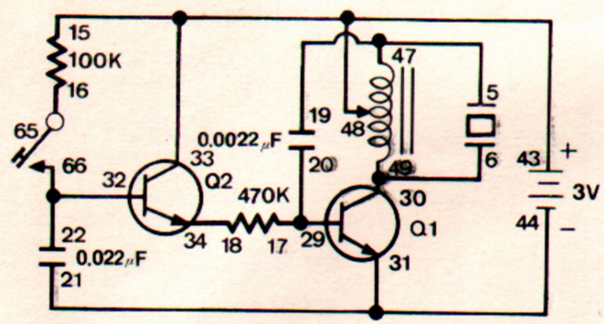
This circuit uses the same oscillator as the last project. But, it uses another transistor to control the current flowing to the input of the oscillator circuit. Connect the wires for this circuit and listen.

When you press the key, the tone gets higher. When you release the key the tone slowly gets lower.

When you press the key, the .022 μF capacitor charges, and the first transistor slowly lets more current flow through the oscillator circuit.

Since the first transistor controls the current for the oscillator, as the first transistor lets more current flow, the oscillator operates faster and faster, producing a higher tone.

When you release the key, the capacitor discharges, reducing the current flowing in first transistor, which reduces the current to the oscillator. This makes the oscillator slow down again.



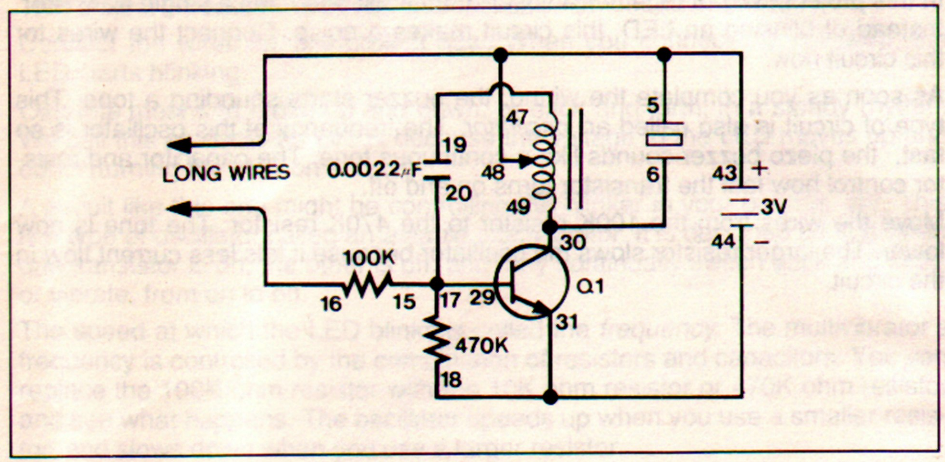
Wiring Sequence
15–33–48–43, 16–65, 66–32–22, 19–47–5, 17–20–29, 18–34, 30–49–6, 21–31–44

29. Music From a Pencil

This circuit also uses an oscillator to produce sound. But, you will control the frequency in an unusual way... with a pencil mark. You might even be able to play a song with this circuit.

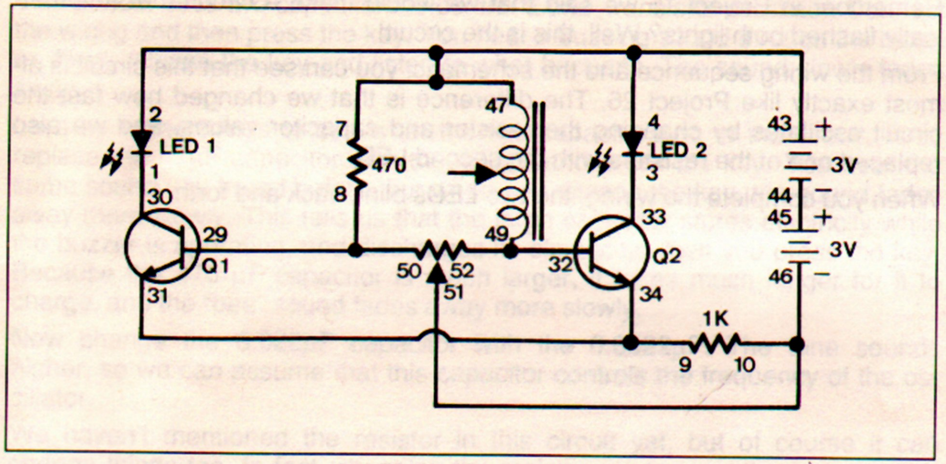
Complete the wiring and then draw a rectangle the full length of a piece of notebook paper and about an inch wide. Fill in the entire rectangle with heavy pencil marks using a very soft lead pencil. Next, tape one of the long wires to one end of the pencil mark. Touch the other long wire to the middle of the pencil mark and listen to the sound the circuit makes. If you move the free wire along the pencil mark the tone will get higher or lower.

Remember that the combination of capacitors and resistors controls the frequency of an oscillator. Well, in this circuit the pencil mark works like a resistor. The lead in a pencil is a form of carbon, and the resistors in your kit are made with carbon, too. When the two wires are closer together the resistance is less and the tone gets higher. When the two wires are farther apart, the resistance is higher and the tone gets lower.



Wiring Sequence
Loose Wire–16, 15–17–29–20, 19–47, 30–49–6, Loose Wire–48–5–43, 18–31–44

30. Electronic Bridge Circuit



This project uses two transistors as amplifiers to light the LEDs. The circuit is called a bridge circuit, and is used in many test circuits. We'll explain how after you connect the wires for the project. Go ahead and do that now.

Now, turn the variable resistor completely counterclockwise. The red LED lights. Quickly turn the variable resistor clockwise. The red LED turns off, and the green LED turns on. Now, slowly turn the variable resistor back counterclockwise while watching both LEDs. The green LED begins to dim, and the red LED turns on. With both LEDs on, gently adjust the variable resistor until both LEDs are about the same brightness.

You have just *balanced* the bridge circuit. This means that the current flowing through the 470 ohm resistor is the same as the current flowing through the transformer. Look at the arrow on the top of the variable resistor. It should be pointing very close to the center point of the variable resistor (almost straight left). This is because the transformer has almost exactly the same resistance as the 470 ohm resistor.

Now, lets see how this circuit can be used to measure an unknown resistance (like test circuits do). Move both wires from Terminal 47 to Terminal 48. The green LED turns on, and the red LED turns off. Slowly turn the variable resistor until both LEDs are of equal brightness again.

The arrow on top of the variable resistor should now be pointing down and to the left. If this were a real test device, there would be numbers around the variable resistor so you could read the value of the unknown resistance (between Terminals 48 and 49). Because there are no markings on your lab, we'll have to tell you that when the arrow is pointing down, the unknown resistance is less than the known resistance of 470 ohms.

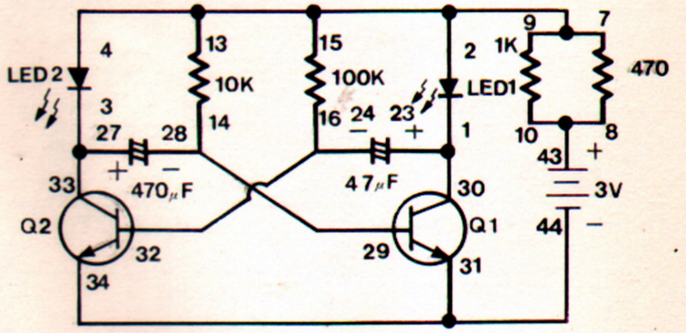
Wiring Sequence
43–4–7–47–2, 29–50–8, 49–52–32, 31–34–9, 46–51–10, 1–30, 3–33, 44–45

31. Police Light

Remember in Project 15 we said that we would make a circuit that automatically flashed both lights? Well, this is the circuit!

From the wiring sequence and the schematic, you can see that this circuit is almost exactly like Project 26. The difference is that we changed how fast the circuit oscillates by changing the resistor and capacitor values, and we also replaced one of the resistors with the second LED.

When you complete the wiring, the two LEDs blink back and forth.



Wiring Sequence
4–13–15–2–9–7, 3–27–33, 34–31–44, 28–14–29, 16–24–32, 1–23–30, 10–8–43

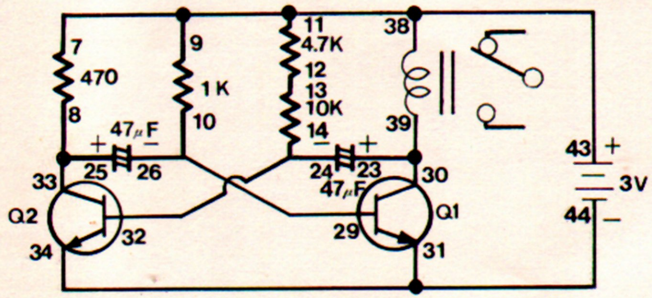
32. Tick–Tock Sound

This project is similar to the last project, we just replace the green LED with the 470 ohm resistor and the red LED with the relay.

When the transistor on the right side of the schematic turns on and off, the relay makes a *tick* sound. When the transistor turns on and off again, the relay makes a *tock* sound.

The transistor on the right turns on for about 1/50th of a second, and then turns off. The transistor on the left turns on for about 1/2 second before it turns off. This is because each transistor is controlled by different capacitors and resistors. The transistor on the left is controlled by the 4.7K resistor, 10K resistor, and the 47 μF capacitor. The transistor on the right is controlled by the 470 ohm resistor and the 47 μF capacitor. Because the resistor controlling the transistor on the right is so much smaller than the resistors controlling the transistor on the left, the transistor on the right operates much faster.

Try connecting a wire between Terminals 13 and 14, shorting around the 10K resistor. The relay clicks about three times faster! This is because the 47μF capacitor charges three times faster through just the 4.7K resistor, instead of through the 14.7K (10K plus 4.7K) resistance of the original circuit.



Wiring Sequence
7–9–11–38–43, 8–25–33, 10–26–29, 12–13, 14–24–32, 23–30–39, 34–31–44

33. Another Sound Maker

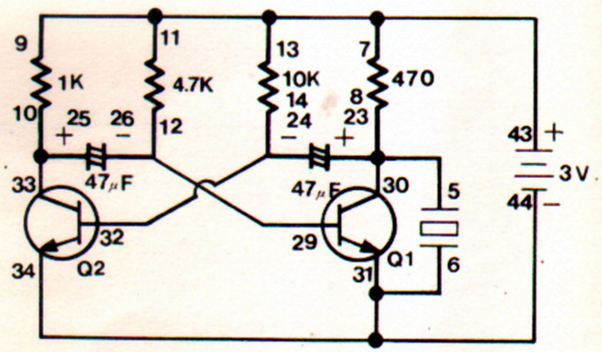
This project uses the same basic circuit used in the last couple of projects to make the buzzer sound.

Go ahead and connect the wires.

When the transistor on the right side of the schematic is off, electricity flows through the buzzer. This current makes the buzzer's diaphragm pull in and click. When the transistor turns on, there is no current flowing through the buzzer, and the buzzer's diaphragm releases, clicking again.

Let's change the circuit a little, so you can see when the transistor is on. Remove the wire from Terminal 6 and connect it to Terminal 3. Then, remove the wire from Terminal 5 and connect it to Terminal 4. The LED turns on and off. When the transistor is on, the LED is off, and when the transistor is off, the LED is on.

Do you remember what this circuit is called? That's right, an astable multi-vibrator.



Wiring Sequence
9–11–13–7–43, 10–25–33, 26–12–29, 14–24–32, 8–23–30–5, 34–31–6–44

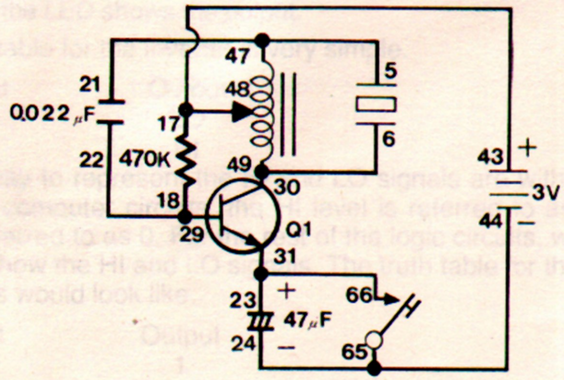
34. Buzzing Bee Noise Maker

This project uses two capacitors to control a one–transistor oscillator. Connect the wiring and then press the key. You hear a buzzing sound through the buzzer. Now, release the key and listen to what happens. The sound slowly fades away.

Let's try some things to see what the two capacitors do in the circuit. First, replace the 47μF capacitor with the 470μF and press the key. You hear the same sound you heard before, but when you release the key, the sound fades away more slowly. This tells us that the large capacitor stores electricity while the buzzer is operating, and discharges its electricity when you press the key. Because the 470 μF capacitor is much larger, it takes much longer for it to charge, and the "bee" sound fades away more slowly.

Now change the 0.022μF capacitor with the 0.0022μF. The tone sounds higher, so we can assume that this capacitor controls the frequency of the oscillator.

We haven't mentioned the resistor in this circuit yet, but of course it can change things too. In fact, changing the resistance changes the frequency of the oscillator and the rate at which the large capacitor charges. Don't take our word for it ... try it yourself!



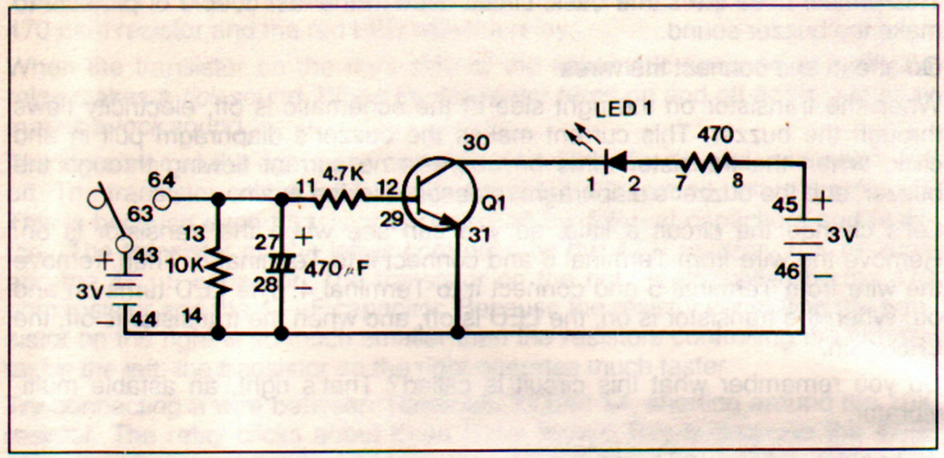
Wiring Sequence
21–47–5, 17–48–43, 22–18–29, 49–30–6, 31–23–66, 24–65–44

35. Delayed Switch–Off Circuit

In this project, the 470μF capacitor is used to create a delay. The capacitor charges and the LED lights when you move the switch down. When you move the slide switch up, the LED stays on for about 5 seconds.

Complete the wiring for this project and try this out for yourself. The transistor stays on until the capacitor discharges through the 10K resistor and through the 4.7K resistor.

Try changing the value of either of the resistors. The delay time changes! A larger resistor makes the delay longer, and a smaller resistor makes the delay shorter, because the larger resistor lets fewer electrons through at a time to charge the capacitor and the smaller resistor lets more electrons through at a time to charge the capacitor.



Wiring Sequence
43–63, 64–13–27–11, 44–14–28–31–46, 12–29, 30–1, 2–7, 8–45

36. Inverter Circuit

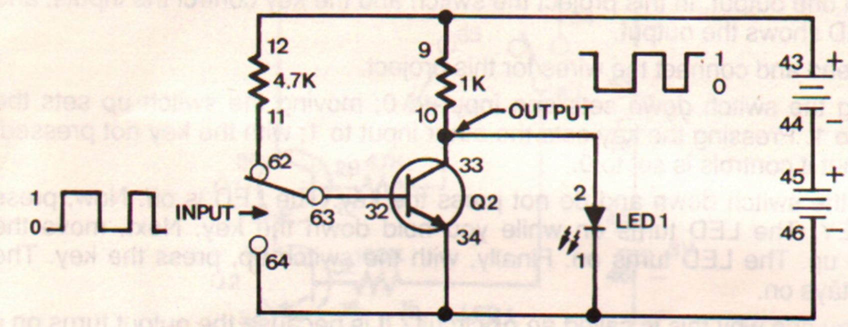
Now let's learn about an important family of circuits. These circuits are called *logic* circuits. They let us control the output of the circuit from one or more inputs.

Connect the wires for this project.

The logic circuit in this project is called an inverter, because the circuit *inverts*, or turns upside–down, the input signal. The switch controls the input for the circuit. When you move the switch up, you apply +6 volts to the input (Terminal 32). When you move the switch down, you apply 0 volts to the input.

The LED in the project lets you see the state of the circuit's output (Terminal 33). When the LED is on, the output is on, and when the LED is off, the output is off.

When you move the switch up, the LED turns off. When you move the switch down, the LED lights.



Going Further...

This type of circuit is used in computers and other digital devices. Usually, we refer to the positive (+) voltage in a logic circuit, as HI. And, we refer to the NEG (–) battery voltage (or 0 volts) in a logic circuit as LO.

The chart below shows what the output does when you apply a particular input. This chart is called a *truth table.* Remember, the switch controls the input, and the LED shows the output.

The truth table for the inverter is very simple.

Input	Output
HI	LO
LO	HI

Another way to represent the HI and LO signals are with the numbers 1 and 0. In computer circuits, the HI level is referred to as 1 and the LO level is referred to as 0. For the rest of the logic circuits, we will use the 1 and 0 to show the HI and LO signals. The truth table for the inverter using 1's and 0's would look like:

Input	Output
0	1
1	0

Wiring Sequence
62–11, 12–9–43, 63–32, 33–10–2, 64–34–1–46, 44–45

37. OR Gate

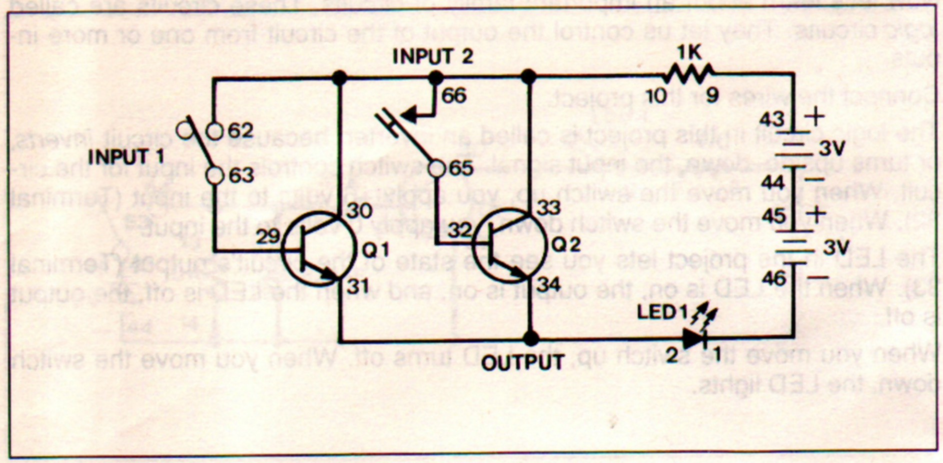
The *OR* gate is the second logic circuit we are going to learn about. In an inverter, a single input controls one output. In an OR gate, two or more inputs control one output. In this project the switch and the key control the inputs, and the LED shows the output.

Go ahead and connect the wires for this project.

Moving the switch down sets one input to 0; moving the switch up sets the input to 1. Pressing the key sets the other input to 1; with the key not pressed, the input it controls is set to 0.

Move the switch down and do not press the key. The LED is off. Now, press the KEY. The LED turns on while you hold down the key. Next, move the switch up. The LED turns on. Finally, with the switch up, press the key. The LED stays on.

Can you see why this is called an **or** circuit? It is because the output turns on if you press the key **or** move the switch up. Your parent's car might have an or circuit in it so that the dome light is on if either the left door or the right door or both doors are open.



Going Further...

Below is the truth table for this circuit:

Input		Output
Key	Switch	
0	0	0
0	1	1
1	0	1
1	1	1

If either or both inputs are set to 1, the output is also set to 1.

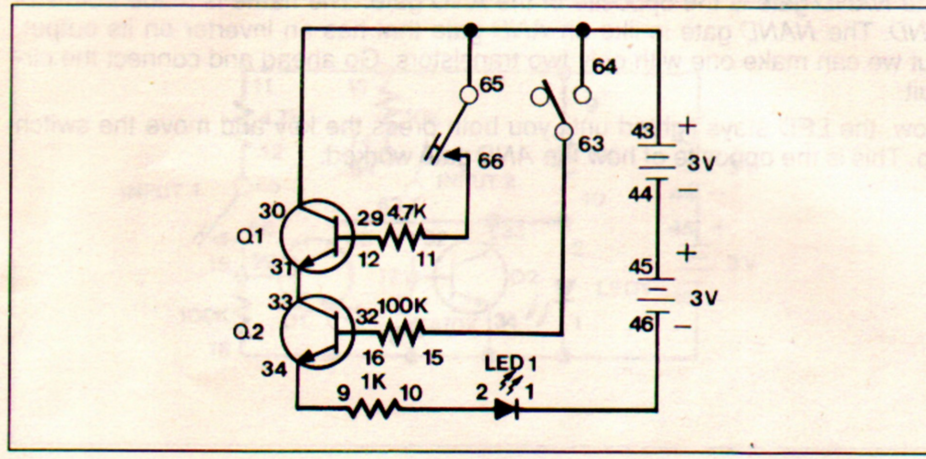
Wiring Sequence
9–43, 10–33–66–30–62, 63–29, 65–32, 31–34–2, 1–46, 44–45

38. AND Gate

The *AND* gate is another logic gate. With this circuit, *both* inputs (the key and the switch) must be 1 for the output to be 1. Remember, 1 means a HI signal, and 0 means a LO signal.

Connect the circuit now, and then we'll see how it works.

You have to move the switch down *and* press the key before the LED lights. This is called an AND gate because you must press the key **and** close the switch for the output to turn on.



Wiring Sequence
43–64–65–30, 66–11, 12–29, 31–33, 63–15, 16–32, 34–9, 10–2, 1–46, 44–45

Going Further...

Fill out the output side of the truth table:

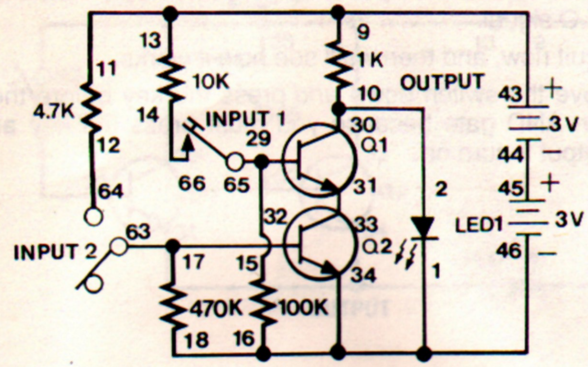
Input		Output
Key	Switch	
0	0	
0	1	
1	0	
1	1	

If you filled the table out correctly, only the last line has a 1 in it. The rest of the combinations cause the output to be 0.

39. NAND Gate

The *NAND* gate is the opposite of the AND gate. The name is made from *Not AND*. The *NAND* gate is like an *AND* gate that has an inverter on its output, but we can make one with only two transistors. Go ahead and connect the circuit.

Now, the LED stays lighted until you both press the key and move the switch up. This is the opposite of how the *AND* gate worked.



Going Further...

Use the space below to write the truth table for this circuit:

Input		Output
Key	Switch	

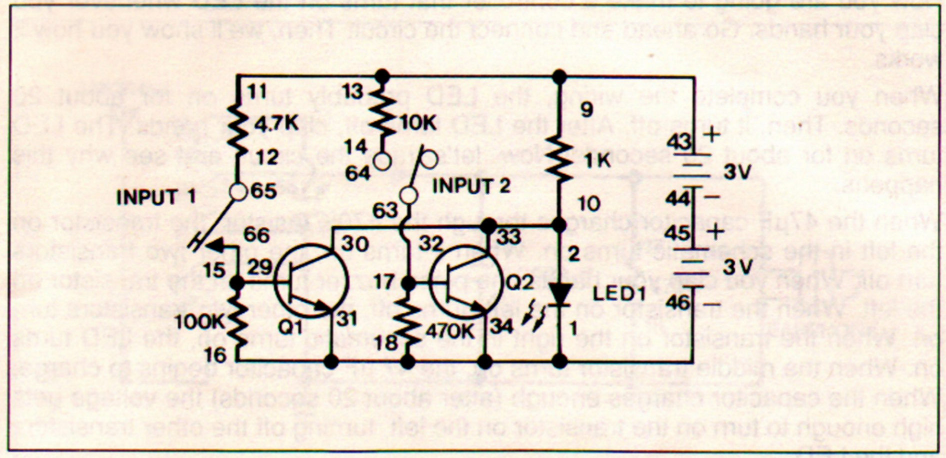
Now, let's see if you completed the truth table correctly. The first two columns are just like the first two columns for the *and* gate and the *or* gate. The output column should have a 1 in all places except where both the key and the switch have a 1.

Wiring Sequence
11–13–9–43, 12–64, 14–66, 63–17–32, 65–29–15, 31–33, 30–10–2, 18–16–34–1–46, 44–45

40. NOR Gate

The *NOR* gate is another logic circuit and is the opposite of the OR gate. The name is made from *Not OR*. Connect the wires for this project.

In this circuit, the LED is on when you do not press the key and the switch is up. If you press the key or move the switch down or both, the LED turns off. This is opposite how the *OR* gate worked.



Going Further...

Fill in the truth table for the NOR gate.

Did you get it right? The output is 1 only when both inputs are 0. If either the key is pressed or the switch is closed, the output is 0, and the LED turns off.

Input		Output
Key	Switch	
0	0	
0	1	
1	0	
1	1	

Did you get it right? The output is 1 only when both inputs are 0. If either the key is pressed or the switch is closed, the output is 0, and the LED turns off.

Wiring Sequence

11–13–9–43, 12–65, 14–64, 66–29–15, 63–32–17, 30–33–10–2, 16–31–18–34–1–46, 44–45

41. *Clap* on a Light

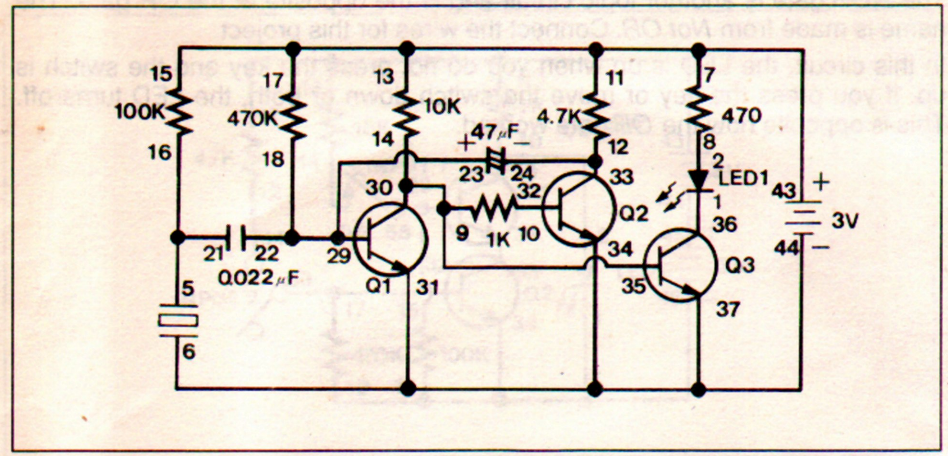
Now you are going to make a controller that turns on the LED whenever you clap your hands. Go ahead and connect the circuit Then, we'll show you how it works.

When you complete the wiring, the LED probably turns on for about 20 seconds. Then, it turns off. After the LED turns off, clap your hands. The LED turns on for about 20 seconds! Now, let's trace the circuit and see why this happens.

When the 47µF capacitor charges through the 470K resistor, the transistor on the left in the schematic turns on. When it turns on, the other two transistors turn off. When you clap your hands, the piezo buzzer turns off the transistor on the left. When the transistor on the left turns off, the other two transistors turn on. When the transistor on the right in the schematic turns on, the LED turns on. When the middle transistor turns on, the 47 µF capacitor begins to charge. When the capacitor charges enough (after about 20 seconds) the voltage gets high enough to turn on the transistor on the left, turning off the other transistors and the LED.

If you replace the 47µF capacitor with the 470µF capacitor, the LED stays on for more than 2 minutes.

This type of circuit is called a *one–shot* circuit. When you trigger the input of the circuit, it turns on for a controlled amount of time. Then, it turns off.



Wiring Sequence

15–17–13–11–7–43, 16–21–5, 18–22–29–23, 14–30–9–35, 12–24–33, 10–32, 8–2, 1–36, 6–31–34–37–44

42. The Invisible–Power Radio

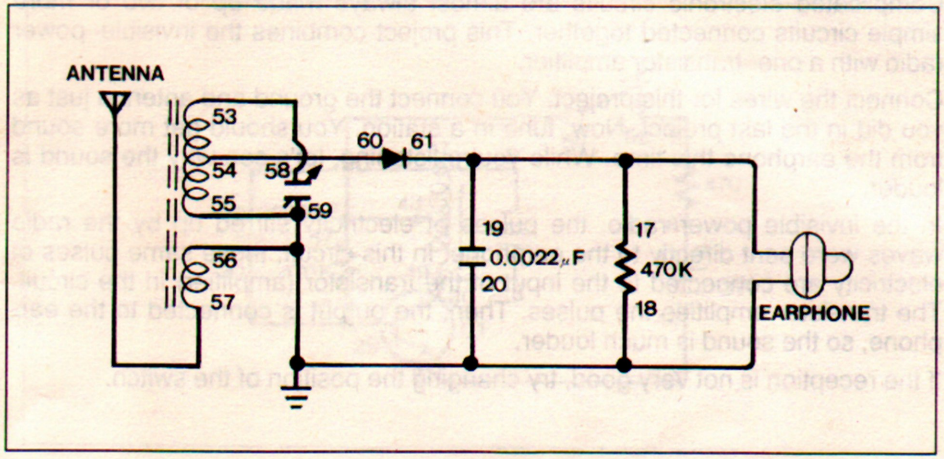
In the wiring sequence you will see a term we have not talked about yet...*ground*. The schematic symbol is . Ground means that you actually connect a wire to the earth or to something metal that goes into the earth. One convenient way to do this is to connect a wire to a metal cold water pipe (water pipes run through the ground. If you can't use a water pipe, you can drive an iron stake into the ground and attach the wire to that. Radio Shack stores sell extra wire and grounding rods. First, use a wire cutter to cut a few feet from the very long yellow wire in your lab. Then, remove about 6 inches of insulation from one end of the wire, and about 1/2 inch of insulation from the other end. Finally, wrap the 6 inches of bare wire around the water pipe or iron stake.

When you complete the wiring, put the earphone in your ear and turn the tuning knob (variable capacitor) until you hear a radio station. This is a very weak radio, and you will have to listen carefully.

After you listen to the radio for a while, take a look at the name of this circuit. We are not using the batteries, so where is the power coming from? Believe it or not, the power is coming from the invisible radio waves that move through the air all of the time. The long wire intercepts the radio waves and sends these waves to the antenna coil. The radio waves *stir up* the atoms in the antenna coil, which causes a little current to flow. The variable capacitor filters out all of the pulses except those you have tuned to, and the earphone changes the pulses into sound.

It is easy to see why the sound is so weak when you see that the power for the radio comes *out of thin air!*

Reception not very good? Try some experiments. Try connecting the ground wire to Terminal 56 instead of 57. Or, try connecting the antenna wire to one of the other antenna terminals. Often, just changing connections like this can make a big difference in how good the radio works. Better still, use an outdoor antenna (Radio Shack stores sell one just for short wave radios—it works well for circuits like this)—BUT BE SURE YOU HAVE AT LEAST ONE ADULT HELP YOU INSTALL THE ANTENNA, AND **DON'T GET NEAR POWER LINES!**



Wiring Sequence
ANTENNA–57, 56–55–59–20–18–EARPHONE–GROUND, 54–60, 53–58, 61–19–17–EARPHONE

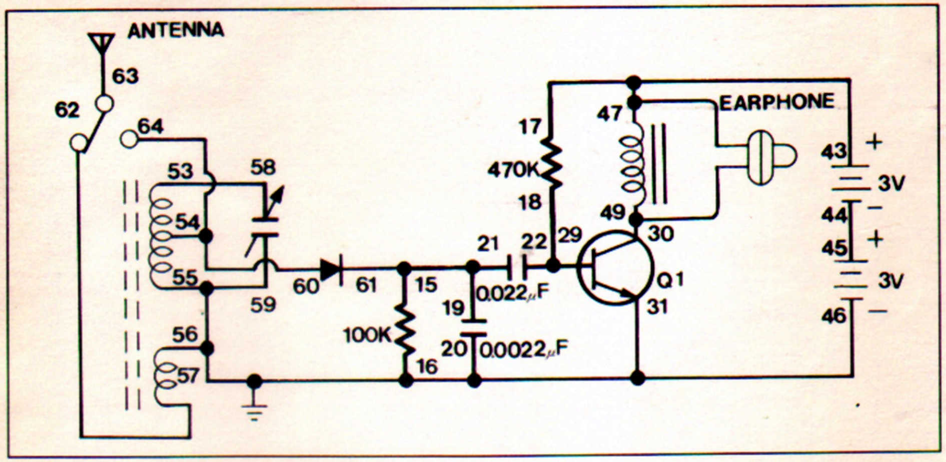
43. A Radio and An Amplifier

Complicated electronic circuits are almost always made up of two or more simple circuits connected together. This project combines the invisible–power radio with a one–transistor amplifier.

Connect the wires for this project. You connect the ground and antenna just as you did in the last project. Now, tune in a station. You should get more sound from the earphone this time. While you're listening, let's see why the sound is louder.

In the invisible power radio, the pulses of electricity stirred up by the radio waves were sent directly to the earphone. In this circuit, those same pulses of electricity are connected to the input of the transistor (amplifier) in the circuit. The transistor amplifies the pulses. Then, the output is connected to the earphone, so the sound is much louder.

If the reception is not very good, try changing the position of the switch.



Wiring Sequence

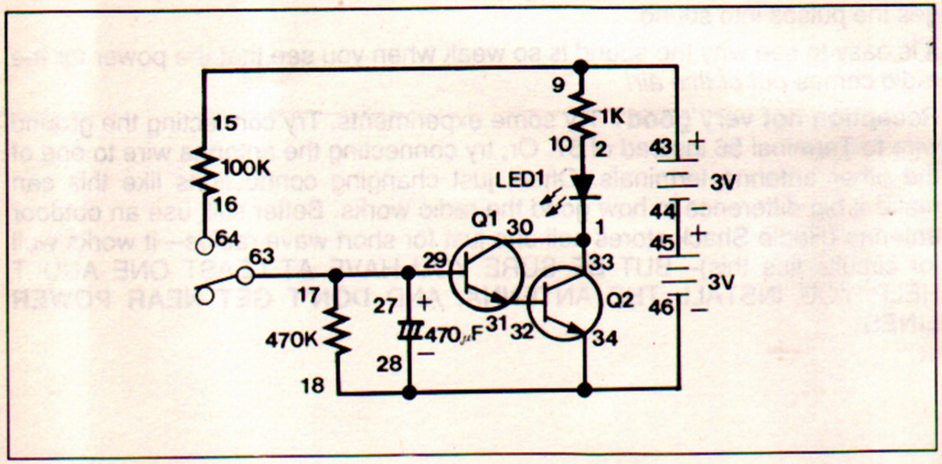
63–ANTENNA, 62–57, 64–54–60, 53–58, 61–15–19–21, 22–18–29, 17–43–47–EARPHONE, 30–49–EARPHONE, 59–56–55–16–20–31–46–GROUND, 44–45

44. Sunrise–Sunset Light

This project reviews some things you learned earlier, so you should have no trouble figuring out what it does. Go ahead and connect the wires.

Finished? Now move the switch down. The LED slowly gets brighter. When you turn off the switch the LED slowly gets dimmer. Can you trace the circuit to see what is happening? When you move the switch down, the capacitor charges through the 100K resistor and slowly turns on the transistors. When you move the switch up, the capacitor discharges through the 470K resistor, and slowly turns off the transistor.

Try replacing the 100K resistor with the 10K resistor. What happens? When you move the switch, the LED gets brighter faster, because the 10K resistor lets the capacitor charge faster.



Wiring Sequence

15–9–43, 16–64, 63–17–27–29, 10–2, 30–33–1, 31–32, 18–28–34–46, 44–45

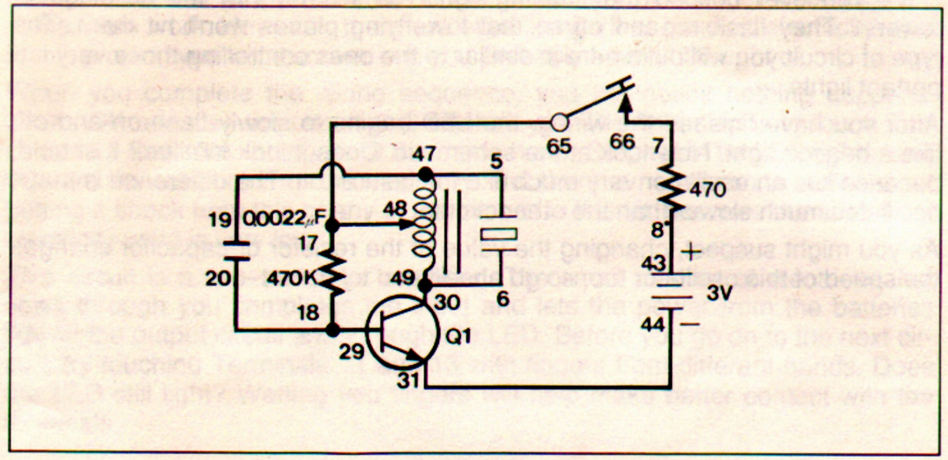
45. Morse Code Key

When you finish making the connections for this project, press the key and you hear a sound from the piezo buzzer. If you follow the Morse code chart below, you can send messages with a series of dots (short sounds) and dashes (longer sounds). Morse code was the first means of electronic communication... by telegraph and then radio. It is still used by radio operators all over the world. You will learn the code faster, and have more fun, if you practice sending messages back and forth with a friend.

Do you remember what we call this type of circuit? That's right, an *oscillator.* When you press the key, the buzzer turns on and off so quickly, you hear it as a continuous tone.

MORSE CODE CHART :

A · —	K — · —	U · · —	4 · · · · —
B — · · ·	L · — · ·	V · · · —	5 · · · · ·
C — · — ·	M — —	W · — —	6 — · · · ·
D — · ·	N — ·	X — · · —	7 — — · · ·
E ·	O — — —	Y — · — —	8 — — — · ·
F · · — ·	P · — — ·	Z — — · ·	9 — — — — ·
G — — ·	Q — — · —		0 — — — — —
H · · · ·	R · — ·	1 · — — — —	. · — · — · —
I · ·	S · · ·	2 · · — — —	, — — · · — —
J · — — —	T —	3 · · · — —	? · · — — · ·



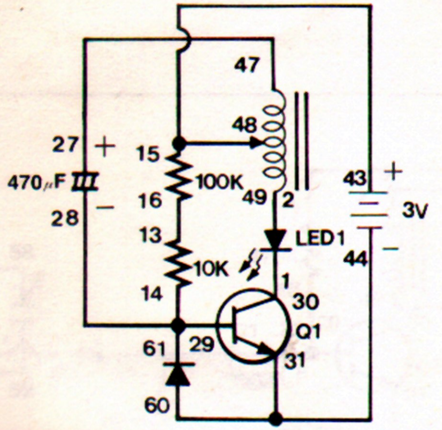
Wiring Sequence
65–17–48, 19–47–5, 20–18–29, 30–49–6, 31–44, 66–7, 8–43

46. Beacon Light

Have you ever noticed the flashing lights on the tops of tall buildings or towers? They flash on and off so that low–flying planes won't hit them. The type of circuit you will build here is similar to the ones controlling those very important lights.

After you have finished the wiring, the LED begins to slowly flash on and off, like a beacon light. Now look at the schematic. Does it look familiar? It should, because it is an oscillator very much like the last circuit. The difference is that it oscillates much slower than the other circuit.

As you might suspect, changing the value of the resistor or capacitor changes the speed of this oscillator too, so go ahead and try it.



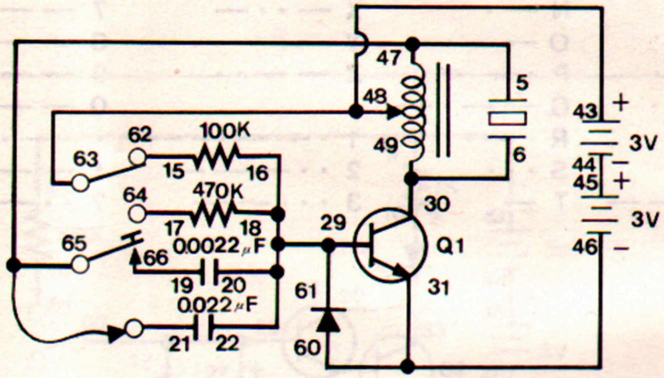
Wiring Sequence
43–15–48, 27–47, 16–13, 28–29–14–61, 30–1, 49–2, 60–31–44

47. Changing the Frequency

This project makes it easy to see how to change the frequency of an oscillator by using the key and the switch to change the resistors and capacitors in the circuit.

When you complete the wiring sequence, hold down the key and move the switch up and down. You hear a different tone for each switch position. Then, touch the loose end of the orange wire to Terminal 21 and move the switch up and down. You hear two more tones. Try different combinations of setting the switch, connecting the wire, and pressing the key.

Moving the switch switches between two different resistors. Pressing the key and touching the orange wire end to Terminal 21 switches between the two capacitors or puts them both in the circuit.

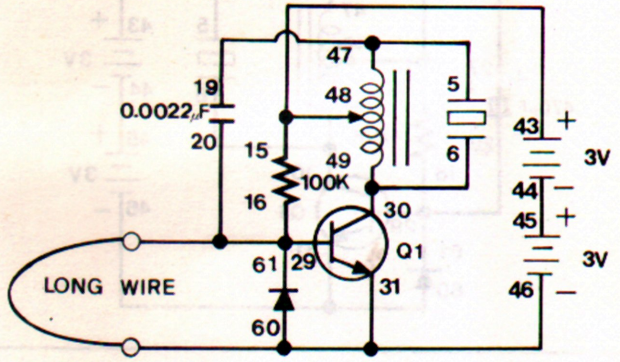


Wiring Sequence
43–48–63, 62–15, 64–17, 5–47–65–Loose Wire, 66–19, 16–18–20–22–29–61, 6–49–30, 60–31–46, 44–45

48. Burglar Alarm

You turn on this circuit by disconnecting a wire, rather than by connecting one. Any time the long wire between Terminals 29 and 31 is disconnected, the alarm goes off. This same type of alarm circuit is used in professional burglar alarms, except that it is connected to very loud bells or buzzers or to a silent alarm that alerts the police, instead of a piezo–electric buzzer.

The *trip* wire keeps the alarm from going off when it is connected because it makes a short circuit around the emitter and base of the transistor. Remember, electrons have to flow through the emitter to the base for the transistor to turn on. This short circuit keeps the transistor from turning on and activating the oscillator.



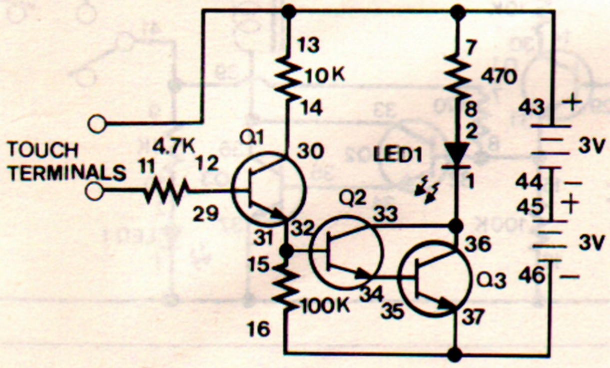
Wiring Sequence
19–47–5, 15–48–43, 20–16–61–29–Orange Wire, 30–49–6, 46–60–31–Orange Wire, 44–45

49. Touch Light

Most circuits use wire or a metal conductor to carry or conduct electricity and make them work. However, there are other things that conduct electricity, and in this project, you will discover one you probably haven't thought of.

When you complete the wiring sequence, you will notice nothing happens. That's OK because the circuit isn't finished yet. The final step is to touch Terminals 11 and 13 with fingers of the same hand. Surprise! The LED lights, and **you** are the conductor for the electricity. But there is no reason to worry about getting a shock from this or any of the circuits in this kit, because the amount of electricity used is very low.

This circuit is a two–transistor amplifier. The small amount of electricity that flows through you completes the input and lets the power from the batteries flow in the output circuit and through the LED. Before you go on to the next circuit, try touching Terminals 11 and 13 with fingers from different hands. Does the LED still light? Wetting you fingers will help make better contact with the terminals.

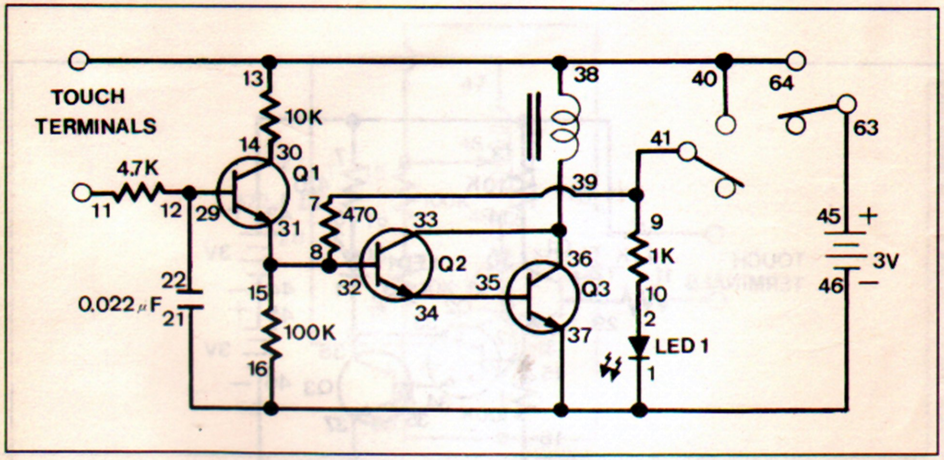


Wiring Sequence
13–7–43, 12–29, 14–30, 31–32–15, 33–36–1, 2–8, 34–35, 16–37–46, 44–45

50. Latching Touch Switch

This project uses the same basic circuit as the last project. But, this time we are going to activate the relay.

Go ahead and connect the wires. Move the switch down. Then, touch Terminals 13 and 11 with fingers from the same hand. The very small current flowing through your hand is amplified by the transistors. The relay stays on even after you stop touching the terminals. To turn off the LED, you have to move the switch up.



Wiring Sequence

13–64–40–38, 12–22–29, 1–46–37–16–21, 14–30, 8–15–31–32, 7–9–41, 2–10, 34–35, 33–36–39, 45–63

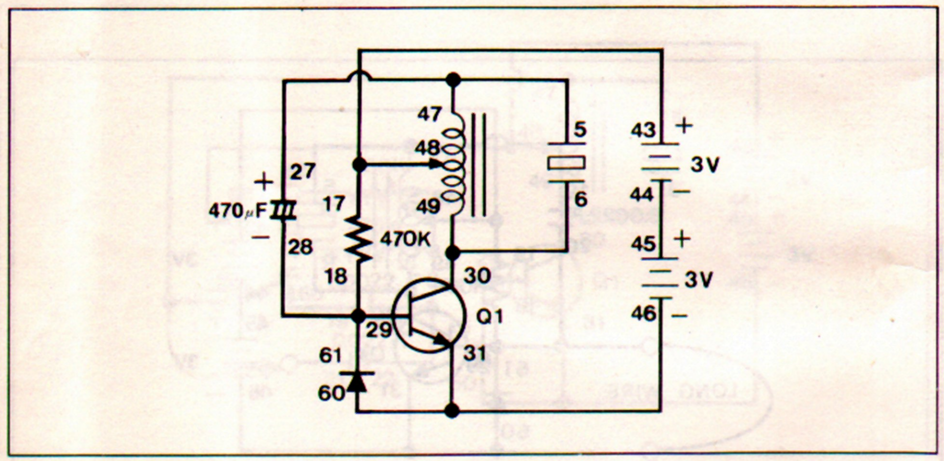
51. Leaky Faucet

By now, you should have no problem recognizing this circuit as an oscillator, and this one works just like the others you have built. But in this circuit we are going to have fun with sound effects.

When you finish the wiring, you will begin to hear a slow clicking sound, something like a dripping faucet. Can you think of a way to make the "dripping" get faster?

Changing to either a smaller–value capacitor or a smaller–value resistor makes the dripping faster.

Replace the 470k ohm resistor with the 4.7k ohm resistor. Now the circuit makes a sound like an idling car engine.



Wiring Sequence

27–47–5, 43–17–48, 28–18–29–61, 49–30–6, 60–31–46, 44–45

52. Rain Detector

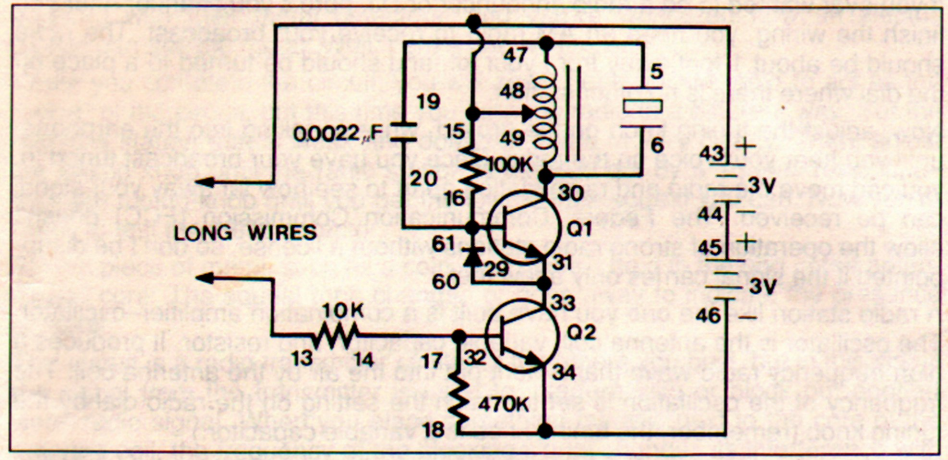
This circuit shows you another thing that conducts electricity... water. This shouldn't be too much of a surprise, because your body conducts electricity and it is mostly water.

When you complete the wiring, put the free ends of the two long wires in a glass of water. Hold them as close together as you can without letting them touch (you might find it easier to tape the wires to a pencil or stick and then put them in the water). The water conducts electricity and you hear a sound from the buzzer. This circuit sounds the alarm any time there is enough water present to connect the two wires.

This type of circuit could be used to tell you if the water level in a bath tub or aquarium is getting too high. And if it was connected to other specialized devices, it could even turn the water on and off.

To use this as a rain detector, you need to get extra wire from a Radio Shack store, and run two wires outside. Tape them close together on a board or piece of plastic, so that just a few drops of rain completes the circuit and sets off the alarm.

If this circuit looks familiar, you're right again! It is another oscillator. The difference is that it is specially designed to use water as a conductor to complete the circuit.



Wiring Sequence

43–15–48–Long Wire, 19–47–5, 20–16–29–61, 30–49–6, 31–33–60, 13–Long Wire, 14–17–32, 18–34–46, 44–45

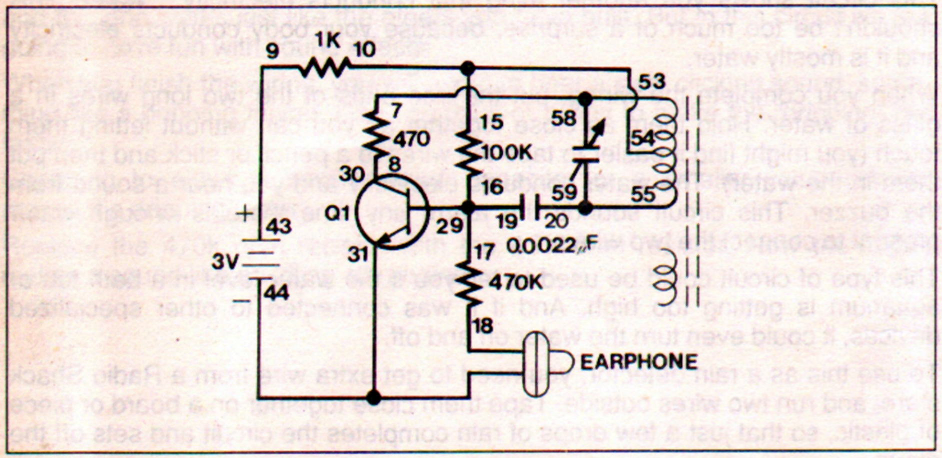
53. Radio Station

If you ever wanted to be a radio announcer or DJ, here's you chance. After you finish the wiring, you need an AM radio to receive your broadcast. The radio should be about 1 foot away from your kit, and should be turned to a place on the dial where there is no other station.

Now, adjust the tuning knob on the project, while speaking into the earphone, until you hear your voice on the radio. Once you have your broadcast tuned in, you can move the radio and radio station apart to see how far away your signal can be received. The Federal Communication Commission (FCC) doesn't allow the operation of strong radio stations without a license, so don't be disappointed if the signal carries only a few feet.

A radio station like the one you have built is a combination amplifier–oscillator. The oscillator is the antenna coil, variable capacitor, and resistor. It produces a high frequency radio wave that is sent out into the air by the antenna coil. The frequency of the oscillation is set to match the setting on the radio dial by the tuning knob (remember, the tuning knob is a variable capacitor.)

The strength or *amplitude* of the radio waves is controlled by the amplifier, which is made from the transistor and resistors. The amplifier is controlled by the small amount of electricity produced by the earphone when you talk into it. In this way, the input from the earphone (your voice) controls, or *modulates* the amplitude of the radio waves. The AM radio is able to turn these changes in the amplitude into the sound that comes out the radio's speaker. Amazing, isn't it! While we're talking about it, have you ever wondered what *AM* stands for? It stands for amplitude modulation.



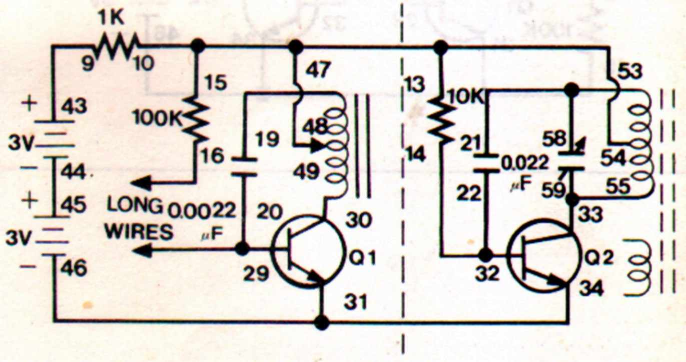
Wiring Sequence
43–9, 10–15–54, 7–58–53, 8–30, 29–16–17–19, 59–20–55, 18–EARPHONE, EARPHONE–31–44

54. Wireless Rain Detector

This circuit is another example of combining two simple circuits to make a more advanced one. Here we have combined the Rain Detector and the Radio Station. Although the two sections of this project are not exactly like the previous circuits, they work in the same way. We had to make some small changes so the two parts would *get along* better. Put the two long wires in water, as you did before, but this time you use the AM radio to receive the alarm signal. Adjust the tuning knob until you can hear the signal coming from the AM radio.

In the schematic, you see that the output that went to the buzzer in the other rain detector is now going to the radio station or *transmitter* section of the circuit. The tuning knob adjusts the transmitter's frequency to match the setting on the radio dial. And the antenna coil sends the signal out into the air where the AM radio picks up and turns the radio wave signal into sound.

You can use this rain detector in the same way as the other one, except you will have the convenience of hearing the alarm over the radio instead of through the buzzer.



Wiring Sequence
43–9, 10–15–48–13–54, 16–Long Wire, 19–47, 20–29–Long Wire, 30–49, 14–22–32, 21–58–53, 33–59–55, 46–31–34, 44–45

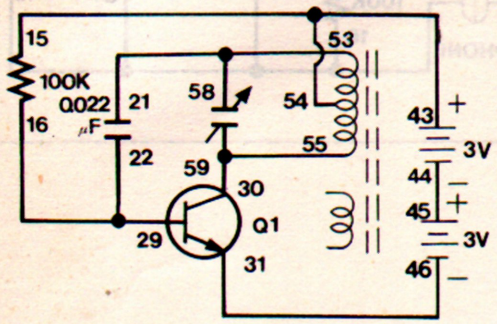
55. Metal Detector

Perhaps you have seen people at a beach or park searching for buried treasure with their metal detectors, and you've wondered how an electric device can *see* the metal. Well, here's one way.

When you complete the circuit, you will again need an AM radio to act as the "voice" of the circuit, but this time you tune the radio in a different way. Set the dial to a station that is weak and does not come in very clearly. Then, adjust the tuning knob until the radio station is blocked out by a *squeal*. Next, fine-tune the tuning knob until you get the lowest tone squeal you can. Now you're ready to test the metal detector.

Take a piece of metal, such as a coin, and place it next to the end of the antenna coil core. The squeal tone changes or goes away to indicate the presence of metal.

This circuit is a radio transmitter similar to the others you built, but in this circuit the signal from the transmitter is used to interfere with or block out another weak radio signal. When you place something metallic next to the core of the antenna coil, the frequency of the blocking signal changes its interference with the weak radio station, and that is your signal that metal is present.

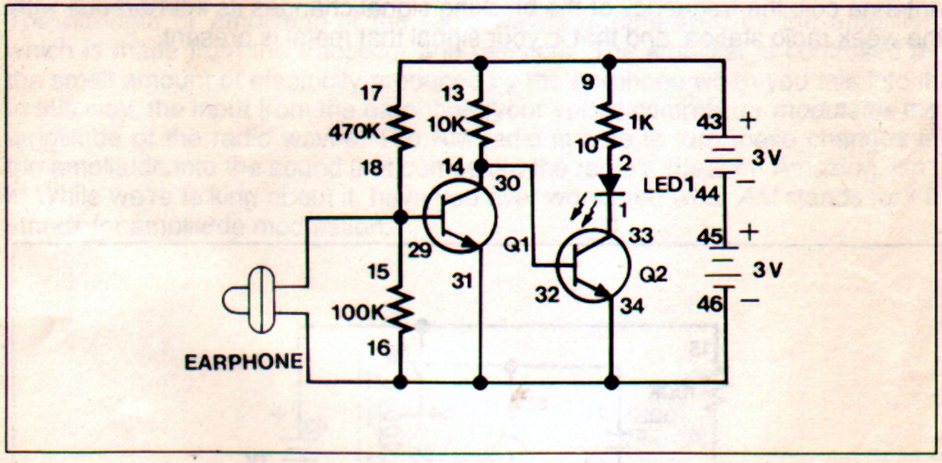


Wiring Sequence
43–54–15, 21–58–53, 16–22–29, 30–55–59, 31–46, 44–45

56. Blowing *ON* a Candle

On your birthday, you make a wish and blow out the candles. Well, in this circuit you can blow *on* the LED (we were just kidding about blowing on a candle). We are using the earphone as a microphone. Once you complete the wiring, blow into the earphone and the LED lights as long as you keep blowing. You can also get the LED to light by yelling into the earphone, but blowing seems easier (and your parents will appreciate that it is much quieter).

This circuit is a two–transistor amplifier that uses the electricity created by the vibrations caused when air hits the earphone to turn on the LED. Your friends will be amazed, but it isn't magic. It's *electronics*!



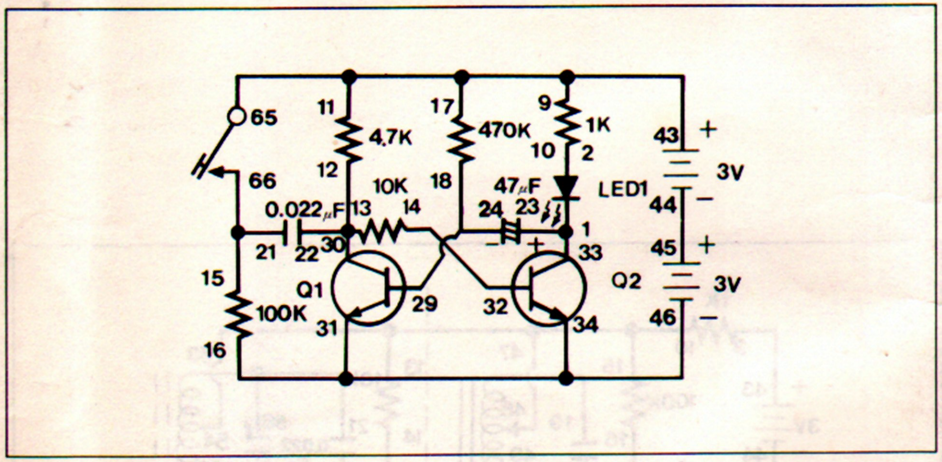
Wiring Sequence

17–13–9–43, 18–29–15–EARPHONE, 14–30–32, 10–2, 1–33, EARPHONE–16–31–34–46, 44–45

57. Light–Off Delay

This circuit shows another way to connect a *one–shot multivibrator*. Connect the wires, and see how it works. The LED might turn on when you complete the wiring. Wait a few seconds and it turns off.

Press the key and release it immediately. The LED lights and stays on for a few seconds and then turns off. It stays on for the same amount of time every time you press the key, no matter how long you hold down the key. The time the LED stays on is controlled by the 47µF capacitor, so you could change the time by replacing the capacitor with one with a different value—or by replacing the resistor that controls the capacitor's discharge (the 470k resistor). Remember, the name *one–shot* comes from the fact that the LED only comes on once each time the input is connected by pressing the key.



Wiring Sequence

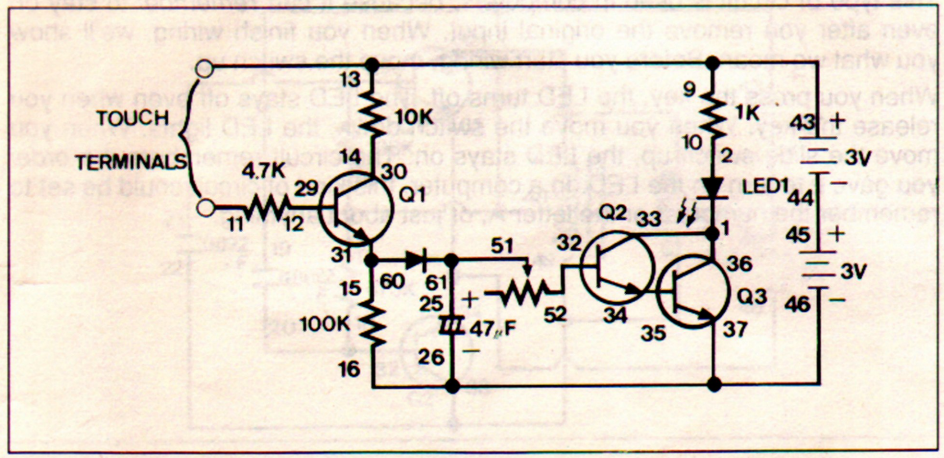
43–9–17–11–65, 66–21–15, 22–12–13–30, 18–24–29, 14–32, 1–23–33, 10–2, 16–31–34–46, 44–45

58. Touch Night Light

Now, you are going to make a touch night light. Connect the wires for the project.

Touch Terminals 11 and 13 with your fingers. The LED turns on. When you remove your fingers from the terminals, the LED slowly fades out.

The variable resistor changes how fast the LED fades out. Try setting the variable resistor to different positions, and note how long the LED takes to fade.

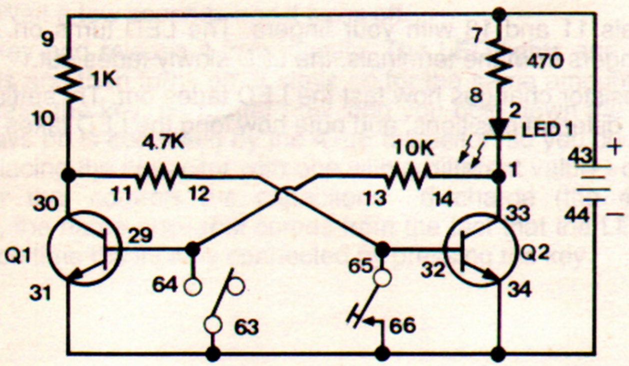


Wiring Sequence
1–33–36, 2–10, 9–13–43, 12–29, 14–30, 15–31–60, 16–26–37–46, 25–51–61, 32–52, 34–35, 44–45

59. Memory Circuit

This type of circuit is used in computers, because it can *remember* to stay on even after you remove the original input. When you finish wiring, we'll show you what we mean. Before you start wiring, move the switch up.

When you press the key, the LED turns off. The LED stays off even when you release the key. When you move the switch down, the LED lights. When you move the slide switch up, the LED stays on. The circuit remembers the *order* you gave it to turn on the LED. In a computer, this kind of circuit could be set to remember the number 3 or the letter A, or just about anything.



Going Further...

Another name for this circuit is the *bistable switch* or *flip–flop.* It works the way it does because of the way the two transistors are connected. The explanation might seem a little confusing at first, but follow it carefully and you'll see that all the components are working just like we've shown you in other circuits.

When you complete the circuit, with the switch up and not pressing the key, the LED turns on. If you look at the circuit, you can see that if the LED is on, then the transistor on the right in the schematic must also be on.

Pressing the key shorts the transistor on the right's emitter to the base and the transistor and LED turn off. When the transistor on the right turns off, this causes the transistor on the left to turn on. Even after you release the key, the transistor on the left stays on, keeping the transistor on the right from turning on.

When you move the switch down, you turn off the transistor on the left. The current that was flowing through the transistor on the left, now flows through the 47K resistor to turn on the transistor on the right, which turns on the LED.

Wiring Sequence
1–14–33, 2–8, 7–9–43, 10–11–30, 12–32–65, 13–29–64, 31–34–63–66–44

60. Push–Pull Circuit Diagram

This final project is a combination oscillator–amplifier. The amplifier part of this circuit is a different type than those we have made before. It is called a *push–pull* amplifier.

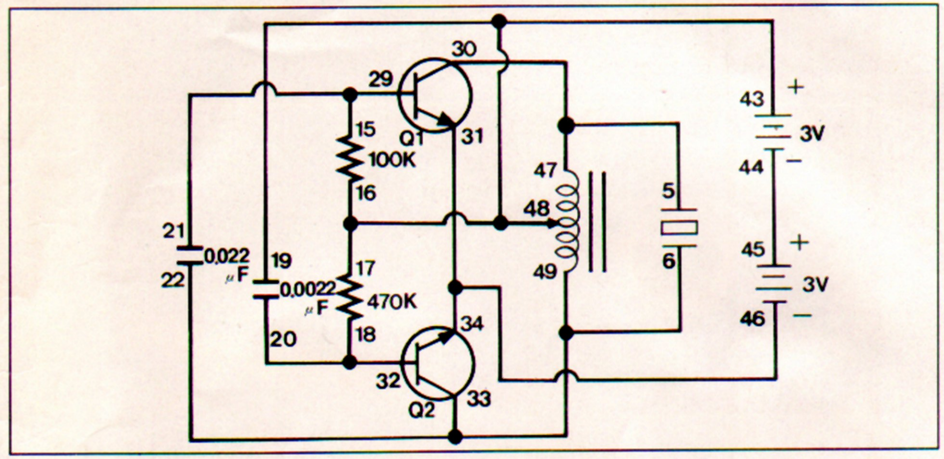
Connect the wires for this project. When you make the last connection, the buzzer starts sounding.

As the circuit oscillates, first the upper transistor turns on. Then, it turns off and the lower transistor turns on. The resistors and capacitors control the frequency of the oscillator.

When the upper transistor is turned on and the lower transistor is turned off, current flows through the buzzer from Terminal 5 to Terminal 6. This makes the buzzers diaphragm push out.

When the upper transistors is turned on and the lower transistor is turned off, current flows through the buzzer from Terminal 6 to Terminal 5. This makes the buzzer's diaphragm pull in.

In the other oscillators you made in this lab, current always flowed through the buzzer in one direction. So the buzzer was always pushed and released to make the sound. In the push–pull amplifier, the buzzer is first *pushed* one direction by the current, and then the current reverses and the buzzer is *pulled* the other direction. This type of amplifier is much more efficient than the push–release type.



Wiring Sequence

5–30–47, 6–22–33–49, 15–21–29, 16–17–19–43–48, 18–20–32, 31–34–46, 44–45

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