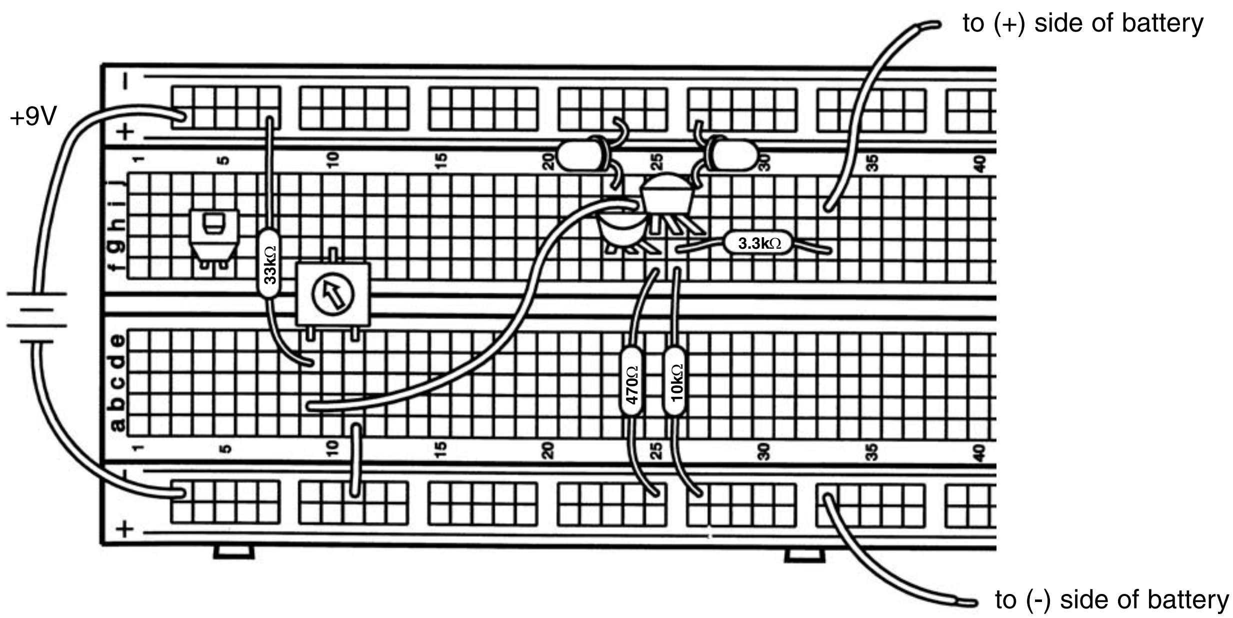
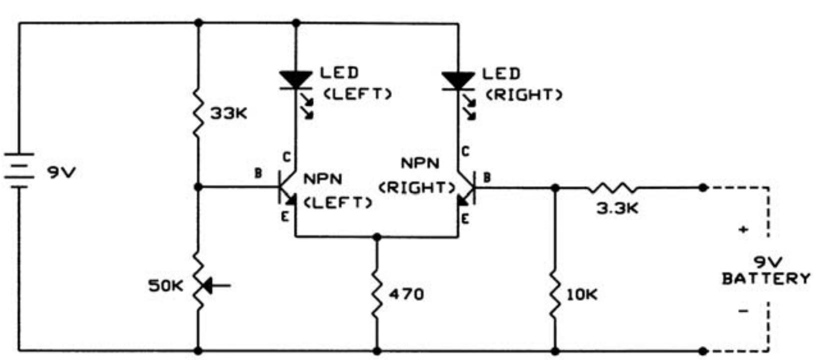
EXPERIMENT #24: 9 VOLT BATTERY TESTER

Make sure you have a strong 9V battery for this experiment. Connect the circuit, and connect the wire to the battery last since this will turn on the circuit. And be sure to disconnect this battery wire when you're not using the circuit to avoid draining the battery. This time you will measure 9V batteries, just like the one you may be using to power your PK-101. Take the battery you want to test and hold it between the loose wires (the 3.3kΩ resistor and ground, be sure to connect to the (+) and (–) battery terminals as shown). If LED-right is bright and LED-left is off then your battery is good, otherwise your battery is weak and should be replaced soon. Don't throw any weak batteries away without making sure some measure good with this test because all batteries could fail if your circuit is wired incorrectly.

As you'd expect, this circuit is similar to Experiments 22 and 23. From the schematic you can see that we are using resistors to set the voltages at the bases of the transistors. The resistor values were selected so that if the two battery voltages are equal then the right transistor's base will have a higher voltage and only LED-right will be lit (as in Experiment 23 when we had a good 1.5V battery). In fact, LED-left will only be on if your PK-101's battery voltage is at least 2V higher than that of the battery you are testing. We do this because we don't want to reject a good battery that's just not as good as our reference battery. Of course, if our reference battery is weak then any battery tested will appear good.

Remember to disconnect the battery (or turn off your power supply) when you're not using the circuit to avoid wasting energy.





Now it's time to introduce another component.....

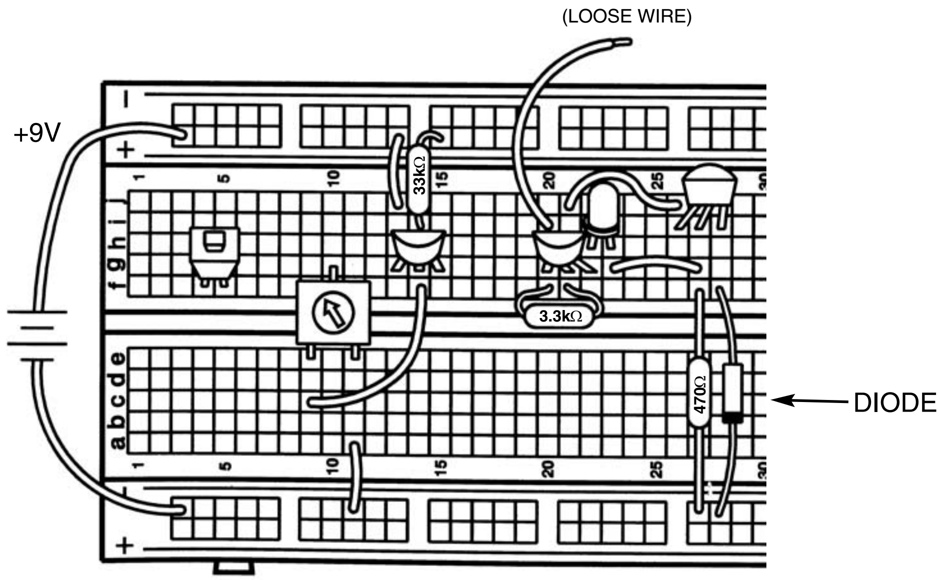
EXPERIMENT #25: BATTERY IMMUNIZER

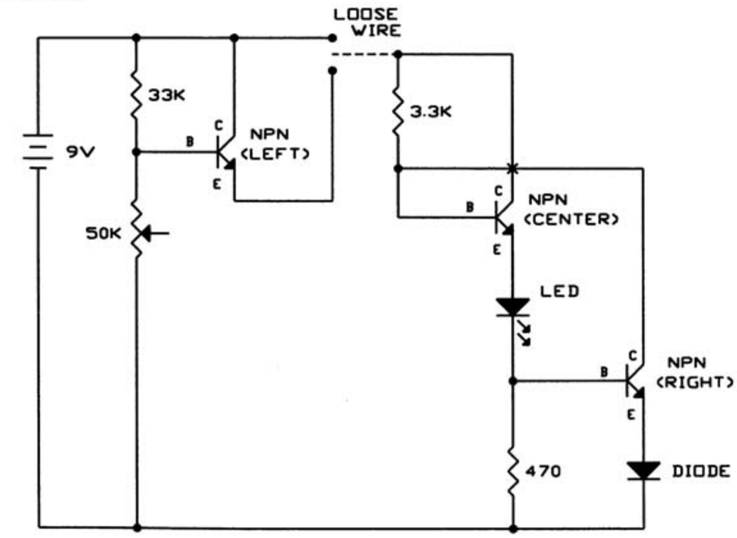
Connect the circuit according to the Wiring Diagram and schematic. Note that the collectors of the center and right transistors are not connected although their wires cross over each other in the schematic. Connect the loose wire to (+)18 or any of the (+) holes in the same row (which are connected to the battery); the LED is bright. Now connect the loose wire to the emitter of the left transistor (holes f15, g15, h15, i15, or j15) as shown in the schematic; the LED is just as bright. So we made a change and nothing happened, does this seem like a dull experiment? It may seem dull but the important idea here is that we made a big change to the circuit but nothing happened to the LED.

Take a look at the schematic. The circuit to the left of the loose wire reduces the voltage to 4.7V. You connect the loose wire to either the 9V battery voltage or the modified 4.7V. The circuit to the right of the loose wire creates a fixed current to the LED, which will not change even if the voltage (9V or 4.7V) to the circuit changes. So when you changed which voltage the loose wire was connected to, you didn't see any change in LED brightness.

In case you're not convinced by this, let's change the circuit to prove it. Place a second LED in series with the 3.3kΩ resistor (reconnect the 3.3kΩ so that it is between d20 and f20, add an LED into holes e20 and f21 with the LED's flat side in f21). Now connect the loose wire to the two voltages as before and you should see the new LED change between bright and dark while the old one remains bright as before.

You could use a circuit like this when you don't want your performance to be affected as your voltage drops, perhaps due to a battery weakening over a long period of use. So you could say your circuit is immune to (protected against) a weak battery.



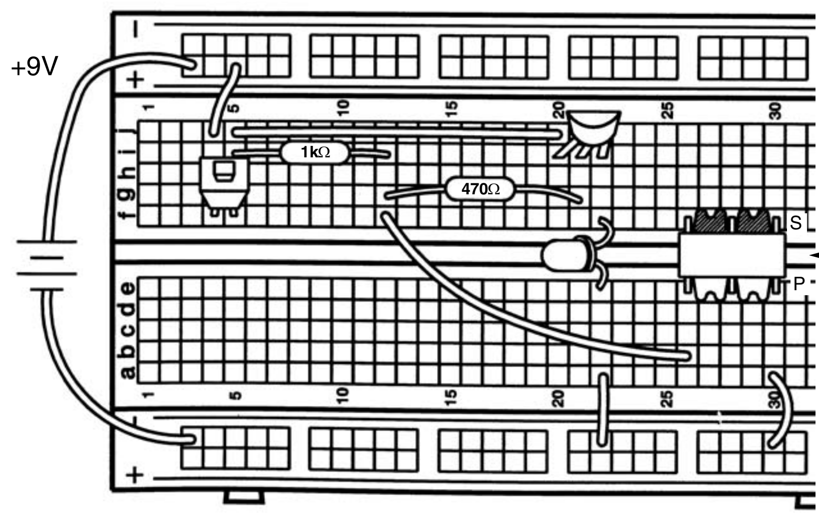


EXPERIMENT #26: THE ANTI-CAPACITOR

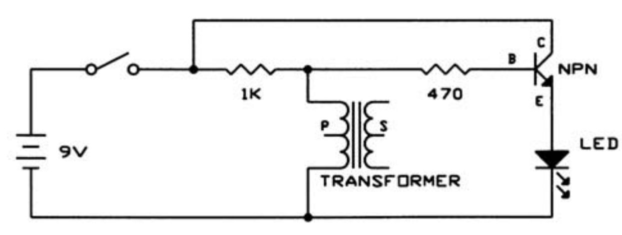
Recall that capacitors blocked direct current (DC) but passed alternating current (AC). Take a look at Experiment 8 again and remember that it took time to light the LED because you had to charge the capacitor first; the capacitor passed the initial current surge through to ground (the negative side of the battery) but blocked the current once it stabilized, forcing it to go through the LED. The **inductor** is the counterpart to this - it blocks current surges (AC) but passes stable currents (DC). Before explaining the inductor further, let's demonstrate it using almost the same circuit as in Experiment 8.

We will be using an inductor that is part of the transformer, we'll explain more about this later. Connect the circuit and press the switch several times. The LED will blink once when the switch is pressed. Note how this is different from the capacitor, when the LED became bright when the switch was pressed and stayed bright until the switch was released. The inductor effects are brief, so we are using the transistor to amplify the current to the LED and make the inductor's effects easier to see.

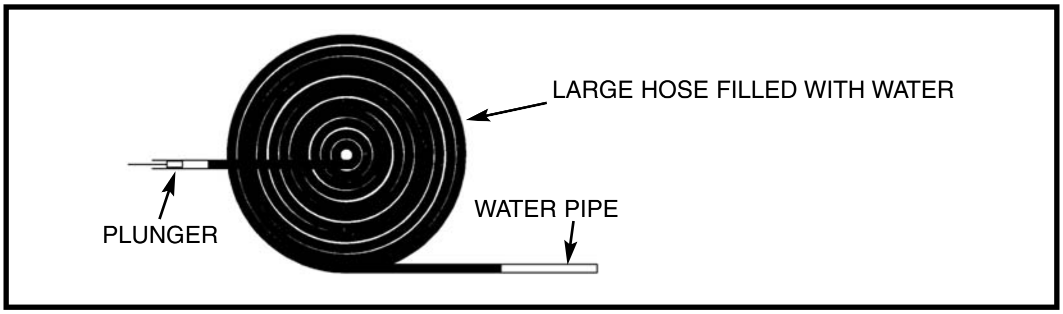
Now remove the wire from hole b26 (on the transformer), connect it to hole b28, and press the switch a few more times. The LED will not blink as brightly now, because we are using less inductance.



TRANSFORMER
(Primary side has 3 wires while secondary side has only 2 wires. The primary goes in holes e26, e28, and e30 while the secondary goes into f26 and f30.)



The Inductor: The inductor can best be described as electrical **momentum** (momentum is the power a moving object has). In our water pipe analogy the inductor can be thought of as a very long hose wrapped around itself many times as shown here:



Since the hose is long it contains many gallons of water. When pressure is applied to one end of the hose with a plunger the water would not start to move instantly, it would take time to get the water moving. After a while the water would start to move and pick up speed. (This is also similar to a long freight train, which takes more than a mile to get to full speed or to stop). The speed would increase until limited by the friction (resistance) of the hose as normal. If you try to instantly stop the water from moving by holding the plunger, the momentum of the water would create a large negative pressure (suction) that would pull the plunger from your hands.

Inductors are made by coiling a wire, hence they are also called coils. From the above analogy it should be apparent that a coiled hose will pass DC (a constant or unchanging current) with only the resistance of the hose, which in electronics will be very low since the hose is a wire. If the pressure on the plunger is alternated (pushed then pulled) fast enough then the water in the coil will never start moving and the AC (constantly changing current) will be blocked. Coils in electronics follow these same principles - <u>a coil will pass DC and block AC</u>. Recall from above that <u>a capacitor will block DC but pass AC</u>. When determining the response of a circuit to DC, inductors are treated as closed switches and capacitors are treated as open switches. For the AC response, the values of the inductors and capacitors must be considered along with the rate at which the current alternates (called the **frequency**). For DC changes to the circuit (called **transients**), such as closing the switch to connect a battery to capacitor circuit, the circuit response is initially AC and then reverts to DC.

How do inductors in series and parallel add up? You saw in Experiment 26 that changing the connection point on the inductor (to reduce the length of the coiled wire) reduced LED brightness. If you think of this in terms of the coiled hose then it is easy - longer hoses will hold more water, hence more inductance. Two hoses in parallel will result in more water coming out (less inductance), since the same water pressure applies to each hose. This situation should sound familiar since inductances in series and parallel add together just like resistors do. For advanced students, the mathematical relationship is ("L" represents inductance):

$$L_{\text{Series}} = L_1 + L_2$$

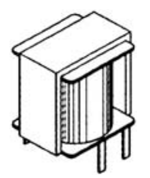
$$L_{\text{Parallel}} = \frac{L_1 \times L_2}{L_1 + L_2}$$

The inductance is expressed in **henrys** (H, named after Joseph Henry who developed electromagnetic induction at the same time as Faraday), or more commonly in millihenrys (mH, thousandths of a henry) or microhenrys (μH, millionths of a henry). A typical inductor and its symbol are shown below:

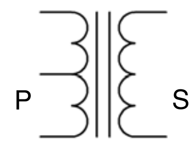
Inductors and Transformers: Our water pipe analogy we have been using all this time is not entirely accurate. Electric current is not the same as water. It is a flow of sub-atomic particles called electrons that not only have electric properties but also magnetic properties; in the water pipe analogy you would have to think of the water as containing millions of very small magnets. Inductance expresses the magnetic effects between electrons flowing in the wire of a coil. The number of turns (windings), diameter, and length of the coil affect the inductance, the thickness of the wire does not. The material inside the coil also affects the inductance; if you wrap the coil wire around an iron bar (which has strong magnetic properties) then the magnetic effects are increased and the inductance is increased. This does not apply to capacitors, which store electric charge in an electric field, not a magnetic field.

If you wrap two wires from different circuits around different ends of an iron bar then a current flowing through the wire from the first circuit will magnetically create a current in the wire from the second circuit! If the second coil has twice as many turns (more magnetic linkage) as the first coil then the second coil will have twice the voltage but half the current as the first coil. A device like this is called a **transformer**. Your PK-101 includes one. It consists of a 400mH coil (called the **primary**) and a 2mH coil (called the **secondary**) wrapped around an iron bar. Both coils have middle tap points allowing use of half the coil's inductance. In Experiment 26 we used the 400mH coil by itself but usually it will be used to drive a speaker, which needs a high current with low voltage. The symbol for a transformer is shown on the right:

TRANSFORMER



Symbol for TRANSFORMER



The magnetic field created in an iron bar by an electric current in the coil around it can be harnessed if the bar is allowed to rotate - it is a motor. It could be used to drive the wheels of a car, for example. The reverse is also true, if a magnet within a coil is rotating then an electric current is created in the coil - a generator. These two statements may not seem important to you at first but they are actually the foundation of our present society. Nearly all of the electricity used in our world is produced at enormous generators driven by steam or water pressure. Wires are used to efficiently transport this energy to homes and businesses where it is used. Motors convert the electricity back into mechanical form to drive machinery and appliances.

It must be remembered that <u>all of the inductance properties discussed here for coils and transformers only apply to AC</u> (alternating current). For DC, inductors act as wires with no special properties and transformers are just two separate, unconnected wires.

TEST YOUR KNOWLEDGE #2

1. A diode has very high resistance when it is __________-biased.
2. Diodes whose turn-on energy is so high that light is generated are known as __________.
3. The transistor is best thought of as a current __________.
4. An __________ circuit is one that might have many resistors, diodes, capacitors and transistors on a single piece of silicon.
5. A transistor is __________ when the circuit resistances, not the transistor itself, are limiting the transistor's collector current.
6. Inductors have low resistance to __________ current and high resistance to __________ current.
7. Adding inductors in parallel __________ the inductance while adding inductors in series __________ the inductance.
8. Electrons not only have electric properties but also __________ properties.
9. Wrapping a coil around an iron bar __________ the inductance.
10. If the second coil in a transformer has half as many turns as the first coil, then the second coil will have __________ as much alternating current as the first coil.

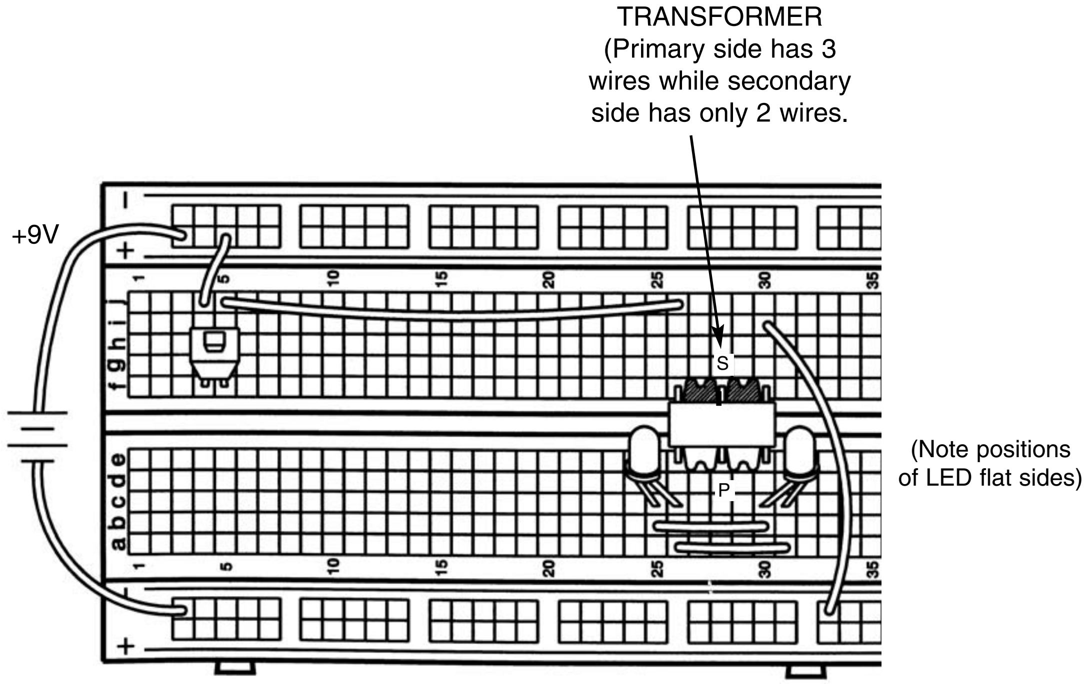
(Answers are on page 3)

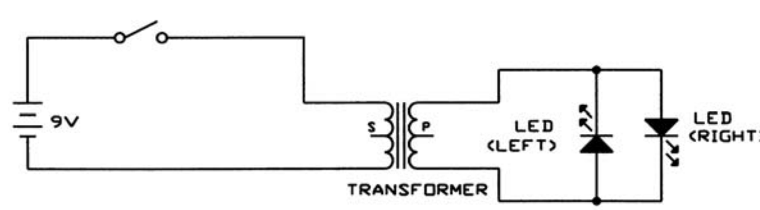
EXPERIMENT #27: THE MAGNETIC BRIDGE

Connect the circuit and press the switch several times. LED-left blinks when the switch is pressed and LED-right blinks when the switch is released.

Although the LED may blink in the same manner as the last experiment, the method is quite different. There is no wire connection across the transformer, its DC resistance is very high. When you press the switch there is a sudden surge of current (AC) through the inductor that magnetically creates a current on the other side of the transformer, lighting LED-left. The current from the battery quickly settles after the initial surge (becomes DC) and the magnetic induction stops because the current is no longer changing, hence no current flows through the LED even though there is current on the battery side of the transformer. When you release the switch the sudden drop in current through the transformer magnetically creates a new current on the other side of the transformer, but this time in the opposite direction so LED-right lights instead of LED-left. Again, this current is brief and the LED only blinks. The transformer has many more turns (more inductance) on the LED side than on the battery side; this boosts the voltage to the LEDs (though it also lowers the current). If you reverse the transformer then you won't have enough voltage to turn on the LEDs.

You might think of a transformer as a magnetic bridge in electronics, since we use magnetism to cross a barrier that electricity cannot cross by itself. Transformers are mainly used for isolating and buffering different circuits from each other, and you will soon see some examples of this.



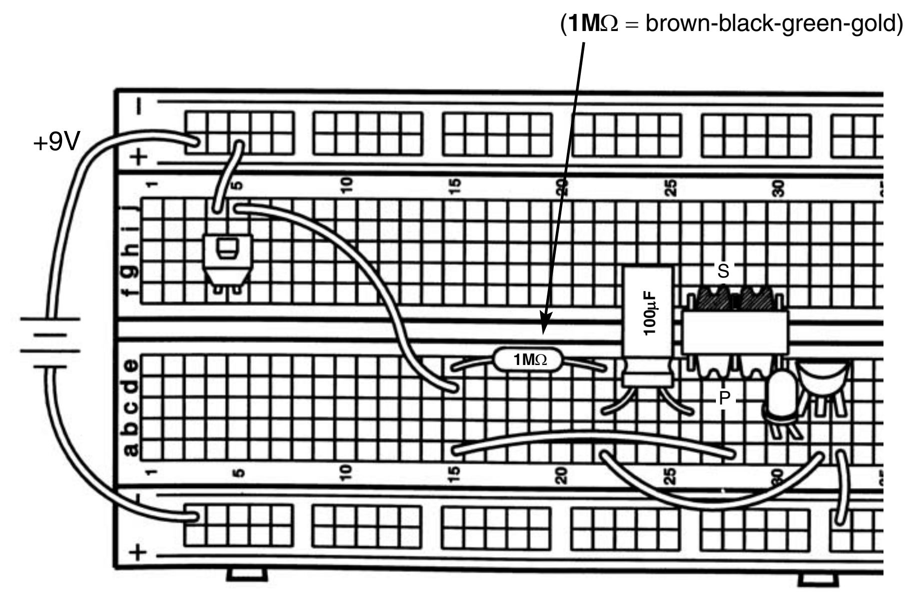


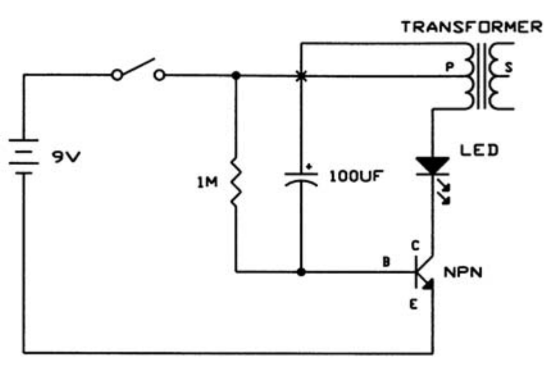
EXPERIMENT #28: THE LIGHTHOUSE

Connect the circuit. Notice that the transformer is being used as two coils (inductors) here. Also notice that two transformer taps are not connected although their wires cross in the schematic. Press the switch and hold it down for a while. The LED blinks every few seconds, like a tiny lighthouse!

Notice that the LED blinks at a constant rate. This circuit is called an **oscillator**. It uses **feedback**. Feedback is when you adjust the input to something based on what its output is doing. The collector signal is fed back to the base through a coil (part of the transformer) and the 100µF capacitor. If you disconnect this feedback path then the LED will be on continuously, because the feedback is what turns the transistor on and off. The rate at which the transistor is turned on and off is called the frequency and is controlled by the resistor, capacitor, and coil in the circuit. You can speed up the frequency (the LED blink rate) by changing the resistor or capacitor to smaller values. Try replacing the 1MΩ resistor with the 100kΩ resistor and see what happens.

Feedback is necessary for this circuit to work, but in some cases it can be harmful. In an auditorium or concert hall you sometimes hear a microphone scream when it is located too close to the speaker. In this case the sound from the speaker is feeding back into the microphone.



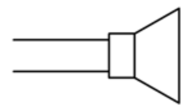


EXPERIMENT #29: ELECTRONIC SOUND

Now it's time to make some noise. To do this we need a **speaker**. A speaker converts electrical energy into sound. It does this by using the energy of an AC electrical signal to create mechanical vibrations. These vibrations create variations in air pressure, called sound waves, which travel across the room. You "hear" sound when your ears feel these air pressure variations. You need high current and low voltage to operate a speaker, so we will always use the transformer with the speaker. (Remember that a transformer converts high-voltage/low-current to low-voltage/high-current). We create an AC signal for the speaker using the oscillator circuit introduced in the last experiment, with minor changes. A speaker has a schematic symbol like this:

SPEAKER

Symbol for SPEAKER

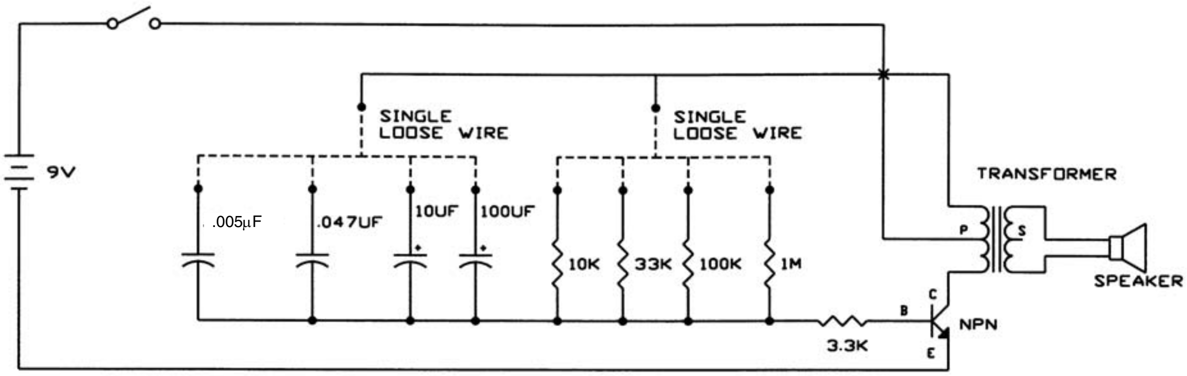


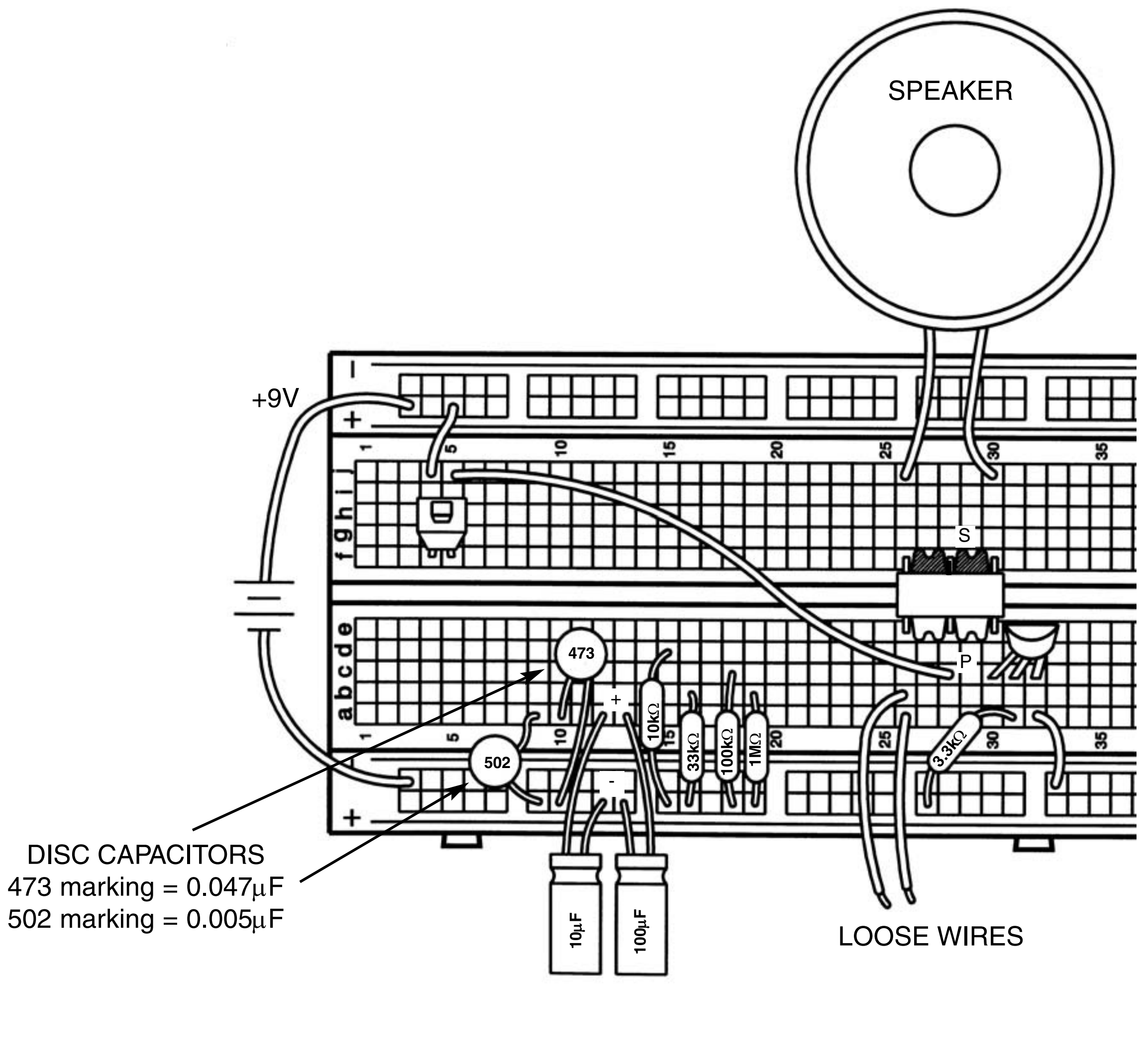
Connect the circuit, notice that two transformer taps are not connected although their wires cross in the schematic. Also notice there are 4 resistors and 4 capacitors connected to the 3.3kΩ resistor (we are using the (+) row of holes at the bottom to make the connections easier) and 2 loose wires connected to the transformer. We are also using the disc capacitors for the first time, refer back to page 19 to review them if you need to. Connect the transformer to one resistor and one capacitor at a time, then press the switch and listen. All the combinations are listed below, you don't need to try all of them but try some and see if there is a pattern in the frequency or **pitch** (a term used in music) of the sound. Record a few comments about the sound you hear.

	10kΩ	33kΩ	100kΩ	1MΩ
0.005μF				
0.047μF				
10μF				
100μF				

You may start to see the same thing we told you about the blinking LED frequency - that the <u>frequency increases when you lower the resistance or capacitance</u>. It also increases if you lower the inductance, but you don't have any other inductors you can substitute.

Oscillators are among the most important circuits in electronics and most of your remaining experiments will use an oscillator of some form. Although the oscillator circuits used here are simple ones, some oscillators can be the most difficult circuits to design.


SINGLE
LOOSE WIRE
SINGLE
LOOSE WIRE
9V
.005µF
.047UF
10UF
100UF
10K
33K
100K
1M
TRANSFORMER
P
S
SPEAKER
C
B
NPN
3.3K
E


SPEAKER
+9V
S
P
473
502
10µF
100µF
10kΩ
33kΩ
100kΩ
1MΩ
3.3kΩ
LOOSE WIRES
DISC CAPACITORS
473 marking = 0.047µF
502 marking = 0.005µF

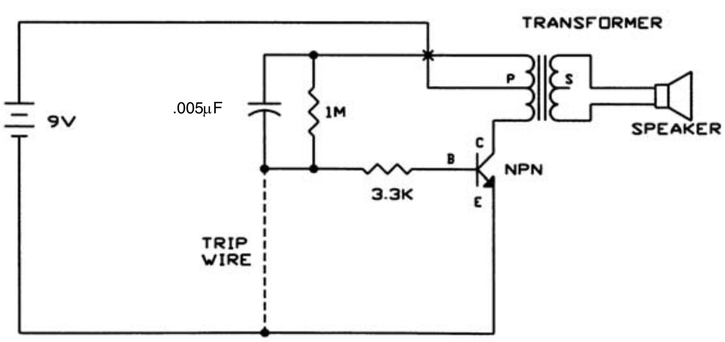
EXPERIMENT #30: THE ALARM

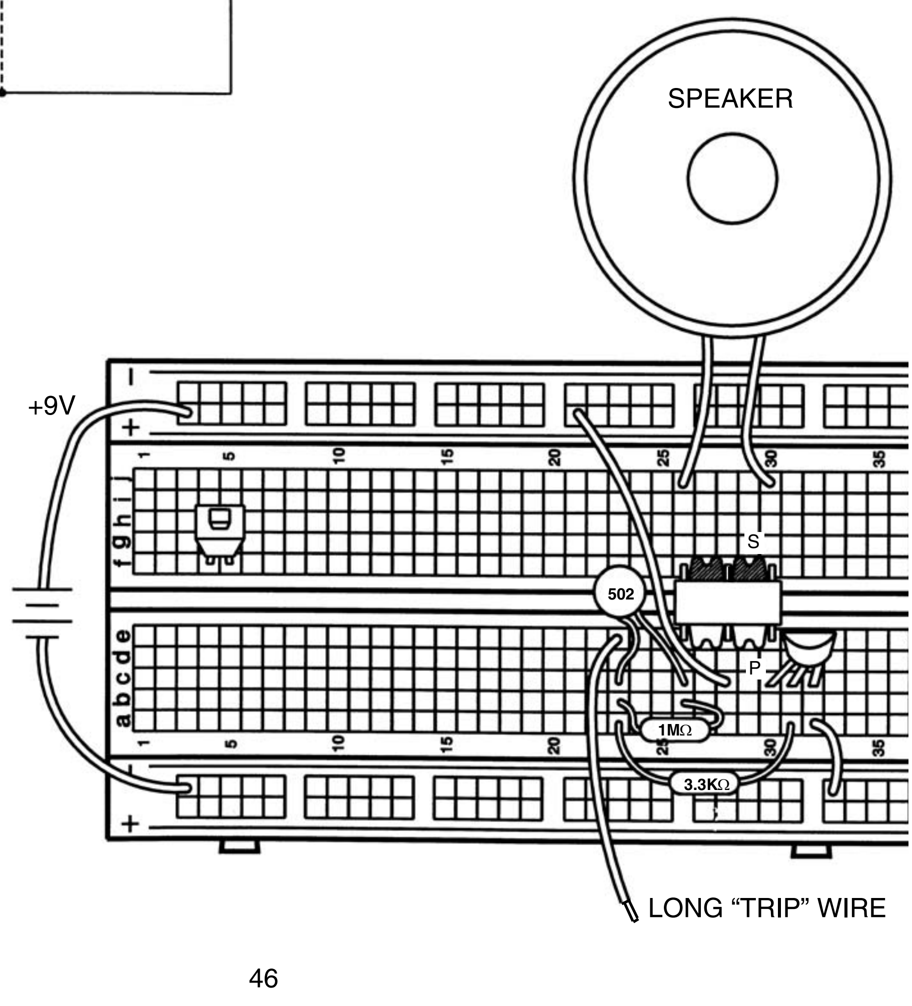
This circuit is unusual in that you turn it on by disconnecting a wire and turn it off by connecting the wire. Connect the circuit, including a long wire as the “trip” wire. Notice that there is no sound. Now disconnect the trip wire and you hear a sound, an alarm.

This type of circuit is used to detect burglars or other intruders. If you use a longer trip wire, you can place it across a doorway or window and when someone goes through the doorway or window they will trip on the wire (disconnecting it) and the alarm will sound. This is how professional burglar alarms work, although some use beams of light across the doorway or window instead of wire for the “trip” mechanism. The trip wire could also alert your local police station instead of turning on the alarm here.

This circuit is the same oscillator circuit you just used except that the trip wire was added. The trip wire creates a “short circuit” across the transistor base, so no current flows into the base and the transistor stays off. Disconnecting the trip wire eliminates the short and the oscillator works normally.

If you like, you can adjust the loudness of the alarm by replacing the 3.3kΩ resistor with the variable resistor.





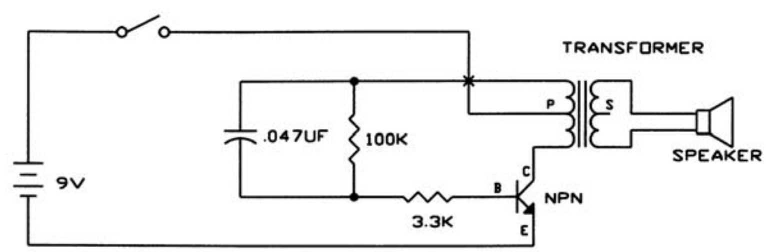
EXPERIMENT #31: MORSE CODE

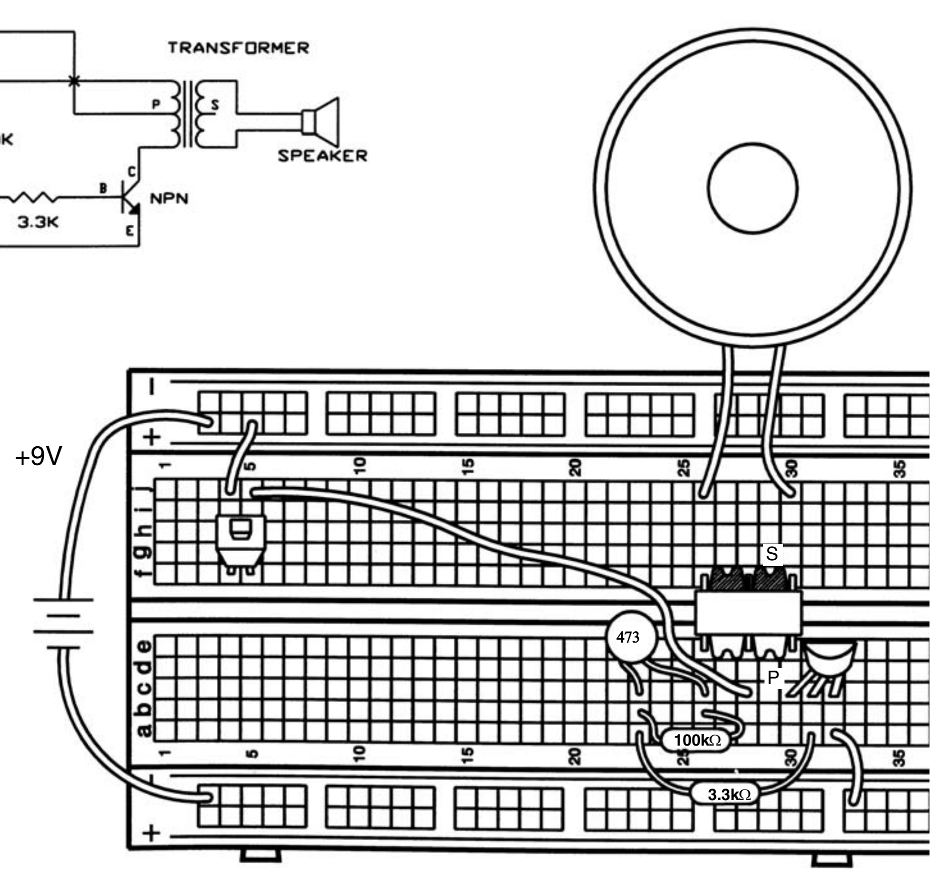
The forerunner of today's telephone system was the telegraph, which was widely used in the latter half of the 19th century. It only had two states – on or off (that is, transmitting or not transmitting), and could not send the range of frequencies contain in human voices or music. A code was developed to send information over long distances using this system and a sequence of dots and dashes (short or long transmit bursts). It was named Morse Code after its inventor. It was also used extensively in the early days of radio communications, though it isn't in wide use today except in amateur radio ("ham" radio). It is sometimes referred to in Hollywood movies, especially Westerns.

MORSE CODE

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

Connect the circuit, it is the same oscillator circuit that you have been using. Press the switch in long and short bursts to make a sound pattern representing the dots and dashes shown in the table above. You can use Morse Code and this circuit to send secret messages to friends in hearing distance without others knowing what you're saying. If the sound bothers others in the room then you may send Morse Code messages using flashes of light instead. Use the same circuit as you used in Experiment 14 (The Electronic Switch) and press the switch in the manner shown here. During World War II Navy ships sometimes communicated by flashing Morse Code messages between ships using searchlights (they did this because radio transmissions might reveal their presence or position to the enemy).



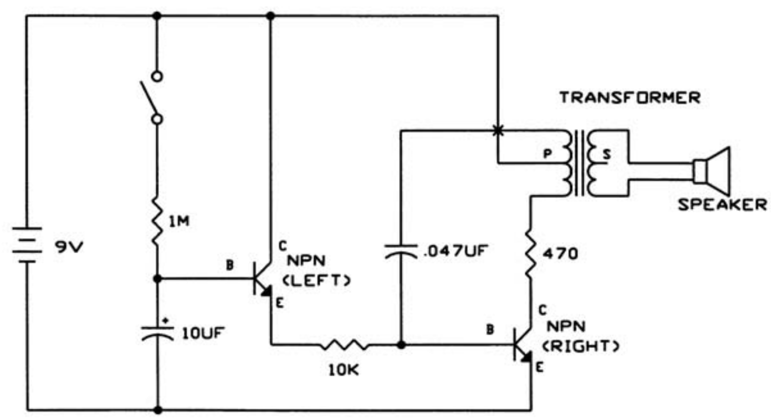


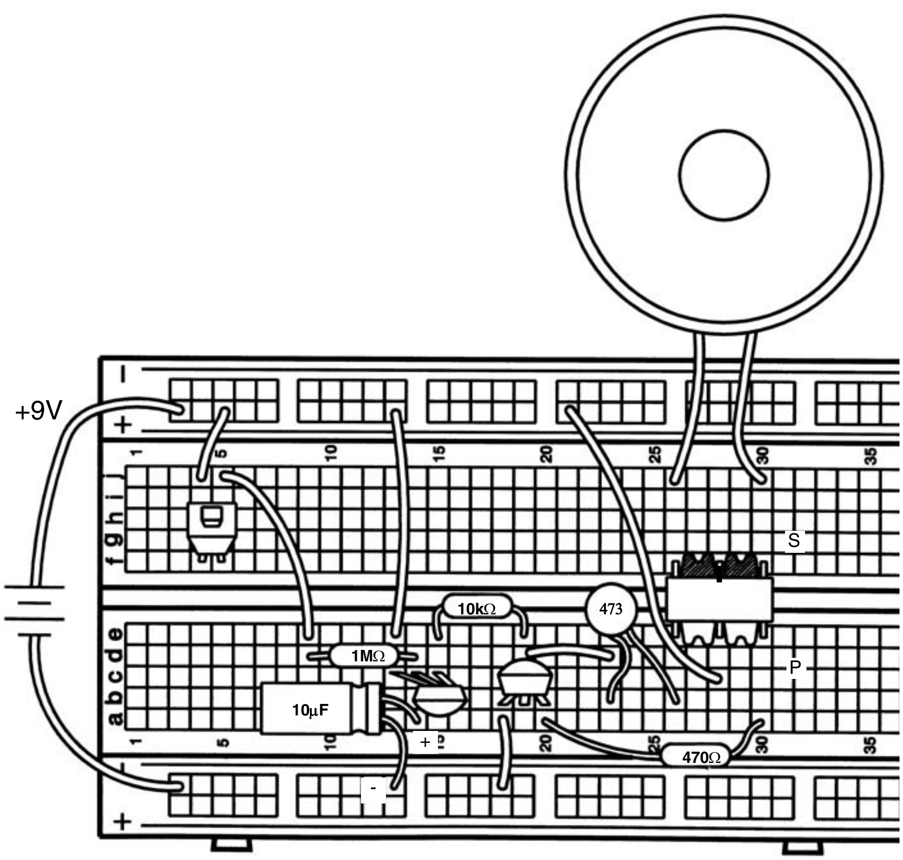
EXPERIMENT #32: SIREN

Connect the circuit and press the switch. It makes a siren sound.

You saw earlier how you could change the frequency (pitch) of the oscillator by changing the oscillator's resistance. Well this is basically the same oscillator circuit you've been using except that now we are electronically varying the oscillator's resistance. The large 1MΩ resistor and 10µf capacitor cause the base voltage (and hence base current) on transistor NPN-left to rise slowly. As the base current slowly increases, NPN-left's collector current also increases slowly (though it is always much higher than the base current). NPN-left is now limiting the current just as a resistor does! Similar effects occur after you release the switch and the 10µF slowly discharges.

If you like you can make the sound louder by adding a 1kΩ resistor in series with the base (middle wire) of NPN-right.



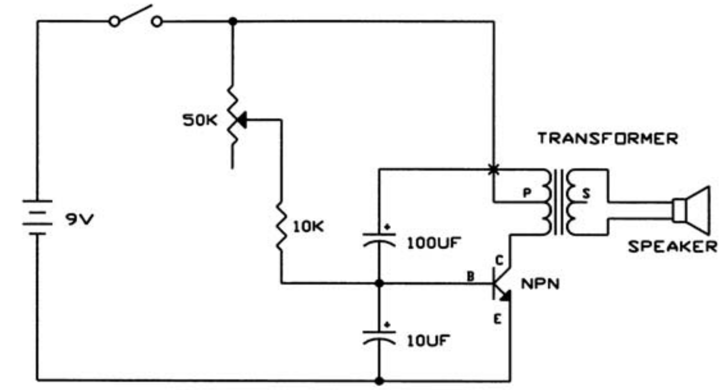


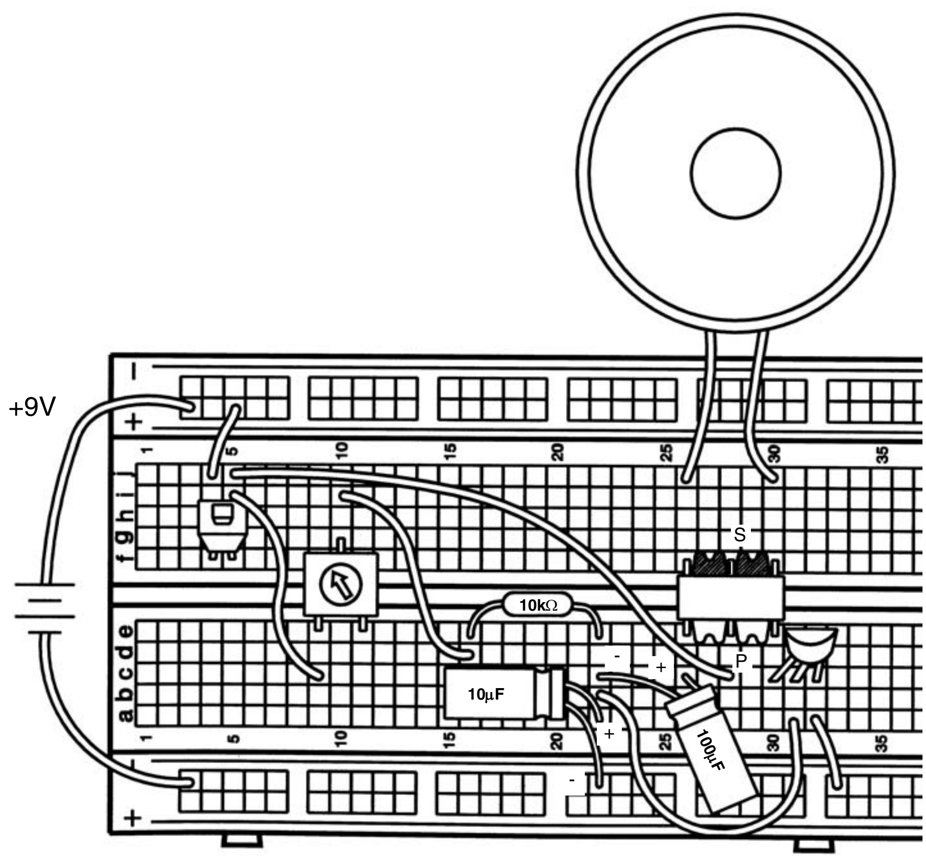
EXPERIMENT #33: ELECTRONIC RAIN

Connect the circuit and press the switch. You hear a sound like raindrops. The variable resistor (VR) knob controls the rain, turn it to the right to make a drizzle and turn to the left to make the rain come pouring down. If you find it inconvenient to turn the VR knob while pressing the switch then just connect a wire across the switch.

Do you know how this circuit works? Remember that as you lower the oscillator's resistance the frequency increases, and obviously the VR controls the resistance. What would happen if you replaced the 10kΩ resistor with the 100kΩ? Try it. The rain is now very slow, and it sounds more like a leaky faucet than raindrops.

You can experiment with changing other component values if you like.



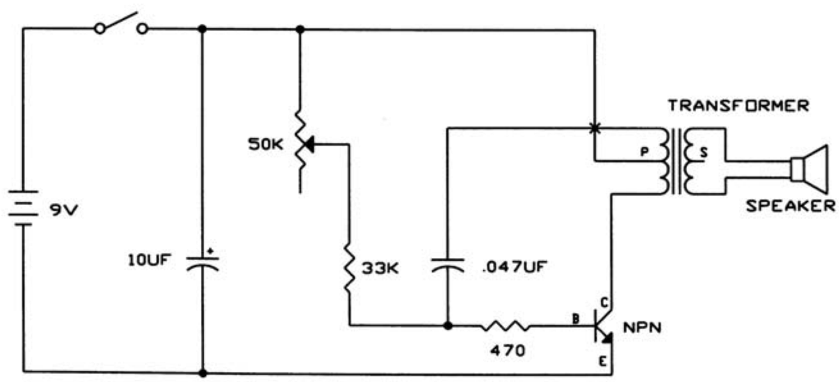


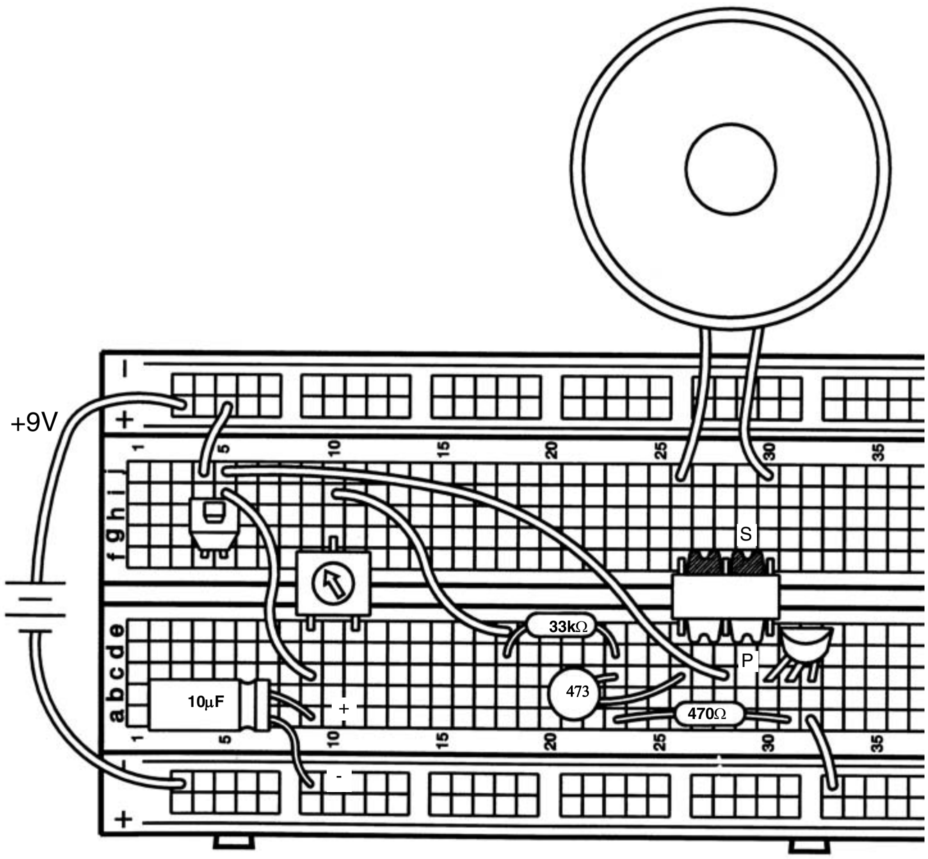
EXPERIMENT #34: THE SPACE GUN

Connect the circuit and press the switch several times quickly. You hear a sound like a space gun in the movies. You can adjust the "gun" sound using the variable resistor. If you find it inconvenient to turn the VR knob while pressing the switch then just connect a wire across the switch.

Do you know how this circuit works? It's basically the same as the last circuit except for the 10µF capacitor, which instantly charges up when you press the switch and then discharges by powering the circuit for a few seconds after you release the switch.

You can experiment with changing component values if you like.



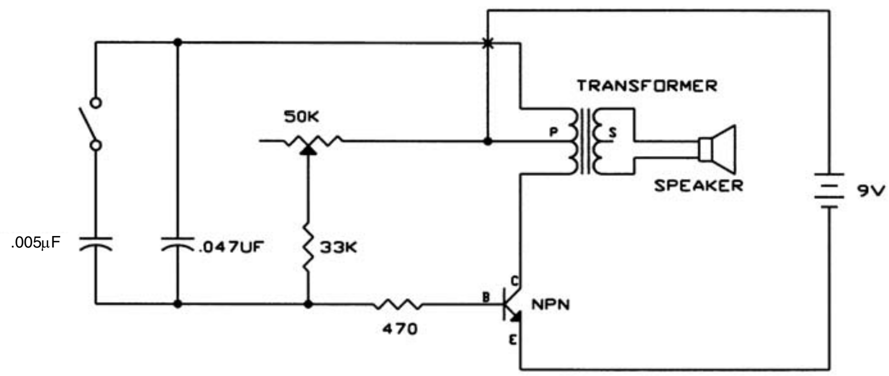


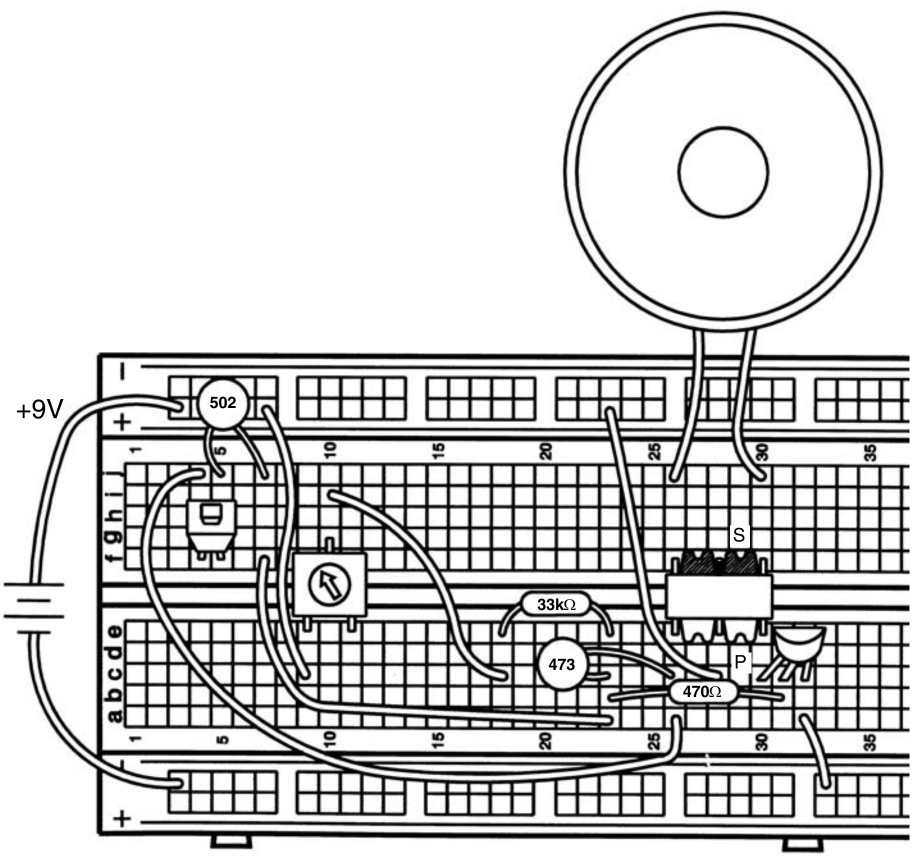
EXPERIMENT #35: ELECTRONIC NOISEMAKER

Connect the circuit, connecting the battery last since it will turn the circuit on. Press the switch several times quickly. Then turn the variable resistor knob to change the frequency of the sounds.

Do you understand what's happening when you press the switch? You increase the oscillator capacitance by putting the 0.005µF in parallel with the 0.047µF, and this lowers the oscillator frequency.

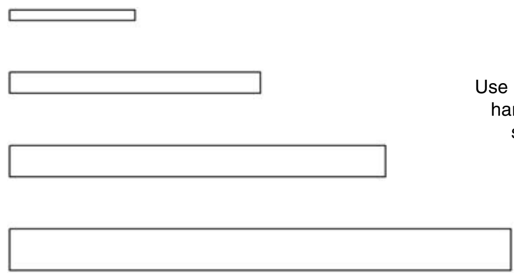
As usual you can experiment with changing component values if you like.





EXPERIMENT #36: DRAWING RESISTORS

You need some more parts to do this experiment, so you're going to draw them. Take a pencil (No. 2 lead is best but other types will also work), **SHARPEN IT**, and fill in the 4 rectangles you see below. You will get better results if you **place a hard, flat surface between this page and the rest of this booklet** while you are drawing. **Press hard** (but don't rip the paper) and **fill in each several times** to be sure you have a **thick, even layer of pencil** lead and try to avoid going out of the boundaries.



Shapes to be drawn.

Use a SHARP No. 2 pencil, draw on a hard surface, press hard and fill in several times for best results.

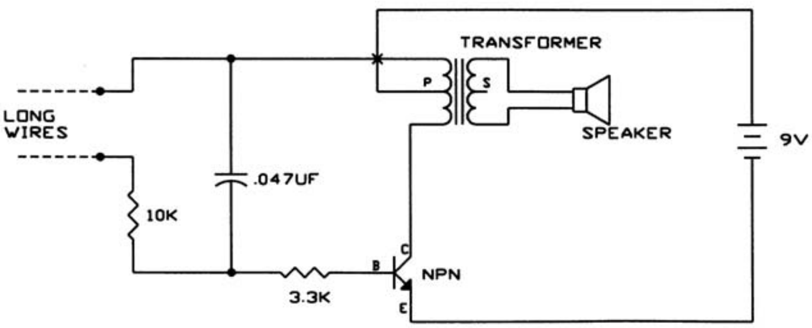
Actually, your pencils aren't made out of lead anymore (although we still call them "lead pencils"). The "lead" in your pencils is really a form of carbon, the same material that resistors are made of. So the drawings you just made should act just like the resistors in your Electronic Playground.

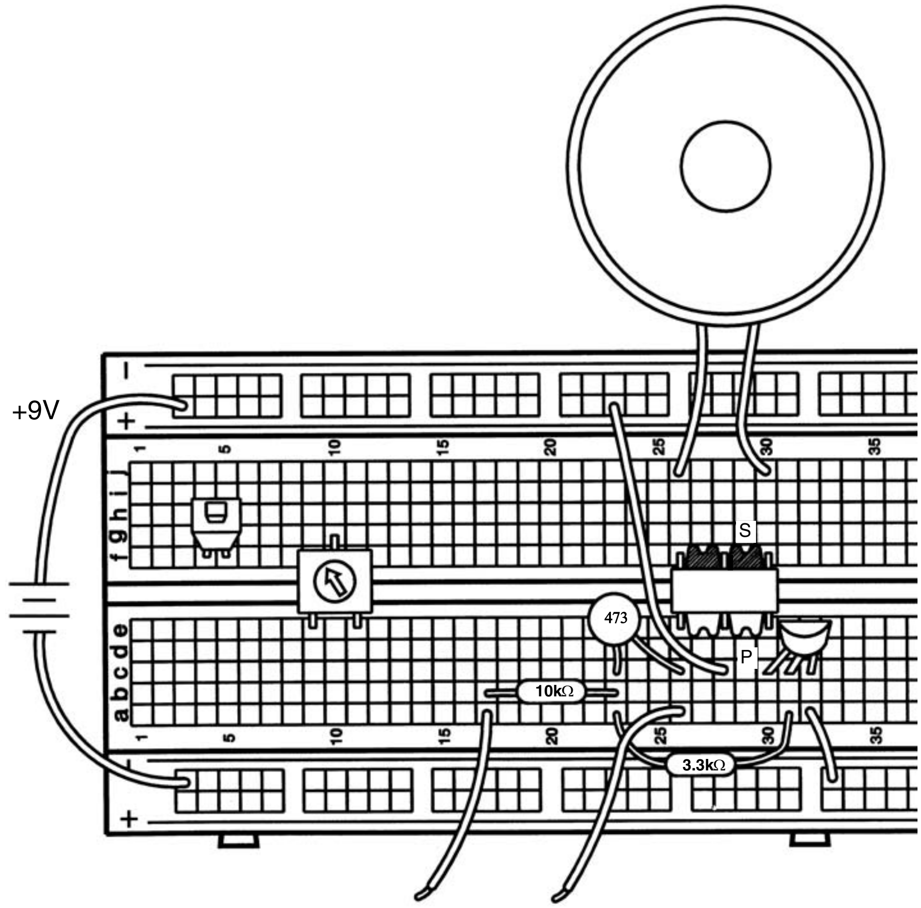
Connect the circuit, it's the same basic oscillator circuit you have been using. Take the two loose wires and touch them to opposite ends of the smallest rectangle you drew, you should hear a sound like an alarm. **Note:** you may get better electrical contact between the wires and the drawings if you wet the wires with a few drops of water or saliva.

What kind of sound do you think you'll get with the other drawings? (**Hint:** think about how resistors operate in series and parallel combinations, or think in terms of the water pipes). Now touch the loose wires to opposite ends of the other rectangles you drew (you may need to wet the wires again) and see if you were right. You can also slide one of the wires along the drawing and see how the sound changes.

Making the drawn resistors longer should increase the resistance (resistors in series or longer water pipes) while making them wider should reduce the resistance (resistors in parallel or larger water pipes). So all 4 rectangles should produce the same sound, though you will see variations due to how thick and evenly you filled in the rectangles, and exactly where you touch the wires. If your 4 shapes don't sound similar then try improving your drawings.

Be sure to wash your hands after this test, unless you're going on to Experiment 37 now.





LONG LOOSE WIRES

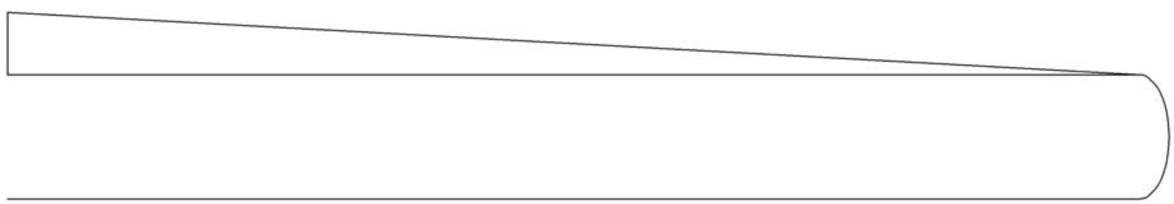
EXPERIMENT #37: ELECTRONIC KAZOO

Now it's time to make your own music. This experiment will use the (almost) same circuit as the last one, so there is no schematic or Wiring Checklist. The only difference is that you will draw a new shape. A Kazoo is a musical instrument that is like a one-note flute, and you change the pitch (frequency) of the sound by moving a plunger up and down inside a tube.

As before, take a pencil (No. 2 lead is best but other types will also work), **SHARPEN IT** again, and fill in the shape you see below. For best results, **SHARPEN IT again**, **place a hard flat surface between this page and the rest of this booklet** while you are drawing. **Press hard** (but don't rip the paper). **Fill in each several times** to be sure you have a **thick, even layer of pencil** lead, and try to avoid going out of the boundaries. **Where the shape is just a line, draw a thick line and go over it several times.** The black ink in this manual is an insulator just like paper, so you have to write over it with your pencil.

Shape to be drawn.

Use a SHARP No. 2 pencil, draw on a hard surface, press hard and fill in several times for best results.



Take one loose wire and touch it to the widest part of this shape, at the upper left. Take the other loose wire and touch it just to the right of the first wire. You should hear a high-pitch sound. How do you think the sound will change as you slide the second wire to the right? Do it, slowly sliding all the way around to the end. The sound changes from high frequency to low frequency, just like a kazoo. **Note:** you may get better electrical contact between the wires and the drawings if you wet the wires with a few drops of water or saliva.

This circuit is nearly the same as for Experiment 29 (Electronic Sound), so you can use the notes you took there to estimate what the resistance is at various points along your kazoo.

Be sure to wash your hands after this test, unless you're going on to Experiment 38 now.

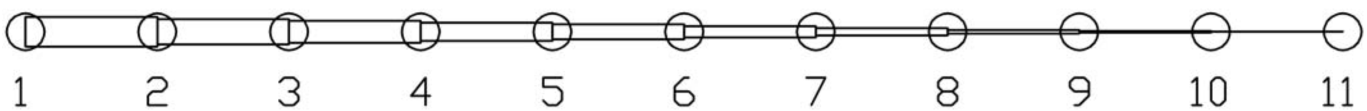
EXPERIMENT #38: ELECTRONIC KEYBOARD

This experiment will use the (almost) same circuit as the last one, so there is no schematic or Wiring Checklist. The only difference is that you will draw a new shape.

As before, take a pencil (No. 2 lead is best but other types will also work), **SHARPEN IT** again, and fill in the shape you see below. For best results, **SHARPEN IT again**, **place a hard flat surface between this page and the rest of this booklet** while you are drawing. **Press hard** (but don't rip the paper). **Fill in each several times** to be sure you have a **thick, even layer of pencil** lead, and try to avoid going out of the boundaries. **Where the shape is just a line, draw a thick line and go over it several times.** The black ink in this manual is an insulator just like paper, so you have to write over it with your pencil.

Shape to be drawn.

Use a SHARP No. 2 pencil, draw on a hard surface, press hard and fill in several times for best results.



Take one loose wire and touch it to the left circle. Take the other loose wire and touch it to each of the other circles. The various circles produce different pitches in the sound, like notes. Since the circles are like keys on a piano, you now have an electronic keyboard! See what kind of music you can play with it. **Note:** you may get better electrical contact between the wires and the drawings if you wet the wires with a few drops of water or saliva.

Now take one loose wire and touch it to the right circle (#11). Take the other wire and touch it to the circles next to the numbers shown below, in order:

7 - 5 - 1 - 5 - 7 - 7 - 7
5 - 5 - 5
7 - 7 - 7
7 - 5 - 1 - 5 - 7 - 7 - 7 - 7 - 5 - 5 - 7 - 5 - 1

Do you recognize this nursery rhyme? It is "Mary Had a Little Lamb".

By now you see that you can draw any shape you like and make electronic sounds with it. Experiment on your own as much as you like. The circuit here is nearly the same as for Experiment 29 (Electronic Sound), so you can use the notes you took there to estimate what the resistance is at various points along your keyboard or any other shapes you make.

Be sure to wash your hands after this test.

EXPERIMENT #39: FUN WITH WATER

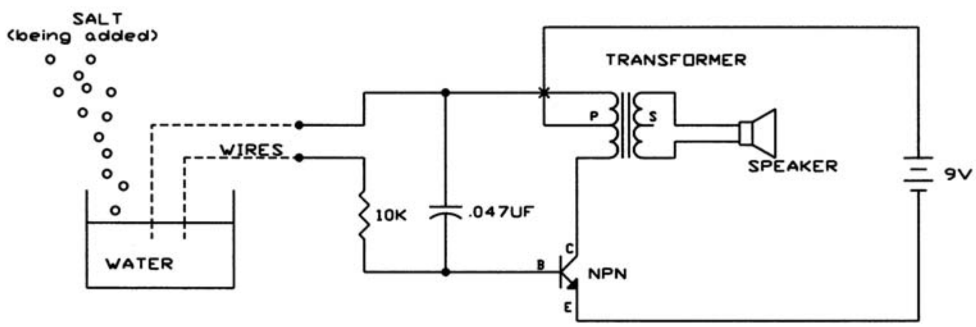
Connect the circuit, initially the two loose wires are unconnected so there is no sound. Now touch each wire with fingers from different hands, you should hear a low-frequency sound. (Wetting your fingers with water or saliva will make better electrical contact). You are using your body as an electrical component, just as you did in Experiment 20 (Two Finger Touch Lamp). If you like you may make the sound louder by replacing the wire between a23 and a31 with a 3.3kΩ resistor (actually this makes the circuit the same as the last experiment), though the tone of the sound will be different.

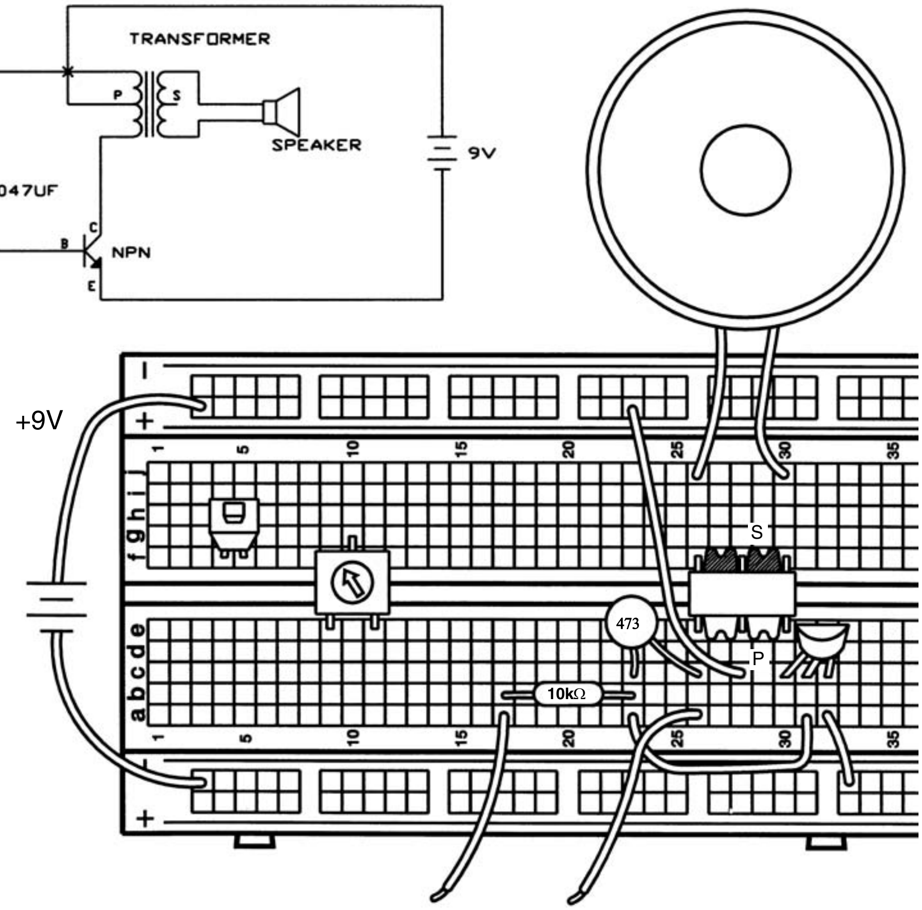
Now take a small cup (make sure it isn't made of metal), fill it half way with water, and place the two wires into the water but without touching each other. The sound will now have a much higher frequency because your drinking water has lower resistance than your body. Now, with the wires still in the water making noise, add some table salt to the water and stir to dissolve the salt. You should hear the frequency increase as you do this.

This circuit makes a good water detector. You could use it as a warning alarm in case your house starts to flood during a storm. Or you could use the frequency of the sound as a water saltiness indicator.

You can also make a water kazoo. Pour a small amount of water on a table or the floor and spread it with your finger into a long line. Place one of the wires at one end and slide the other along the water. You should get an effect just like the kazoo you drew with the pencil, though the frequency will probably be different.

You've seen how adding salt to water decreases its resistance. So would it surprise you to know that pure water (distilled water) has very high resistance? The drinking water you are using here has small amounts of minerals in it, which decrease its resistance just like salt does. Your body conducts electricity because your body is mostly water, with many things mixed in. When salt dissolves in water it breaks up into particles called ions, which are electrically charged. The ions make it easier for electrons to travel through the water, similar to how adding impurities makes it easier for electrons to flow through semiconductors. Their overall effect is that the resistance of the water is reduced. If you have some distilled water in your house, try using it with this test.





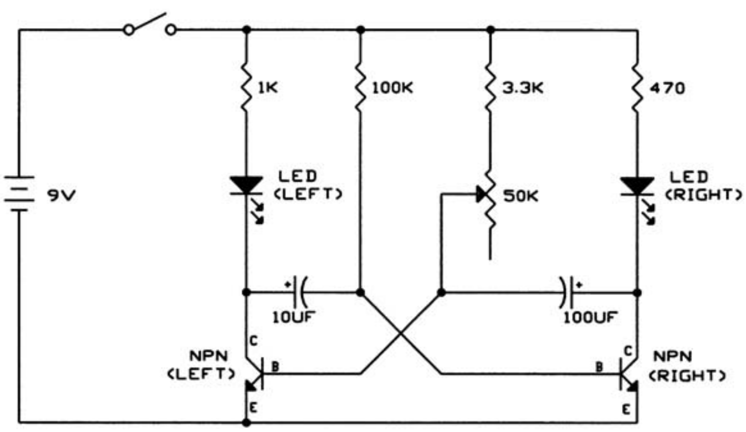
LONG WIRES TO WATER

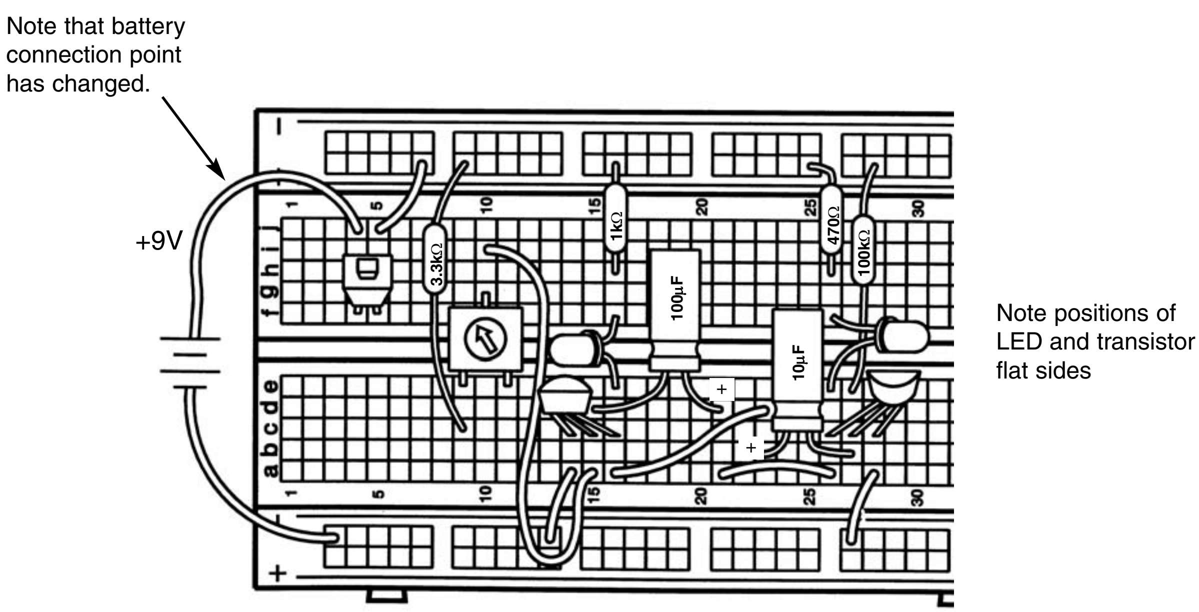
EXPERIMENT #40: BLINKING LIGHTS

Take a look at the schematic. This circuit configuration is a type of oscillator called an astable multivibrator. What do you think it will do? Connect the circuit, noting that the transistor bases are not connected although their wires cross in the schematic. Initially set the variable resistor (VR) to its minimum value (turn it to the left). Press the switch and hold it down. One LED is on while the other is off, and they change about every second. What do you think will happen as you turn the knob on the VR? The right LED stays on longer than the left one.

In this circuit, one transistor is always on while the other is off. In this type of oscillator there is no inductor, the frequency is controlled only by the resistors and capacitors. The 100kΩ and 10μF determine how long the left transistor is on and the 3.3kΩ, VR, and 100μF determine how long the right transistor is on. If you want to experiment with changing part values, go ahead. But don't replace the capacitors with the smaller disc ones (you'll see why in the next experiment).

Blinking lights like this are often used to attract people's attention.

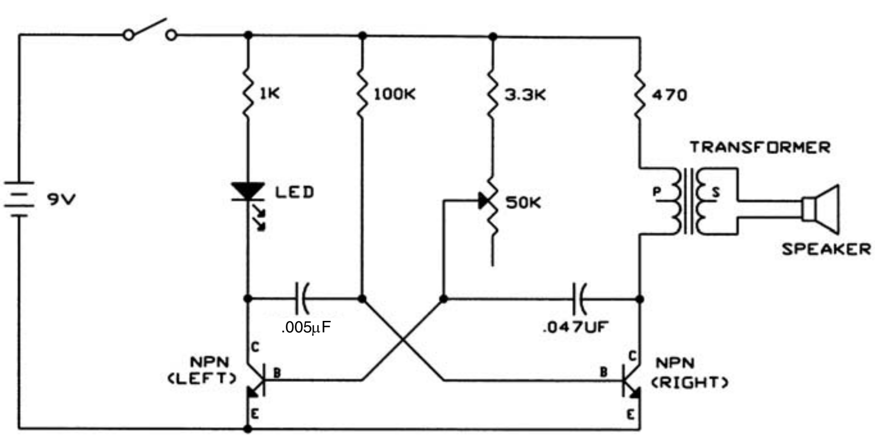


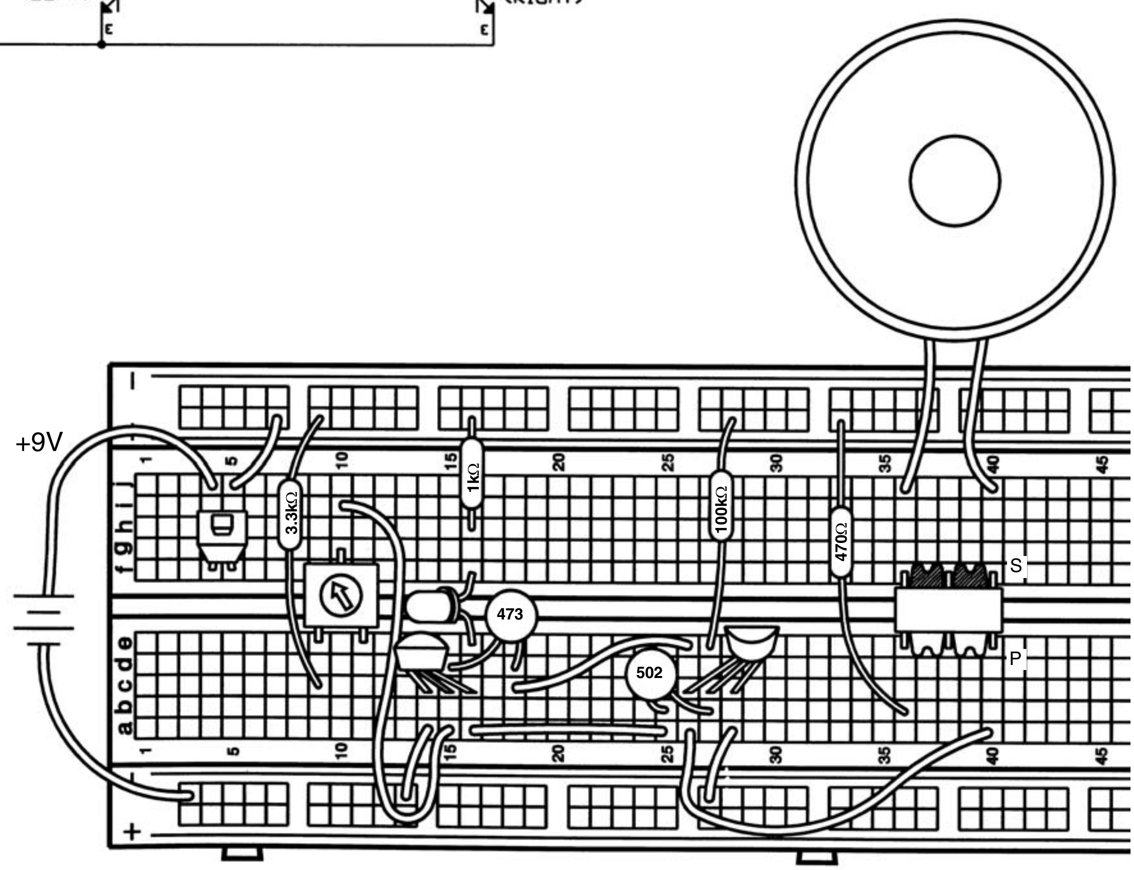


EXPERIMENT #41: NOISY BLINKER

This circuit is similar to the last one. Connect the circuit (noting that the transistor bases are not connected although their wires cross in the schematic). Press the switch and hold it down. The LED lights and you hear sound from the speaker. Turn the knob on the variable resistor and the frequency of the sound changes. Can you tell what the LED is really doing? It is actually blinking about 500 times a second, but to your eyes it appears as a blur or just dim. (This is why we told you not to replace the large capacitors with small ones like these in the last experiment).

You can experiment with changing component values if you like. The 470Ω resistor limits the sound loudness, replace it with a wire to make the sound louder and replace it with a 10kΩ to make the sound softer. Swapping the two capacitors in the circuit will make the sound frequency higher, replacing them with the 10µF or 100µF will make the frequency much lower. You can also change some of the other resistors.

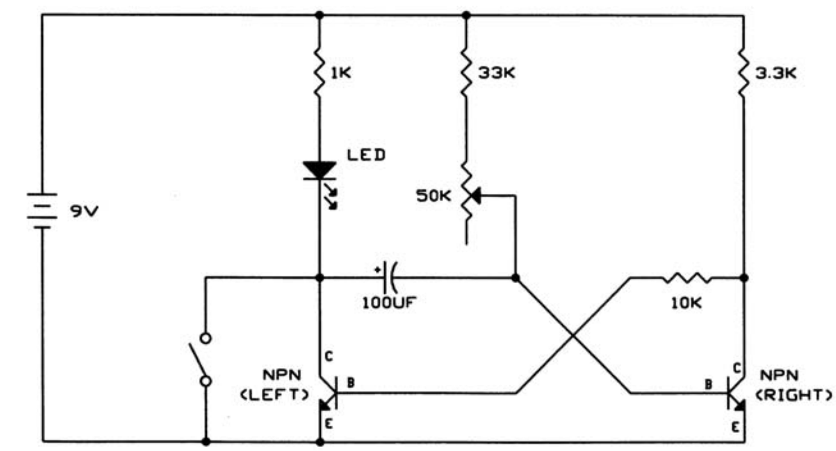


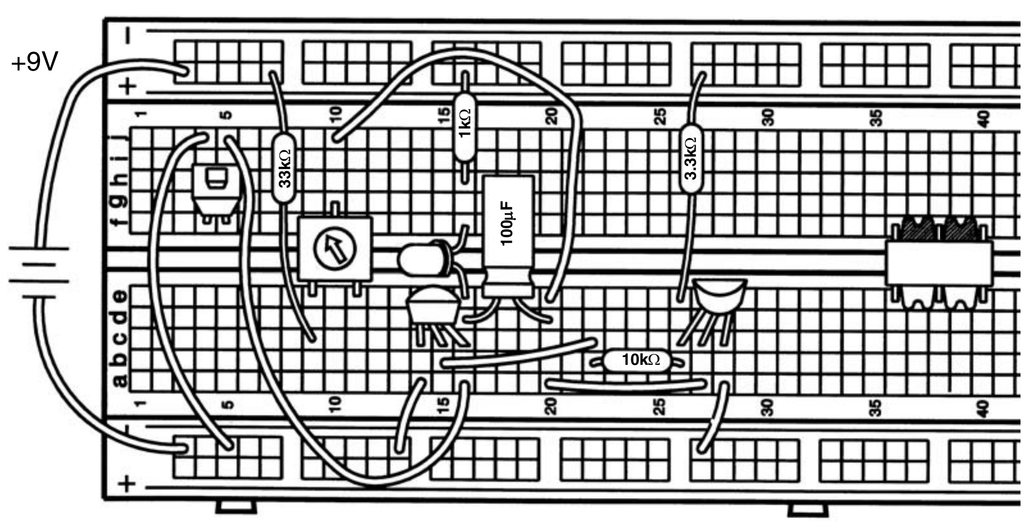


EXPERIMENT #42: ONE-SHOT

Do you know what this circuit will do? Connect everything, then press the switch and release it. The LED is on for a few seconds and then goes out. What effect do you think changing the value of the variable resistor will have? Try it. The higher the resistance the longer the LED stays on.

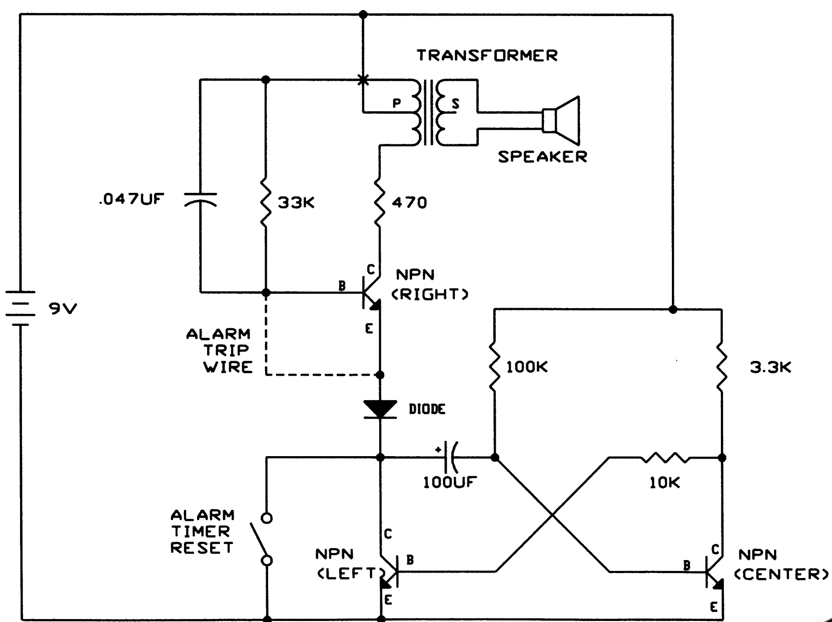
This circuit is a variation of the astable multivibrator and is called a one-shot multivibrator, because the LED comes on once each time the switch is pressed. The 33kΩ, variable resistor, and 100μF control how long the LED is on. This circuit can be used as a timer. You might use a circuit like this with your microwave oven. You press the switch to turn the oven on and have a knob (the variable resistor) to adjust how long the oven stays on; it then shuts off automatically.

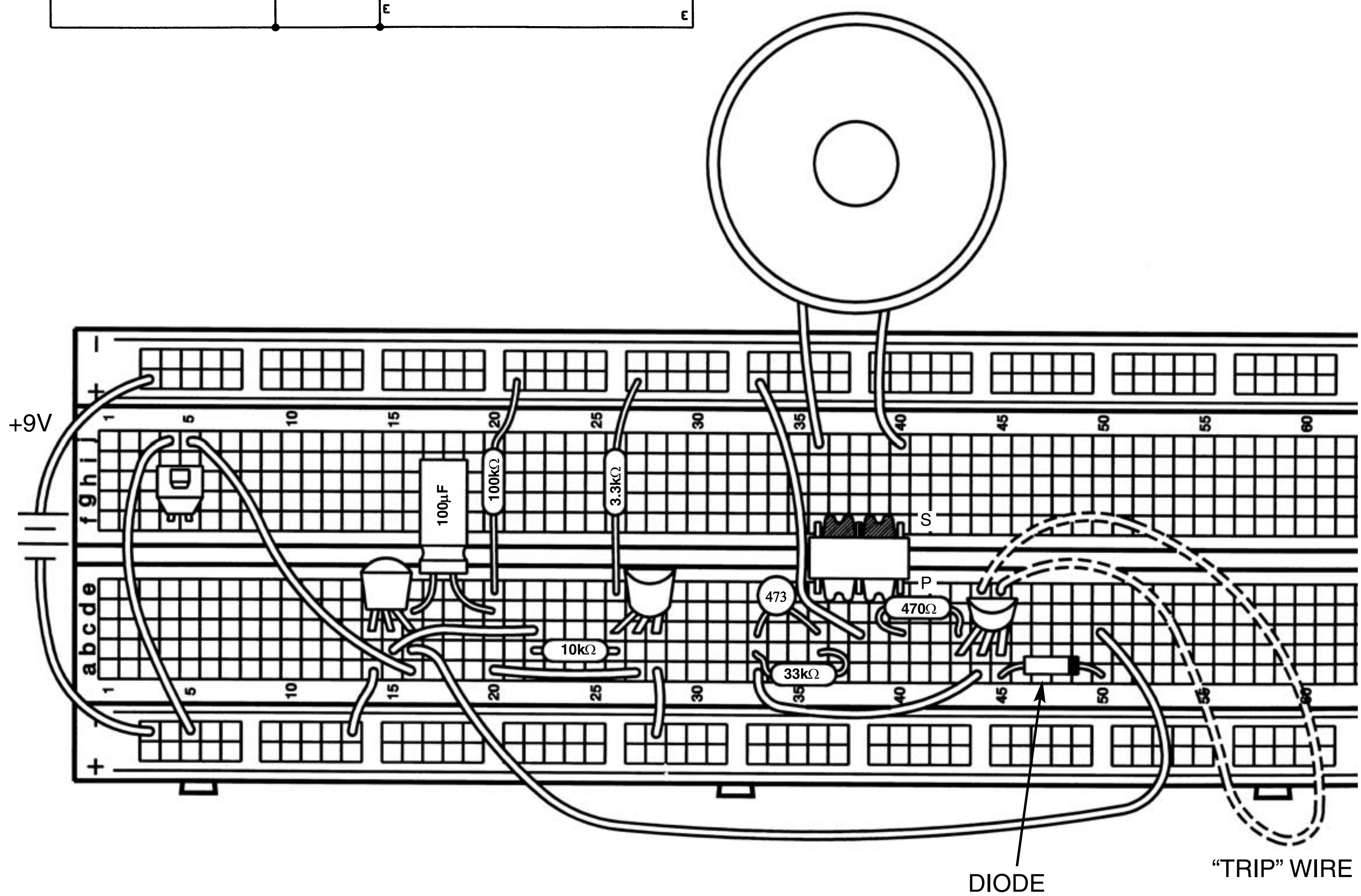




EXPERIMENT #43: ALARM WITH SHUT-OFF TIMER

Let's demonstrate a use for the timer circuit you just built by combining it with Experiment 30, the Alarm. Connect the circuit (noting that the transistor bases and transformer signals are not connected although their wires cross in the schematic). Connect the alarm trip wire and then connect the battery wire to turn the circuit on. Press the switch once. Now disconnect the trip wire to activate the alarm. The alarm stays on for a few seconds and then goes off. Re-connect the trip wire and press the switch to reset the alarm and timer. If you only re-connect the trip wire without resetting the timer then the alarm won't work the next time. You could use a circuit like this where you get lots of false alarms and you want to shut off the alarm before the battery gets weak. Automobile alarms, for example, get lots of false alarms.

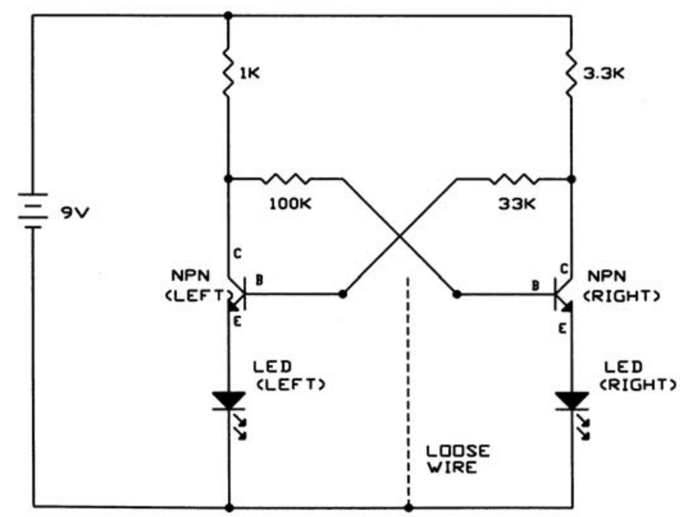


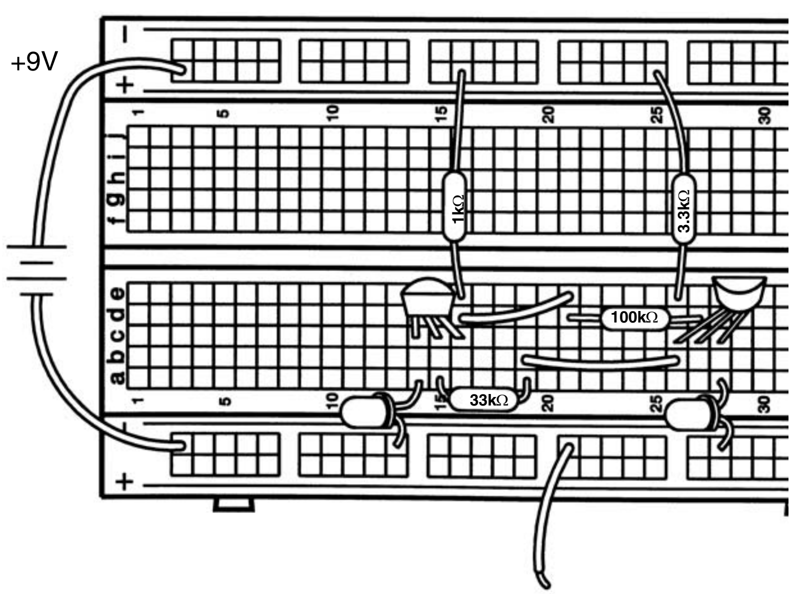


EXPERIMENT #44: THE FLIP - FLOP

This circuit is yet another variation of the basic multivibrator configuration. Connect the circuit. One LED will be on, the other off. Take the loose wire and touch it to the base of the transistor that is on (holes b15 and a27 will do, or you can touch the resistor leads connected to these points). That transistor turns off and the other turns on. Do this a few more times until you see that touching the “on” transistor base “flips” the transistors and the LEDs. You might say that the transistor turning on “flips” and the one turning off “flops”. Notice that touching the “off” transistor base has no effect.

This circuit is called formally known as the bistable switch, but is nicknamed the “flip-flop” due to the way it operates. The name flip-flop may seem silly to you at first, but variations of this circuit form one of the basic building blocks for digital computers. This circuit can be thought of as a memory because it only changes states when you tell it to, it “remembers” what you told it to do even though you removed the loose wire. By combining several of these circuits you can remember a letter or number. By combining thousands of these circuits a computer can remember a small book. A typical computer has many thousands of flip-flops, all in integrated circuit form. The operation of this circuit is simple. If NPN-left is on then it will have a low collector voltage. Since this collector voltage also connects to NPN-right’s base, NPN-right will be off. But if you ground NPN-left’s base then it will turn off and its collector voltage rises, turning on NPN-right. NPN-right will stay on until you ground its base.



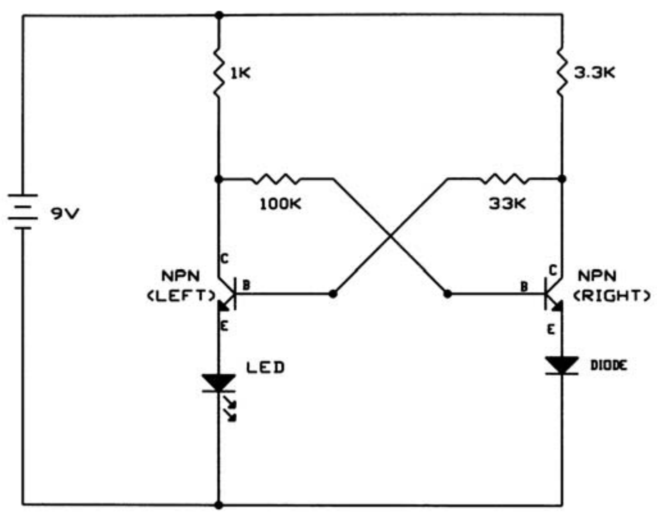


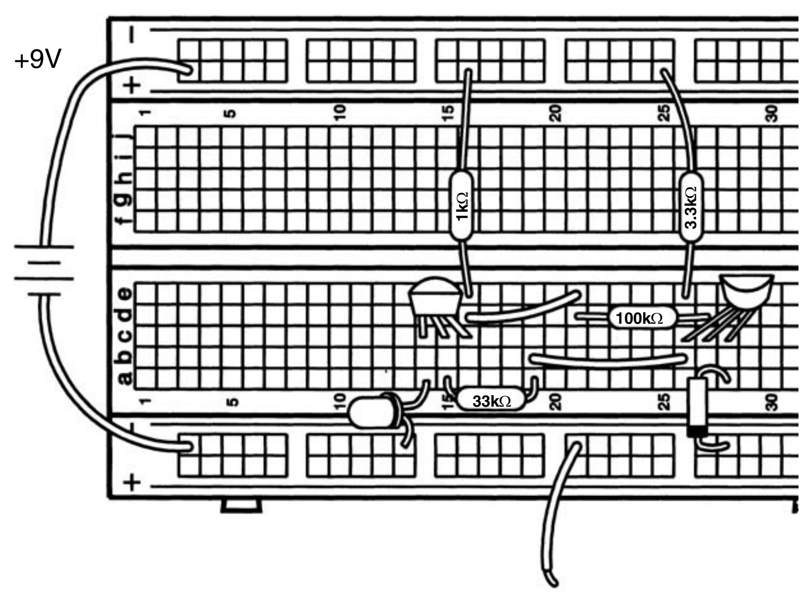
LOOSE WIRE

EXPERIMENT #45: FINGER TOUCH LAMP WITH MEMORY

Instead of using the wire to flip-flop the LED you may also use your fingers as you did in Experiment 20, the Two Finger Touch Lamp. We'll use almost the same circuit here as in the last experiment. Remove the loose wire and replace the right LED with a diode, because we don't need two "lamps". Wet two fingers and hold one on 9V (the (+) row of holes) while touching the other to one of the transistor bases. (This is easy if you touch the metal leads of the resistors connected to these points, or you may insert wires into the holes and touch the wires). But now you must touch the base of the "off" transistor to make them flip-flop, not the "on" base. Do you know why? Your body has more resistance than the other resistors in the circuit and cannot "short circuit" the transistor bases to circuit ground like the wire can. So instead we connect the off transistor to the battery to turn it on.

But this uses two fingers and in Experiment 21 we also had a one-finger version, so can we do that here? Change your wiring (add wires or move parts) so that metal from 9V is close to metal from the transistor bases. Wet a large area of one of your fingers and touch it to 9V and a transistor base at the same time. Now we have a one-finger touch lamp with memory!



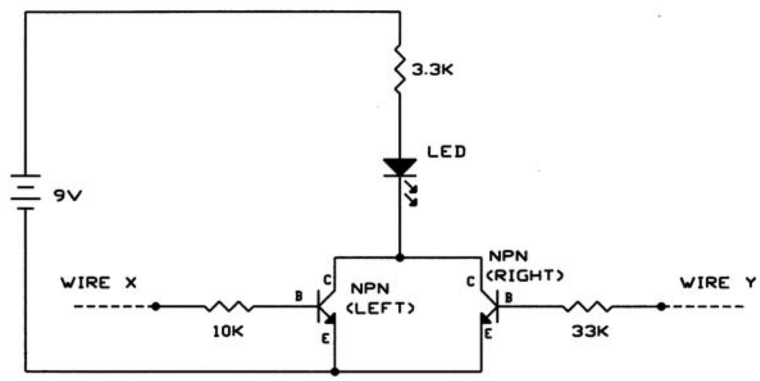


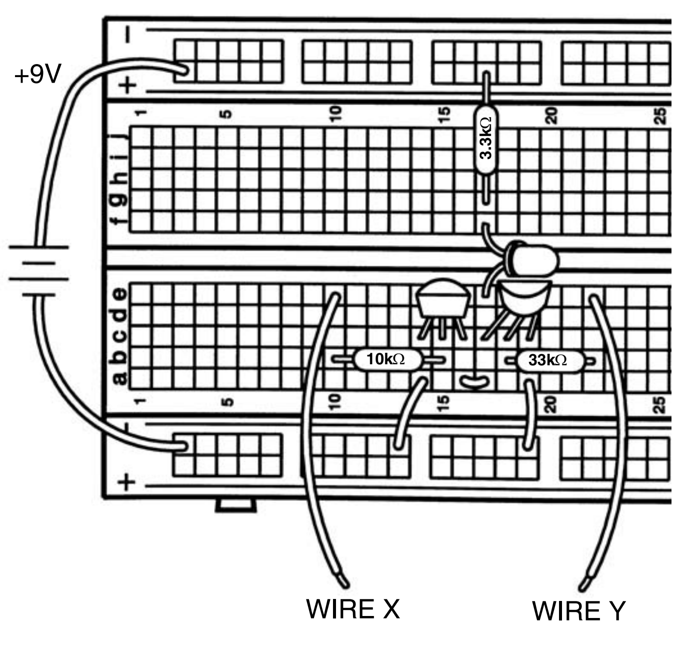
EXPERIMENT #46: THIS OR THAT

Now that you're familiar with the flip-flop, let's introduce some more digital circuits. Digital circuits are circuits that have only two states, such as high-voltage/low-voltage, on/off, yes/no, and true/false. Connect the circuit. Take a look at the schematic, it is very simple. Wires X and Y are considered to be digital inputs, so connect them to either the (+) row of holes (9V, or HIGH) or leave them unconnected (this is the same as connecting them to 0V, or LOW). Test the four combinations of X and Y to determine the state of the LED (ON or OFF), filling in the table below:

X	Y	LED
LOW/UNCONNECTED	LOW/UNCONNECTED	
LOW/UNCONNECTED	HIGH/9V	
HIGH/9V	LOW/UNCONNECTED	
HIGH/9V	HIGH/9V	

This type of table is called a **truth table**. From it, you can see that if X *or* Y is HIGH then the LED will be ON. Hence, this configuration is called an **OR gate**. X and Y might represent two switches to turn on a light in your house. Or they might represent sensors at a railroad crossing; if either senses a train coming they start the ding-ding sound and lower the gate. You could also have more than two inputs, by adding more parts to your circuit and more columns to the truth table.





EXPERIMENT #47: NEITHER THIS NOR THAT

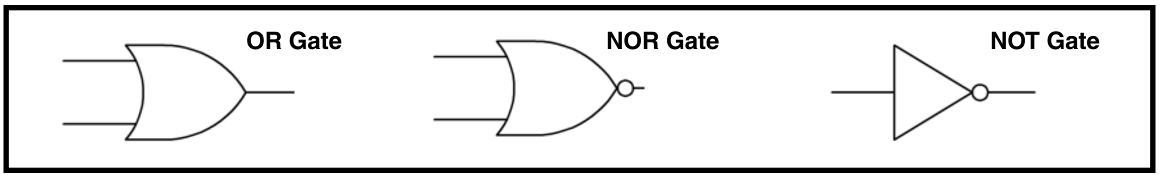
Now let's add on to the previous circuit. Everything from Experiment 46 remains in place, just add the new parts and wires shown in the schematic and Wiring Diagram. Test the four combinations of X and Y as before to determine the state of LED-right (ON or OFF), filling in the table at right:

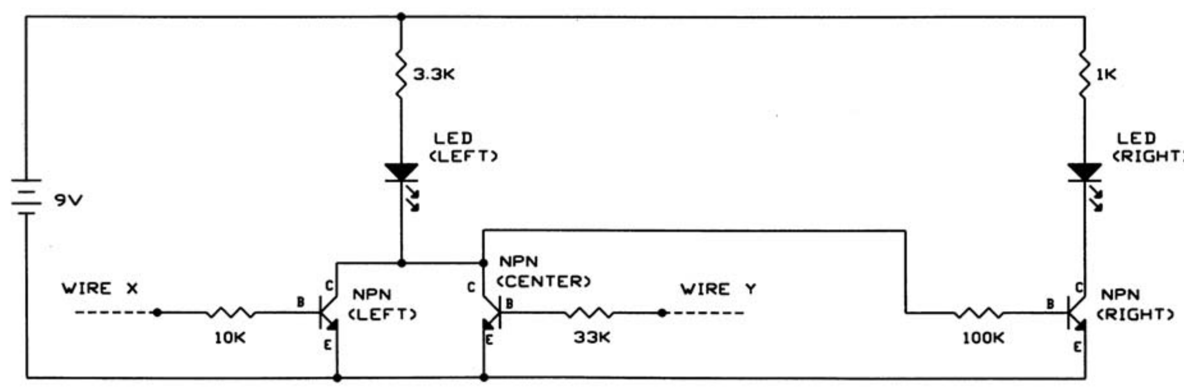
X	Y	LED-right
LOW	LOW	
LOW	HIGH	
HIGH	LOW	
HIGH	HIGH	

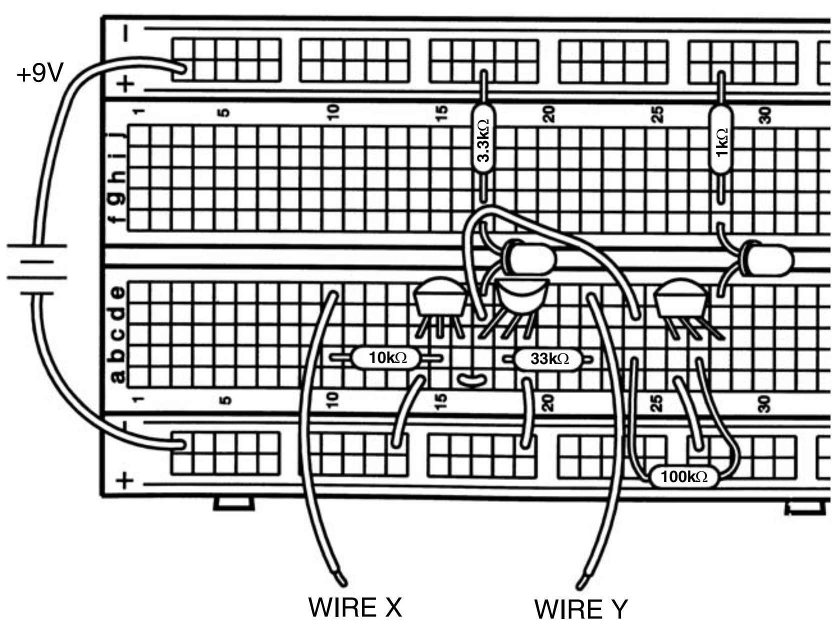
This table shows that if neither X *nor* Y is HIGH then LED-right is ON. Hence, this configuration is called a **NOR gate**. X and Y might represent your burglar alarm and flood detector, so if neither X nor Y is on then your "all clear" light goes on. You may also think of this as adding a NOT gate to an OR gate to produce a NOR gate. A **NOT gate** is just the opposite of its input:

Input	NOT
LOW	HIGH
HIGH	LOW

Gates such as OR, NOR, and NOT form some of the basic building blocks for computers. The combinations of resistors and transistors shown here to build them are a form of Resistor-Transistor-Logic, which was used extensively in early generations of computers and which led to the development of many of today's logic families. These basic gates are so commonly used that they have their own symbols:







EXPERIMENT #48: THIS AND THAT

Take a look at the schematic. Can you guess what kind of digital gate this is? We'll use almost the same circuit here as in the last experiment. Remove the wire between holes a16 and a17, and the one between holes a19 and (–)19. Add a wire between holes a16 and a19. Also, remove the 100kΩ resistor, we'll re-connect it later.

Test the four combinations of X and Y to determine the truth table:

X	Y	LED-left
LOW	LOW	
LOW	HIGH	
HIGH	LOW	
HIGH	HIGH	

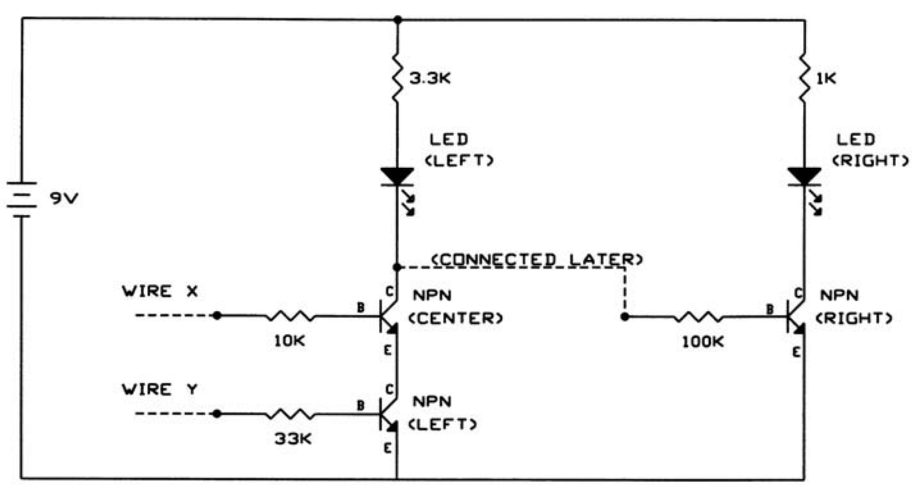
From it, you can see that if X *and* Y are HIGH then LED-left will be ON. Hence, this configuration is called an **AND gate**. X and Y might represent two switches to turn on the same light in your house, the room switch and the master switch in the electrical box. As with the gates we showed you earlier, you could have more than two inputs by just adding more parts to the circuit.

Now place the 100kΩ back into the circuit (between holes b24 and b27 as before), and look at LED-right. Since you are just adding a NOT gate as you did in the last experiment you probably know what the new truth table will look like:

X	Y	LED-right
LOW	LOW	
LOW	HIGH	
HIGH	LOW	
HIGH	HIGH	

It is a **NAND gate**, a combination of AND and NOT. X and Y might represent different trip wires for your burglar alarm (if either is tripped then that input goes LOW and the alarm sounds). AND and NAND have the schematic symbols shown below:

Combinations of AND and OR gates are used to add and multiply numbers together in computers. The additional use of NOT, NOR, and NAND gates allows a computer to represent any input/output pattern you can think of. By combining these gates with the memory and timing control that flip-flops provide, today's computers are created.

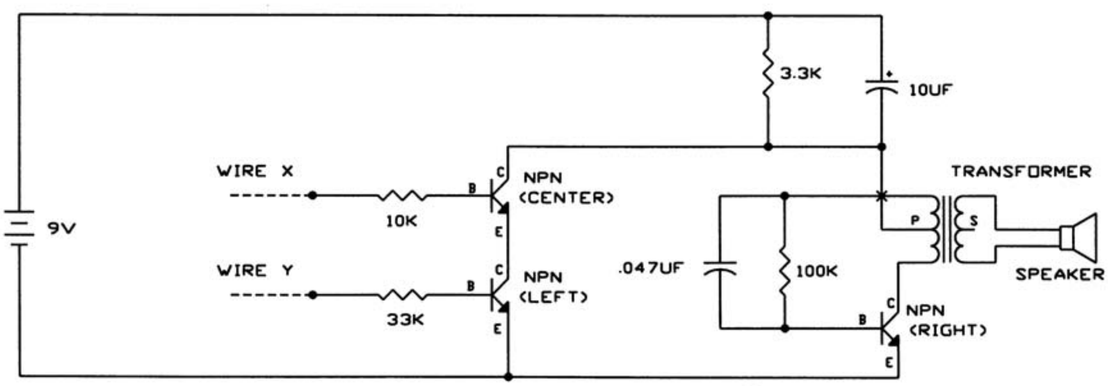


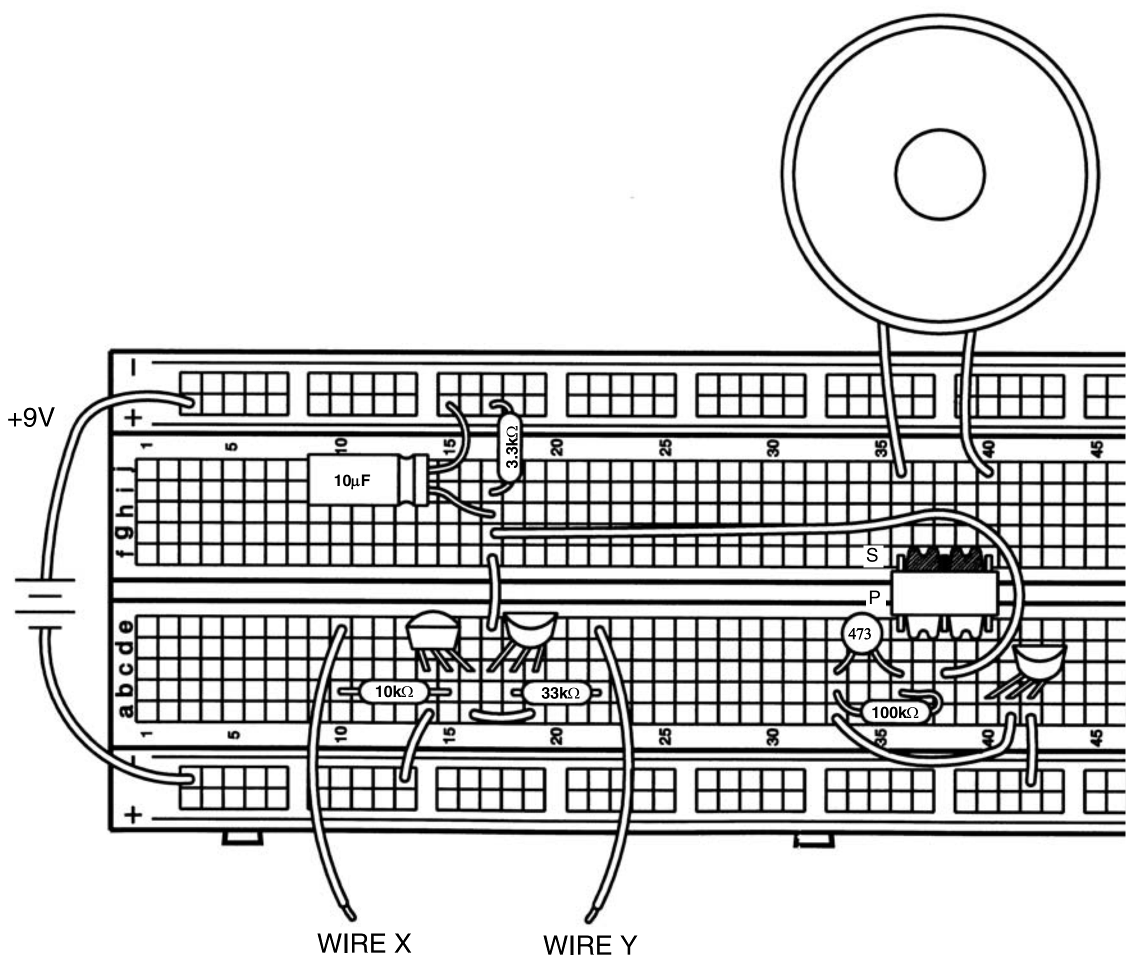
EXPERIMENT #49: AUDIO AND, NAND

Using the LEDs for these truth tables probably seems a little boring. So let's use an audio circuit to make a sound instead of turning on the LED. Connect the wires according to the schematic and Wiring Diagram. Can you tell which digital gate this circuit represents? Construct the truth table to find out.

It is the NAND gate. If you use longer wires for X and Y and leave them connected HIGH then you have an alarm with two separate trip wires.

You can easily modify the circuit to be an AND gate. Remove the 3.3kΩ resistor, the 10μF capacitor, and wires e17-to-f17, g17-to-c38, and a42-to-(–)42. Add wires a42-to-e17 and c38-to-(+)30. This audio circuit can also be used with the OR and NOR gates simply by rewiring NPN-left, NPN-center, and the 10kΩ, 33kΩ resistors.



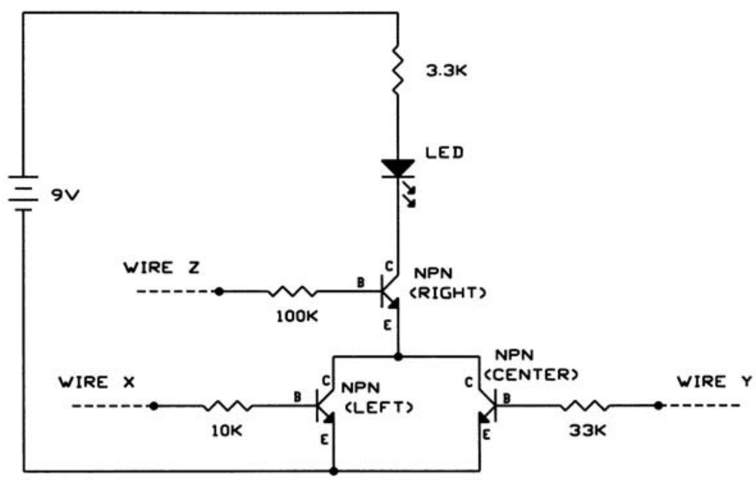


EXPERIMENT #50: LOGIC COMBINATION

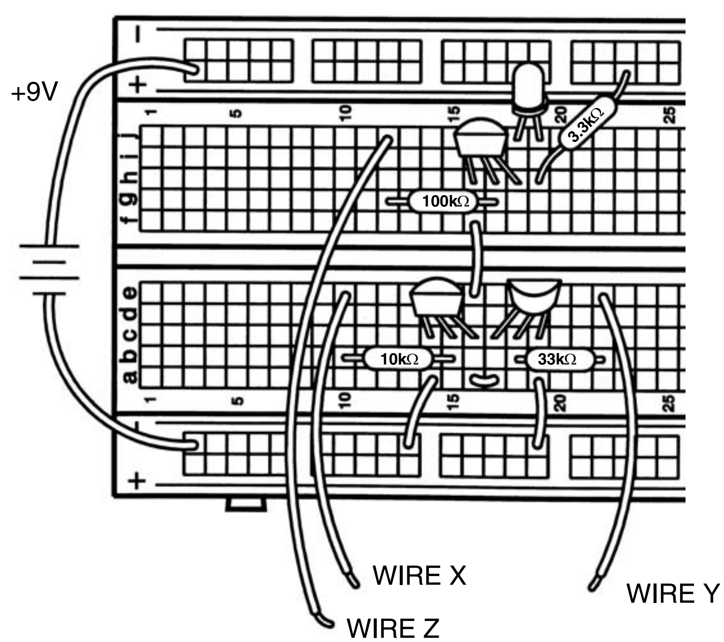
This last circuit is a combination of some of the other digital gates, and has 3 inputs. See if you can fill in the truth table by just looking at the schematic. Then connect the circuit, test all eight input combinations, and see if you were right.

X	Y	Z	LED Predicted	LED Measured
LOW	LOW	LOW		
LOW	LOW	HIGH		
LOW	HIGH	LOW		
LOW	HIGH	HIGH		
HIGH	LOW	LOW		
HIGH	LOW	HIGH		
HIGH	HIGH	LOW		
HIGH	HIGH	HIGH		

What could this circuit be used for? It might be used to provide power for your telephones. Z would be controlled by the phone company and would be high if you paid your phone bill. X and Y could be different phones in your house and would be high when you pick up the phone. The transistor emitters would then provide voltage to the rest of the telephone circuit.



Congratulations! You've finished all the experiments and can now show your friends how much you know about electronics! You are now ready to move on to the next level of Elenco Electronics' Learning Series. You can also learn how to solder using Elenco's line of quality soldering kits! Check out our website (http://www.elenco.com) or see the back cover of this booklet for how to contact us to order these products.



TEST YOUR KNOWLEDGE #3

1. Adjusting the input to something based on what its output is doing is an example of __________.

2. A speaker converts electrical energy into __________ __________ variations, called sound waves.

3. An oscillator's frequency __________ when you add resistance or capacitance.

4. A NOR gate followed by a NOT gate is the same as an __________ gate.

5. An AND gate followed by a NOT gate is the same as a __________ gate.

(Answers are on page 3)

TROUBLESHOOTING GUIDE

- Check your wiring against the Wiring Diagram and the schematic, very carefully. Be sure all your wires and components are securely in place in the correct hole and not loose. Make sure the metal in the wires and components is not contacting any other metal, since this will create "short circuits". Nearly all problems are due to wiring errors.

- Remember that the battery and electrolytic capacitors have "+" and "–" terminal markings, and be sure to correctly position the transistors, LEDs, diode, and transformer as per the guides.

- Be sure you have a good 9V battery. If not sure then try a new battery.

- Be sure you understand how to read the resistor color code, so that you use the right value parts.

- Be sure you understand which breadboard holes are connected to which.

Contact ELENCO® (our address/phone/website is on the back of this booklet) if you further assistance. DO NOT contact your place of purchase as they will not be able to help you.

DEFINITION OF TERMS
(Most of these are introduced and explained during the experiments.)

AC.................................... Common abbreviation for alternating current.
Alternating Current...... A current that is constantly changing.
Amp................................. Shortened name for ampere.
Ampere (A).................... The unit of measure for electric current. Commonly shortened to amp.
Amplitude....................... Strength or level of something.
Analogy.......................... A similarity in some ways.
AND Gate....................... A type of digital circuit which gives a HIGH output only if all of its inputs are HIGH.
Astable Multivibrator... A type of transistor configuration in which only one transistor is on at a time.
Atom................................ The smallest particle of a chemical element, made up of electrons, protons, etc..
Audio............................... Electrical energy representing voice or music.
Base................................ The controlling input of an NPN bipolar junction transistor.
Battery............................ A device which uses a chemical reaction to create an electric charge across a material.
Bias................................. The state of the DC voltages across a diode or transistor.
Bipolar Junction Transistor (BJT)............ A widely used type of transistor.
Bistable Switch............. A type of transistor configuration, also known as the flip-flop.
BJT.................................. Common abbreviation for Bipolar Junction Transistor.
Capacitance................... The ability to store electric charge.
Capacitor........................ An electrical component that can store electrical pressure (voltage) for periods of time.
Carbon............................ A chemical element used to make resistors.
Clockwise...................... In the direction in which the hands of a clock rotate.
Coil.................................. When something is wound in a spiral. In electronics this describes inductors, which are coiled wires.
Collector......................... The controlled input of an NPN bipolar junction transistor.
Color Code..................... A method for marking resistors using colored bands.
Conductor...................... A material that has low electrical resistance.
Counter-Clockwise....... Opposite the direction in which the hands of a clock rotate.
Current........................... A measure of how fast electrons are flowing in a wire or how fast water is flowing in a pipe.
Darlington....................... A transistor configuration which has high current gain and input resistance.
DC.................................... Common abbreviation for direct current.
Decode........................... To recover a message.
Detector......................... A device or circuit which finds something.
Diaphragm..................... A flexible wall.
Differential Pair............. A type of transistor configuration.
Digital Circuit................ A wide range of circuits in which all inputs and outputs have only two states, such as high/low.
Diode.............................. An electronic device that allows current to flow in only one direction.
Direct Current............... A current that is constant and not changing.
Disc Capacitor.............. A type of capacitor that has low capacitance and is used mostly in high frequency circuits.
Electric Field................. The region of electric attraction or repulsion around a constant voltage. This is usually associated with the dielectric in a capacitor.
Electricity....................... A flow of electrons between atoms due to an electrical charge across the material.
Electrolytic Capacitor.. A type of capacitor that has high capacitance and is used mostly in low frequency circuits. It has polarity markings.
Electron.......................... A sub-atomic particle that has an electrical charge.

Electronics..................... The science of electricity and its applications.
Emitter............................ The output of an NPN bipolar junction transistor.
Encode........................... To put a message into a format which is easier to transmit.
Farad, (F)....................... The unit of measure for capacitance.
Feedback....................... To adjust the input to something based on what its output is doing.
Flip-Flop......................... A type of transistor configuration is which the output changes every time it receives an input pulse.
Forward-Biased............ The state of a diode when current is flowing through it.
Frequency...................... The rate at which something repeats.
Friction........................... The rubbing of one object against another. It generates heat.
Gallium Arsenide.......... A chemical element that is used as a semiconductor.
Generator....................... A device which uses steam or water pressure to move a magnet near a wire, creating an electric current in the wire.
Germanium.................... A chemical element that is used as a semiconductor.
Ground............................ A common term for the 0V or "–" side of a battery or generator.
Henry (H)........................ The unit of measure for Inductance.
Inductance..................... The ability of a wire to create an induced voltage when the current varies, due to magnetic effects.
Inductor.......................... A component that opposes changes in electrical current.
Insulator......................... A material that has high electrical resistance.
Integrated Circuit......... A type of circuit in which transistors, diodes, resistors, and capacitors are all constructed on a semiconductor base.
Kilo- (K).......................... A prefix used in the metric system. It means a thousand of something.
LED.................................. Common abbreviation for light emitting diode.
Leads............................. The wires sticking out of an electronic component, used to connect it to the circuit.
Light Emitting Diode.... A diode made from gallium arsenide that has a turn-on energy so high that light is generated when current flows through it.
Magnetic Field............. The region of magnetic attraction or repulsion around a magnet or an AC current. This is usually associated with an inductor or transformer.
Magnetism..................... A force of attraction between certain metals. Electric currents also have magnetic properties.
Meg- (M)......................... A prefix used in the metric system. It means a million of something.
Micro- (μ)....................... A prefix used in the metric system. It means a millionth (0.000,001) of something.
Milli- (m)......................... A prefix used in the metric system. It means a thousandth (0.001) of something.
Momentum..................... The power of a moving object.
Morse Code................... A code used to send messages with long or short transmit bursts.
NAND Gate..................... A type of digital circuit which gives a HIGH output if some of its inputs are LOW.
NOR Gate....................... A type of digital circuit which gives a HIGH output if none of its inputs are HIGH.
NOT Gate........................ A type of digital circuit whose output is opposite its input.
NPN................................ Negative-Positive-Negative, a type of transistor construction.
Ohm's Law..................... The relationship between voltage, current, and resistance.
Ohm, (Ω)......................... The unit of measure for resistance.
OR Gate.......................... A type of digital circuit which gives a HIGH output if any of its inputs are HIGH.
Oscillator........................ A circuit that uses feedback to generate an AC output.
Parallel........................... When several electrical components are connected between the same points in the circuit.
Pico- (p).......................... A prefix used in the metric system. It means a millionth of a millionth (0.000,000,000,001) of something.
Pitch............................... The musical term for frequency.

Primary........................... The larger of the two coils in a transformer.

Printed Circuit Board... A board used for mounting electrical components. Components are connected using metal traces "printed" on the board instead of wires.

Receiver......................... The device which is receiving a message (usually with radio).

Resistance..................... The electrical friction between an electric current and the material it is flowing through; the loss of energy from electrons as they move between atoms of the material.

Resistor.......................... Components used to control the flow of electricity in a circuit. They are made of carbon.

Resistor-Transistor-Logic (RTL).................... A type of circuit arrangement used to construct digital gates.

Reverse-Biased............ When there is a voltage in the direction of high-resistance across a diode.

Saturation...................... The state of a transistor when the circuit resistances, not the transistor itself, are limiting the current.

Schematic...................... A drawing of an electrical circuit that uses symbols for all the components.

Secondary...................... The smaller of the two coils in a transformer.

Semiconductor.............. A material that has more resistance than conductors but less than insulators. It is used to construct diodes, transistors, and integrated circuits.

Series.............................. When electrical components are connected one after the other.

Short Circuit.................. When wires from different parts of a circuit (or different circuits) connect accidentally.

Silicon............................. The chemical element most commonly used as a semiconductor.

Solder............................. A tin-lead metal that becomes a liquid when heated to above 360 degrees. In addition to having low resistance like other metals, solder also provides a strong mounting that can withstand shocks.

Speaker.......................... A device which converts electrical energy into sound.

Switch............................. A device to connect ("closed" or "on") or disconnect ("open" or "off") wires in an electric circuit.

Transformer................... A device which uses two coils to change the AC voltage and current (increasing one while decreasing the other).

Transient........................ Temporary. Used to describe DC changes to circuits.

Transistor....................... An electronic device that uses a small amount of current to control a large amount of cur rent.

Transmitter.................... The device which is sending a message (usually with radio).

Truth Table.................... A table which lists all the possible combinations of inputs and outputs for a digital circuit.

Tungsten........................ A highly resistive material used in light bulbs.

Variable Resistor.......... A resistor with an additional arm contact that can move along the resistive material and tap off the desired resistance.

Voltage........................... A measure of how strong an electric charge across a material is.

Voltage Divider............. A resistor configuration to create a lower voltage.

Volts (V).......................... The unit of measure for voltage.

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