BASIC ELECTRONIC EXPERIMENTS

MODEL PK-101

TRANSFORMS ANY STANDARD BREADBOARD INTO AN ELECTRONIC LEARNING CENTER!

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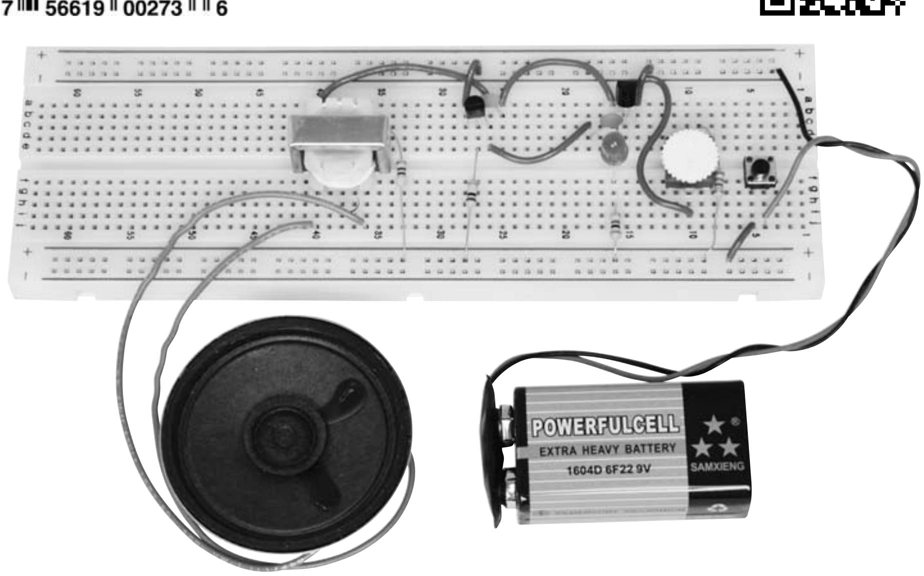


Perform 50 Experiments!

Build an Electronic Keyboard, Electronic Kazoo, Battery Tester, Finger Touch Lamp, Burglar and Water Alarms, a Siren, a Magnetic Bridge, and a whole lot more! No soldering or tools required, all parts are included!

(Requires a breadboard and a 9V battery or power supply.)

ELENCO®

In this booklet you will learn:

- The basic principles of electronics.
- How to build circuits using a breadboard.
- How all of the basic electronic components work and how to read their values.
- How to read electronic schematics.
- How to design and troubleshoot basic electronic circuits.
- How to change the performance of electronic circuits by changing component values within the circuit.

TABLE OF CONTENTS

THE EXPERIMENTS IN THIS BOOKLET REQUIRE A BREADBOARD OR CAN BE DONE ON THE ELENCO® XK-150, XK-550, OR XK-700 TRAINERS.

PARTS LIST

Quantity	Part Number	Description
❒ 1	134700	470Ω Resistor, 0.25W
❒ 1	141000	1kΩ Resistor, 0.25W
❒ 1	143300	3.3kΩ Resistor, 0.25W
❒ 1	151000	10kΩ Resistor, 0.25W
❒ 1	153300	33kΩ Resistor, 0.25W
❒ 1	161000	100kΩ Resistor, 0.25W
❒ 1	171000	1MΩ Resistor, 0.25W
❒ 1	191549	50kΩ Variable Resistor, lay-down, with dial
❒ 1	235018	0.005μF Disc Capacitor
❒ 1	244780	0.047μF Disc Capacitor
❒ 1	271045	10μF Electrolytic Capacitor
❒ 1	281044	100μF Electrolytic Capacitor
❒ 1	314148	Diode, 1N4148
❒ 3	323904	Transistor, NPN, 2N3904
❒ 2	350002	Light Emitting Diodes (LEDs)
❒ 1	442100	Transformer
❒ 1	540100	Switch, push-button
❒ 1	590098	9V Battery Clip
❒ 1	590102	Speaker, 8Ω, 0.25 Watt, with wires added
❒ 1	-	Wires Bag

QUIZ ANSWERS

First Quiz: 1. electrons; 2. short; 3. battery; 4. increase; 5. insulators, conductors; 6. decreases, increases; 7. decreases; 8. voltage; 9. alternating, direct; 10. increases, decreases.

Second Quiz: 1. reverse; 2. LEDs; 3. amplifier; 4. integrated; 5. saturated; 6. direct, alternating; 7. decreases, increases; 8. magnetic; 9. increases; 10. twice

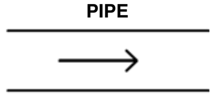
Third Quiz: 1. feedback; 2. air, pressure; 3. decreases; 4. OR; 5. NAND

INTRODUCTION TO BASIC COMPONENTS

Welcome to the exciting world of Electronics! Before starting the first experiment, let's learn about some of the basic electronic components. **Electricity** is a flow of sub-atomic (very, very, very, small) particles, called **electrons**. The electrons move from atom to atom when an electrical charge is applied across the material. Electronics will be easier to understand if you think of the flow of electricity through circuits as water flowing through pipes (this will be referred to as the water pipe analogy).

Wires: Wires can be thought of as large, smooth pipes that allow water to pass through easily. Wires are made of metals, usually copper, that offer very low resistance to the flow of electricity. When wires from different parts of a circuit connect accidentally we have a **short circuit** or simply a short. You probably know from the movies that this usually means trouble. You must always make sure that the metal from different wires never touches except at springs where the wires are connecting to each other. The electric **current**, expressed in **amperes** (A, named after Andre Ampere who studied the relationship between electricity and magnetism) or milliamps (mA, 1/1000 of an ampere), is a measure of how fast electrons are flowing in a wire just as a water current describes how fast water is flowing in a pipe.

PIPE

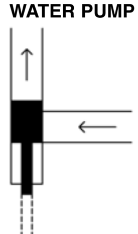


WIRE

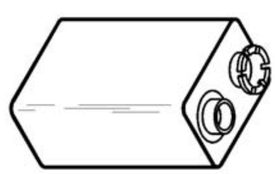
Batteries and Generators: To make water flow through a pipe we need a pump. To make electricity flow through wires, we use a **battery** or a **generator** to create an electrical charge across the wires. A battery does this by using a chemical reaction and has the advantage of being simple, small, and portable. If you move a magnet near a wire then electricity will flow in the wire. This is done in a generator. The electric power companies have enormous generators driven by steam or water pressure to produce electricity for your home.

The **voltage**, expressed in **volts** (V, and named after Alessandro Volta who invented the battery in 1800), is a measure of how strong the electric charge from your battery or generator is, similar to the water pressure. Your PK-101 may be used with either a 9V battery or the adjustable power supply that is part of the XK-150, XK-550, and XK-700 Trainers. A power supply converts the electricity from your electric company into a simple form that can be used in your PK-101. If using the power supply, then adjust it for 9V. (This manual will usually refer to the battery, this is also meant to refer to the 9V power supply if you are using that instead). Notice the "+" and "–" signs on the battery. These indicate which direction the battery will "pump" the electricity, similarly to how a water pump can only pump water in one direction. The 0V or "–" side of the battery is often referred to as "**ground**". Notice that just to the right of the battery pictured below is a symbol, the same symbol you see next to the battery holder. Engineers are not very good at drawing pictures of their parts, so when engineers draw pictures of their circuits they use symbols like this to represent them. It also takes less time to draw and takes up less space on the page. Note that wires are represented simply by lines on the page.

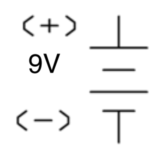
WATER PUMP



BATTERY

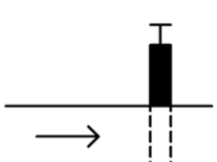


Symbol for BATTERY

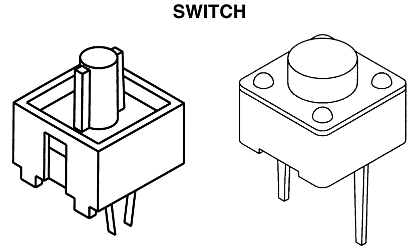


The Switch: Since you don't want to waste water when you are not using it, you have a faucet or valve to turn the water on and off. Similarly, you use a switch to turn the electricity on and off in your circuit. A switch connects (the "closed" or "on" position) or disconnects (the "open" or "off" position) the wires in your circuit. As with the battery, the switch is represented by a symbol, shown below on the right.

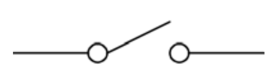
VALVE



SWITCH



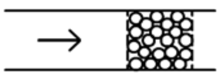
Symbol for SWITCH



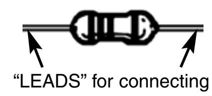
You have been given one of the two above switches.

The Resistor: Why is the water pipe that goes to your kitchen faucet smaller than the one that comes to your house from the water company? And why is it much smaller than the main water line that supplies water to your entire town? Because you don't need so much water. The pipe size limits the water flow to what you actually need. Electricity works in a similar manner, except that wires have so little resistance that they would have to be very, very thin to limit the flow of electricity. They would be hard to handle and break easily. But the water flow through a large pipe could also be limited by filling a section of the pipe with rocks (a thin screen would keep the rocks from falling over), which would slow the flow of water but not stop it. Resistors are like rocks for electricity, they control how much electric current flows. The **resistance**, expressed in **ohms** (Ω, named after George Ohm), kilohms (kΩ, 1,000 ohms), or megohms (MΩ, 1,000,000 ohms) is a measure of how much a resistor resists the flow of electricity. To increase the water flow through a pipe you can increase the water pressure or use less rocks. To increase the electric current in a circuit you can increase the voltage or use a lower value resistor (this will be demonstrated in a moment). The symbol for the resistor is shown on the right.

ROCKS IN THE PIPE

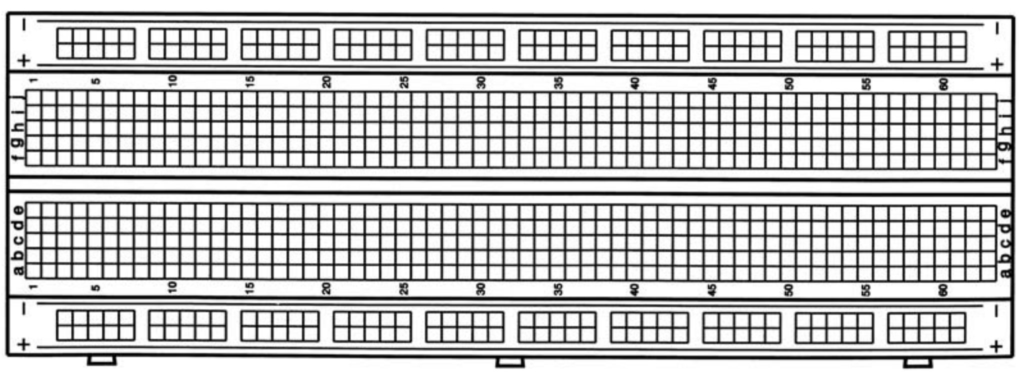


RESISTOR



Symbol for RESISTOR

Your Breadboard: Breadboards are used for mounting electronic components and to make connecting them together easy, and are similar to the printed circuits boards used in most electronic devices. Breadboards make it easy to add and remove components. Your breadboard has 830 holes arranged into rows and columns (some models may have more or less holes but will be arranged the same way):

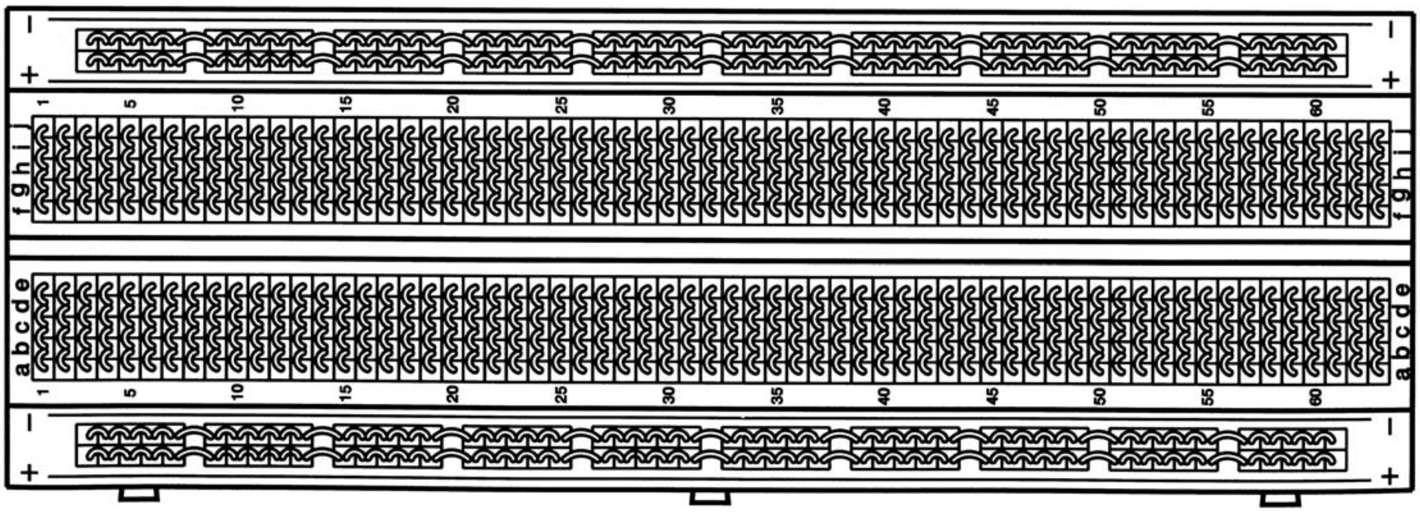


BREADBOARD

The holes are connected together as follows:

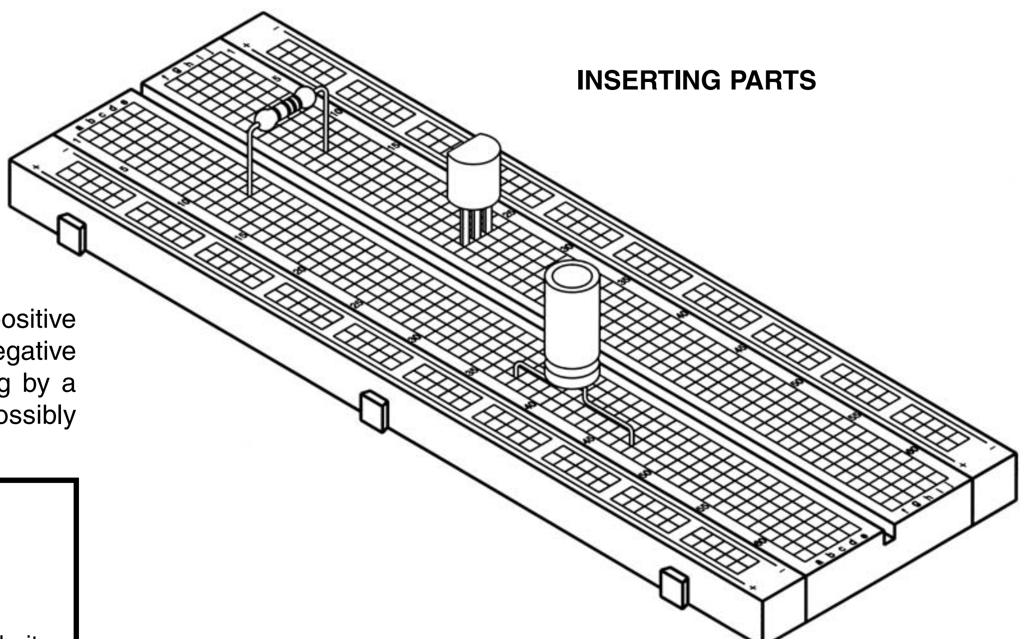
- There are many columns of 5 holes each. The 5 holes within each column are electrically connected together, but the columns are not electrically connected to each other. This makes 126 columns of 5 holes each. Note that “electrically connected together” means that there is a wire within the breadboard connecting the 5 holes.
- All holes in the rows marked with a blue “–” or a red “+” are electrically connected together, but none of these rows are electrically connected to each other. This makes 6 rows of 100 holes. The red “+” holes will usually be used for your “+” battery or power supply connections and the blue “–” holes will usually be used for your ground (“–” battery or power supply) connections.

BREADBOARD CONNECTIONS



<u>Inserting Parts into the Breadboard:</u> To insert components into the breadboard, keep their pins straight and gently push into the holes. If the pins get bent and become difficult to insert, they can be straightened with a pliers. Always make sure components do not touch each other.

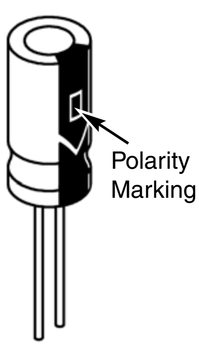
INSERTING PARTS



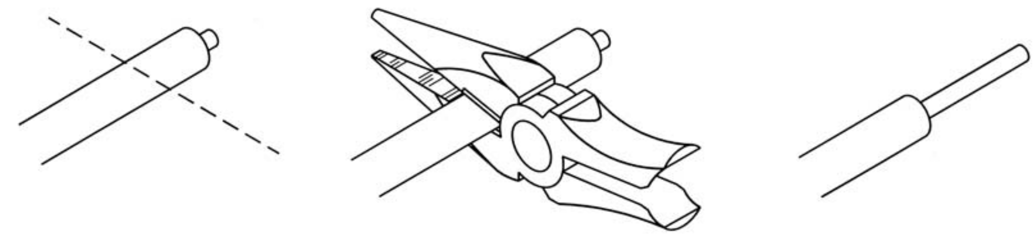
Electrolytic capacitors have a positive and a negative electrode. The negative lead is indicated on the packaging by a stripe with minus signs and possibly arrowheads.

Warning:

If the capacitor is connected with incorrect polarity, it may heat up and either leak, or cause the capacitor to explode.

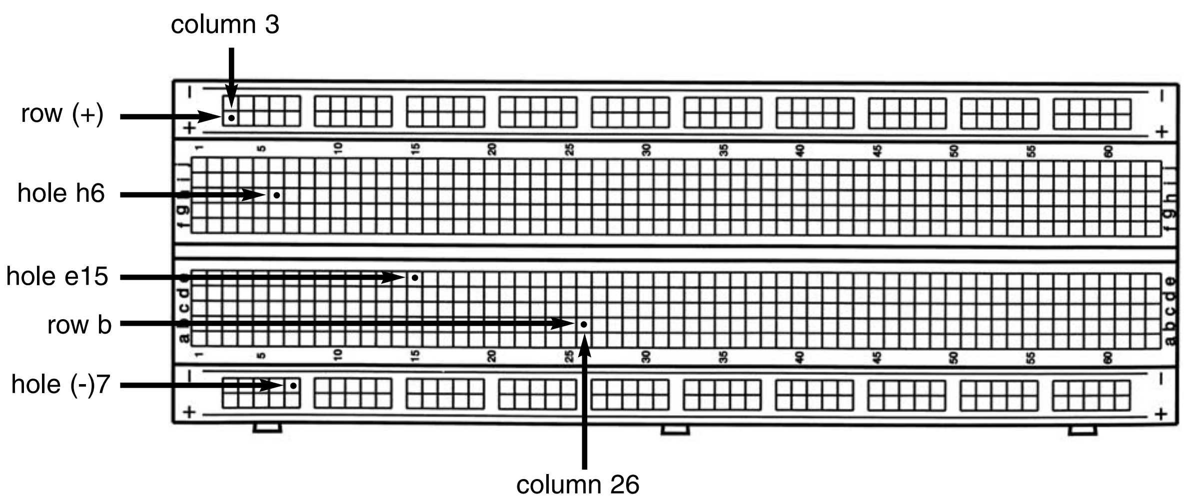


After using your kit for a while, some of the wire ends may break off. If so, you should remove about 3/8 inch of insulation from the broken end with a wire stripper or scissors.



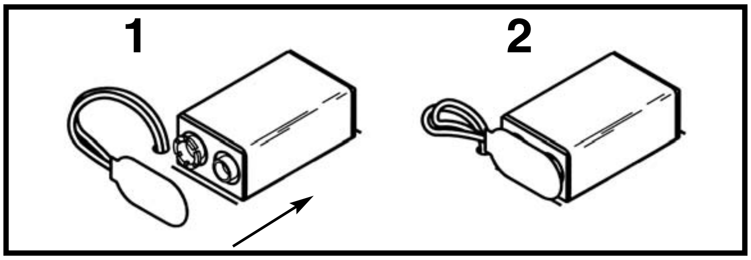
Before You Begin: The rows of the breadboard are marked with letters (some rows are marked "+" and "–") and the columns are marked by numbers, this allows each hole to be identified individually. We will use this notation to smoothly guide you through the experiments. Depending on the size of your breadboard, several sets of rows may be marked with the same letter, but only a portion of the overall breadboard will be used so this will not be a problem. The row and column numbers will be expressed as a row/column number. For example, a connection at row b, column 26 will be called hole b26. And a connection at row +, column 3 will be called hole (+)3. Some examples of this are shown below:

IDENTIFYING HOLE LOCATIONS



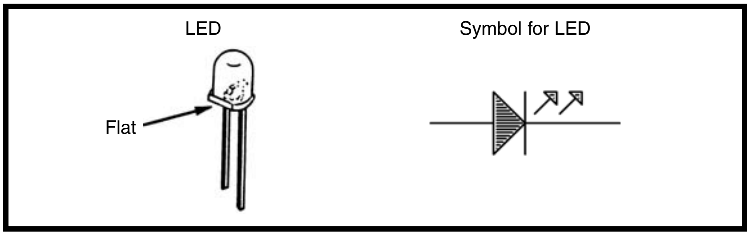
EXPERIMENT #1: The Light Bulb

First, decide if you will use a 9V battery (alkaline is best) or the adjustable power supply that is part of the XK-150, XK-550, and XK-700 Trainers. If using a battery then snap it into its clip. Always remove the battery from its clip if you won't be using your PK-101 for a while. Insert the red wire from the battery clip into hole j4 and the black wire into hole (–)3.



If using the adjustable power supply then turn it on and adjust it for 9V. Connect a wire from the positive adjustable voltage output to hole j4 and another wire from the power supply negative output (ground) to hole (–)3.

Let's introduce another component, the LED (light emitting diode). It is shown below, with its symbol. We'll explain what it does in just a few moments.



Now insert the components for this circuit into your breadboard according to the list below (the first item is for the battery/power supply which you already did above), which we'll call the Wiring Checklist. When you're finished your wiring should look like the diagram shown at right:

Parts Needed:

- a 9V battery or power supply
- one Switch
- one 10kΩ resistor
  (marked brown-black-orange-gold, in that order)
- one LED
- 2 wires

Wiring Checklist:

☑ Insert red battery wire or positive power supply into hole j4 and black battery wire or negative power supply (ground) into hole (–)3.

☐ Insert switch into holes f4 and f5.

☐ Insert the 10kΩ resistor into holes j5 and j9.

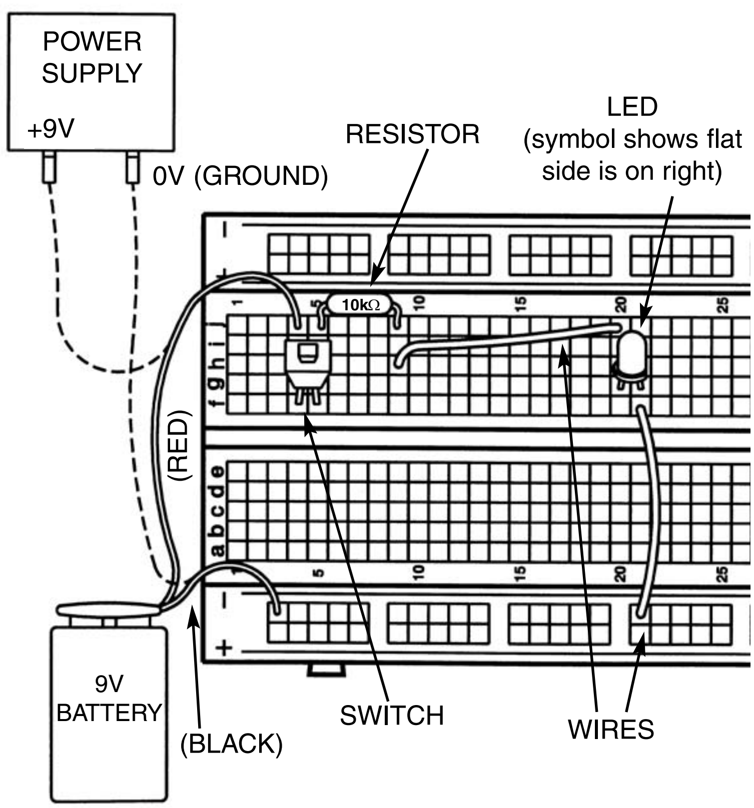
☐ Insert the LED into holes g20 and g21. **NOTE:** The "flat" side of the LED (as shown on the picture above, and usually the shorter wire) goes into g21.

☐ Insert a short wire between holes h9 and j20.

☐ Insert a short wire between holes f21 and (–)21.

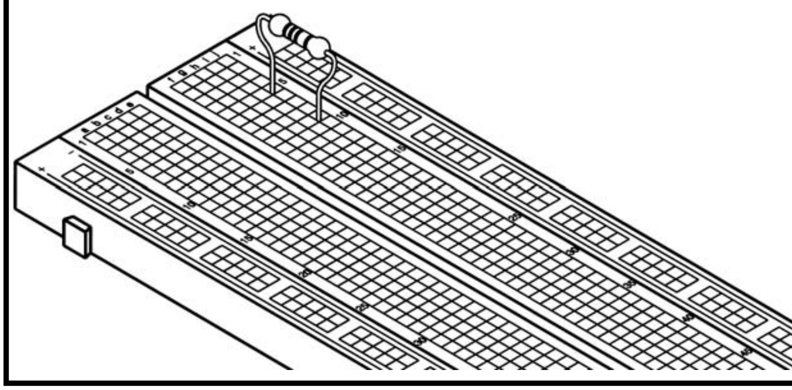
Be sure all your wires are securely in place and not loose. Also **make sure the metal into each hole is not touching any other metal, including other parts of the same component.**

WIRING DIAGRAM

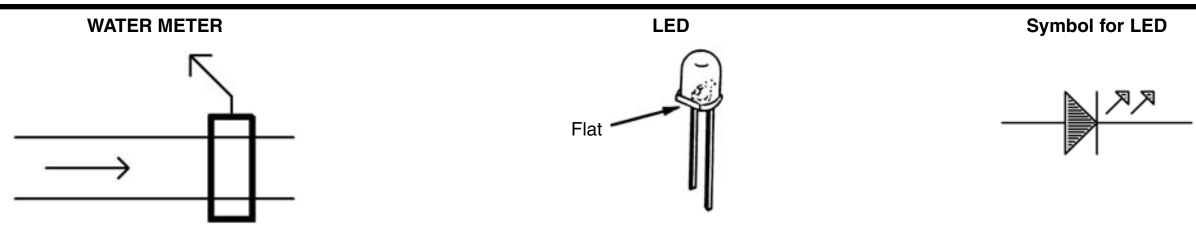


The Wiring Checklist and Wiring Diagram show you ONE way of connecting the circuit components using your breadboard. There are many other ways that are also correct. The important thing is that the electrical connections are as shown in the schematic (see below).

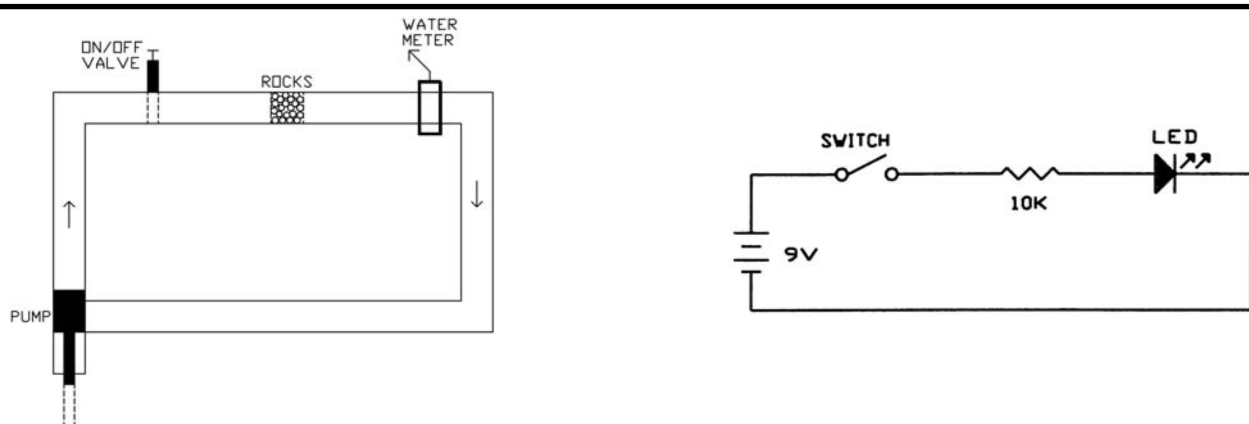
Example of Inserting the Resistor



Press the switch and the **LED** lights up, and turns off when you release the switch. The LED converts electrical energy into light, like the light bulbs in your home. You can also think of an LED as being like a simple water meter, since as the electric current increases in a wire the LED becomes brighter. It is shown again here, with its symbol.



Take a look at the water diagram that follows. It shows the flow of water from the pump through the faucet, the small pipe, the water meter, the large pipes, and back to the pump. Now compare it to the electrical diagram next to it, called a **schematic**. Schematics are the “maps” for electronic circuits and are used by all electronic designers and technicians on everything from your PK-101 to the most advanced supercomputers. They show the flow of electricity from the battery through the switch, the resistor, the LED, the wires, and back to the battery. They also use the symbols for the battery, switch, resistor, and LED that we talked about. Notice how small and simple the schematic looks compared to the water diagram; that is why we use it.



Now you will see how changing the resistance in the circuit increases the current through it. Press the switch again and observe the brightness of the LED. Now remove the 10kΩ resistor and replace it with a 1kΩ resistor (marked brown-black-red-gold, in that order) in the same holes (j5 and j9). Press the switch. The LED is brighter now, do you understand why? We are using a lower resistance (less rocks), so there is more electrical current flowing (more water flows), so the LED is brighter. Now replace the 1kΩ resistor with the 100kΩ resistor (marked brown-black-yellow-gold, in that order) and press the switch again. The LED will be on but will be very dim (this will be easier to see if you wrap your hand near the LED to keep the room lights from shining on it).

Well done! You’ve just built ***YOUR*** first electronic circuit!

MORE ABOUT RESISTORS

Ohm's Law: You just observed that when you have less resistance in the circuit, more current flows (making the LED brighter). The relationship between voltage, current, and resistance is known as **Ohm's Law** (after George Ohm who discovered it in 1828):

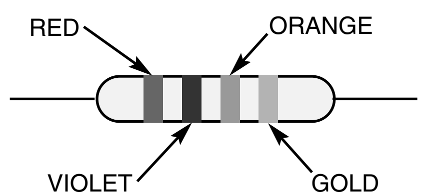
$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Resistance: Just what is Resistance? Take your hands and rub them together very fast. Your hands should feel warm. The **friction** between your hands converts your effort into heat. Resistance is the electrical friction between an electric current and the material it is flowing through; it is the loss of energy from electrons as they move between atoms of the material. Resistors are made using carbon and can be constructed with different resistive values, such as the seven parts included in your PK-101. If a large amount of current is passed through a resistor then it will become warm due to the electrical friction. Light bulbs use a small piece of a highly resistive material called tungsten. Enough current is passed through this tungsten to heat it until it glows white hot, producing light. Metal wires have some electrical resistance, but it is very low (less than 1Ω per foot) and can be ignored in almost all circuits. Materials such as metals which have low resistance are called conductors. Materials such as paper, plastic, and air have extremely high values of resistance and are called insulators.

Resistor Color Code: You are probably wondering what the colored bands on the resistors mean. They are the method for marking the value of resistance on the part. The first ring represents the first digit of the resistor's value. The second ring represents the second digit of the resistor's value. The third ring tells you the power of ten to multiply by, (or the number of zeros to add). The final and fourth ring represents the construction tolerance. Most resistors have a gold band for a 5% tolerance. This means the value of the resistor is guaranteed to be within 5% of the value marked. The colors below are used to represent the numbers 0 through 9.

COLOR	VALUE
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

Example of Color Code

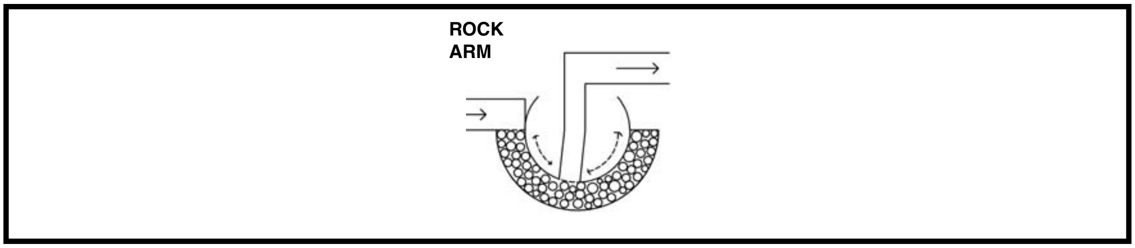


27 X 10,000 = 27,000 Ω, with 5% Tolerance

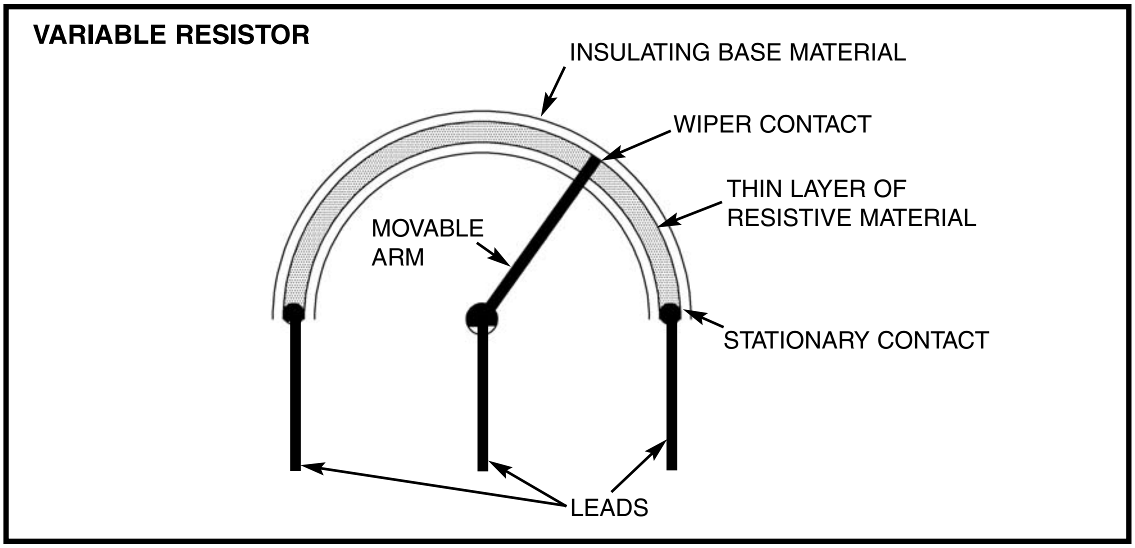
Use the color code to check the values of the seven resistors included in your PK-101, and compare to the list below:

YELLOW - VIOLET - BROWN - GOLD is 470 Ω with 5% tolerance
BROWN - BLACK - RED - GOLD is 1,000 Ω (or 1 kΩ) with 5% tolerance
ORANGE - ORANGE - RED - GOLD is 3,300 Ω (or 3.3 kΩ) with 5% tolerance
BROWN - BLACK - ORANGE - GOLD is 10,000 Ω (or 10 kΩ) with 5% tolerance
ORANGE - ORANGE - ORANGE - GOLD is 33,000 Ω (or 33 kΩ) with 5% tolerance
BROWN - BLACK - YELLOW - GOLD is 100,000 Ω (or 100 kΩ) with 5% tolerance
BROWN - BLACK - GREEN - GOLD is 1,000,000 Ω (or 1 MΩ) with 5% tolerance

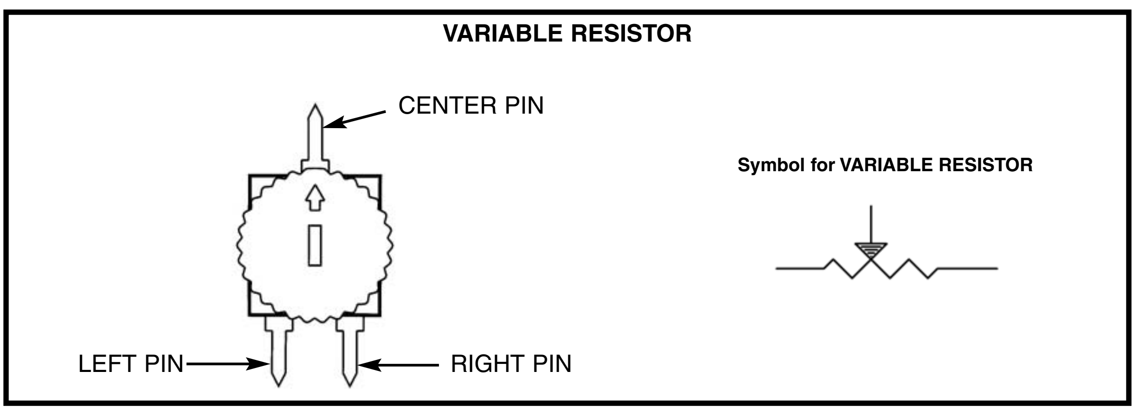
The Variable Resistor: We talked about how a switch is used to turn the electricity on and off just like a valve is used to turn the water on and off. But there are many times when you want some water but don't need all that the pipe can deliver, so you control the water by adjusting an opening in the pipe with a faucet. Unfortunately, you can't adjust the thickness of an already thin wire. But you could also control the water flow by forcing the water through an adjustable length of rocks, as in the rock arm shown below.



In electronics we use a variable resistor. This is a normal resistor (50kΩ in your PK-101) with an additional arm contact that can move along the resistive material and tap off the desired resistance.



The dial on the variable resistor moves the arm contact and sets the resistance between the left and center pins. The remaining resistance of the part is between the center and right pins. For example, when the dial is turned fully to the left, there is minimal resistance between the left and center pins (usually 0Ω) and maximum resistance between the center and right pins. The resistance between the left and right pins will always be the total resistance, (50kΩ for your part).



Now let's demonstrate how this works.

EXPERIMENT #2: THE BRIGHTNESS CONTROL

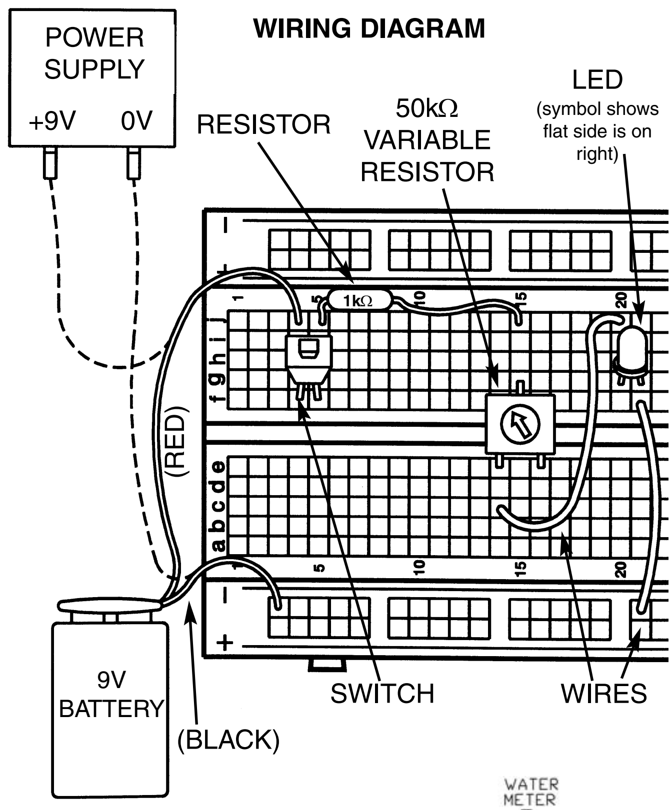
Remove the 10kΩ resistor used in Experiment #1; the other parts are used here. Insert the new parts according to the Wiring Checklist below. Press the switch and the LED lights up (it may be dim). Now hold the switch closed with one hand and turn the dial on the variable resistor with the other. When the dial is turned to the left, the resistance in the circuit is low and the LED is bright because a large current flows. As you turn the dial to the right the resistance increases and the LED will become dim, just as forcing the water through a section of rocks would slow the water flow and lower the reading on your water meter.

You may be wondering what the 1kΩ resistor is doing in the circuit. If you set the dial on the variable resistor for minimum resistance (0Ω) then Ohm's Law tells us the current will be very large - and it might damage the LED (think of this as a very powerful water pump overloading a water meter). So the 1kΩ was put in to limit the current while having little effect on the brightness of the LED.

Now remove the wire from c14 and connect it to c16. Do you know what will happen now? Close the switch and you will see that as you turn the dial from the left to the right the LED goes from very dim to very bright (the opposite of when connected to c14), because you are decreasing the resistance between the center and right pins.

Now remove the 1kΩ resistor from hole j15 and insert it into hole c14 (the other end stays in j5). What do you think will happen? Close the switch and turn the dial on the variable resistor. The LED is dim and turning the resistor dial won't make it any brighter. As discussed above, the resistance between the left and right pins is always 50kΩ and the part acts just like one of the other resistors in your PK-101.

Variable resistors like this one are used in the light dimmers you may have in your house, and are also used to control the volume in your radio, your TV, and many electronic devices.



Parts Needed:

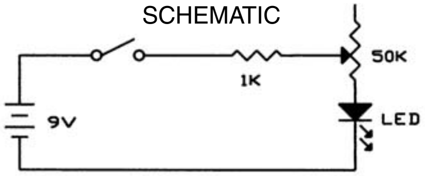
- a 9V battery or power supply
- Switch
- one 1kΩ resistor (marked brown-black-red-gold)
- 50kΩ variable resistor
- one LED
- 2 wires

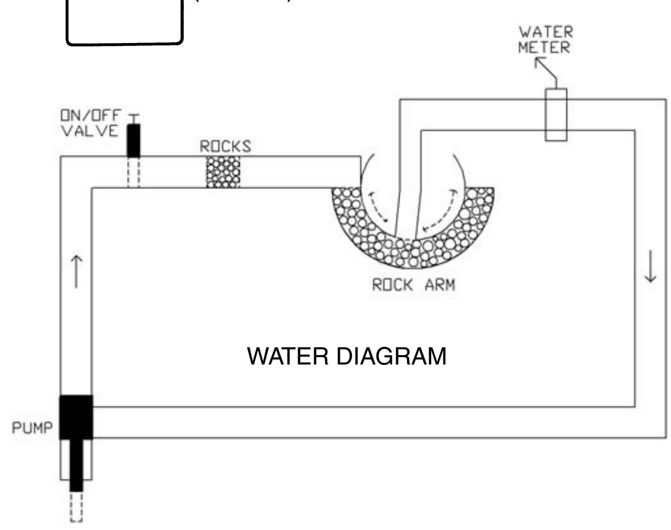
Wiring Checklist (✓indicates same position as last experiment):

☑ Insert red battery wire or positive power supply into hole j4 and black battery wire or negative power supply (ground) into hole (–)3.
☑ Insert switch into holes f4 and f5.
☑ Insert the LED into holes g20 and g21 ("flat" side goes into g21).
☑ Insert a short wire between holes f21 and (–)21.
☐ Insert the 1kΩ resistor into holes j5 and j15.
☐ Insert the 50kΩ variable resistor into holes e14, g15, and e16. It may be a tight fit, carefully press it in slowly.
☐ Insert a short wire between holes c14 and j20.

Be sure all your wires are securely in place and not loose. Also **make sure the metal into each hole is not touching any other metal, including other parts of the same component.**

SCHEMATIC





EXPERIMENT #3: RESISTORS IN SERIES

Remove the resistors used in Experiment #2; the other parts are used here. Insert the new parts according to the Wiring Checklist and press the switch. The LED is on but is very dim (this will be easier to see if you wrap your hand near the LED to keep the room lights from shining on it). Take a look at the schematic. There is a low 3.3kΩ resistor and a high 100kΩ resistor in **series** (one after another). Since the LED is dimly lit, we know that the larger 100kΩ must be controlling the current. You can think of this as where two sections of the pipe are filled with rock, if one section is much longer than the other then it controls the water flow. If you had several rock sections of different lengths then it is easy to see that these would add together as if they were one longer section. The total length is what matters, not how many sections the rock is split into. The same is true in electronics - **resistors in series add together** to increase the total resistance for the circuit. (In our circuit the 3.3kΩ and 100kΩ resistors add up to 103.3kΩ).

To demonstrate this, remove the 100kΩ resistor and insert the 10kΩ in the same holes, press the switch; the LED should be easy to see now (total resistance is now only 13.3kΩ). Next, remove the 10kΩ resistor and replace it with the 1kΩ. The LED is now bright, but not as bright as when you used the 1kΩ in Experiment #1. Why? Because now the 3.3kΩ is the larger resistor (total resistance is 4.3kΩ).

Also, in Experiment #2 you saw how the 1kΩ resistor would dominate the circuit when the variable resistor was set for 0Ω and how the variable resistor would dominate when set for 50kΩ.

Parts Needed:

- a 9V battery or power supply
- Switch
- one 1kΩ resistor (brown-black-red-gold)
- one 3.3kΩ resistor (orange-orange-red-gold)
- one 10kΩ resistor (brown-black-orange-gold)
- one 100kΩ resistor (brown-black-yellow-gold)
- one LED
- 1 wire

Wiring Checklist (✓ indicates same position as last experiment):

☑ Insert red battery wire or positive power supply into hole j4 and black battery wire or negative power supply (ground) into hole (–)3.

☑ Insert switch into holes f4 and f5.

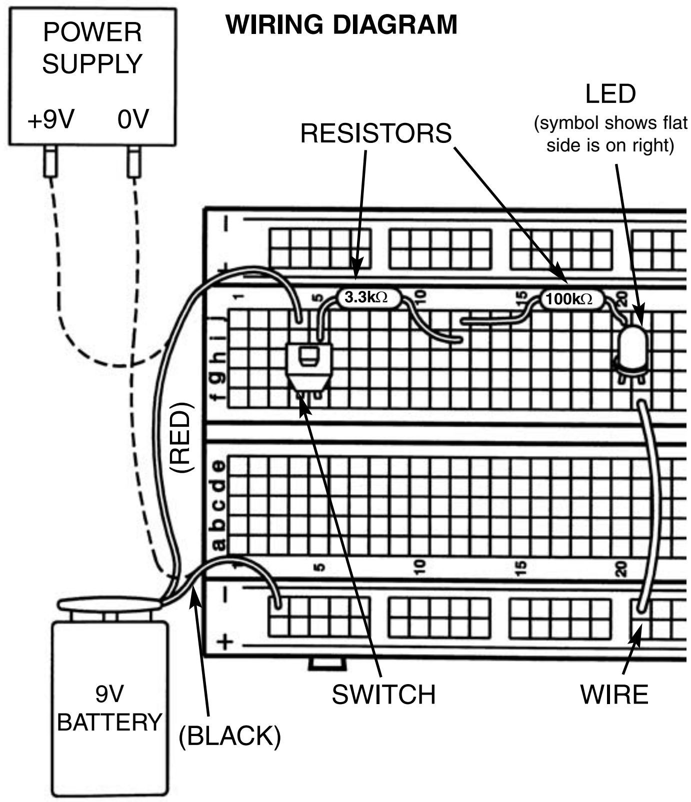
☑ Insert the LED into holes g20 and g21 ("flat" side goes into g21).

☑ Insert a short wire between holes f21 and (–)21.

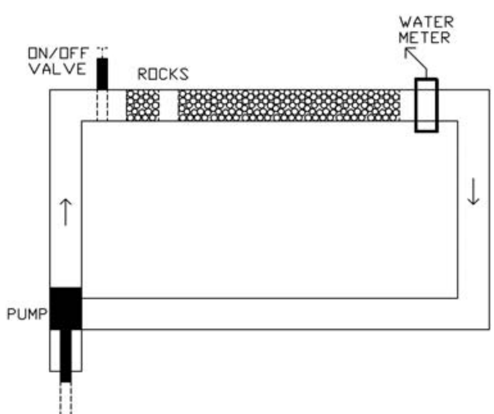
☐ Insert the 3.3kΩ resistor into holes i5 and i12.

☐ Insert the 100kΩ resistor into holes j12 and j20 (avoid touching other components).

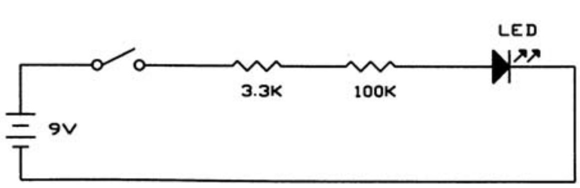
WIRING DIAGRAM



WATER DIAGRAM



SCHEMATIC



EXPERIMENT #4: PARALLEL PIPES

Remove the resistors used in Experiment #3; the other parts are used here. Insert the new parts according to the Wiring Checklist. Take a look at the schematic. There is a low 3.3kΩ resistor and a high 100kΩ resistor in **parallel** (connected between the same points in the circuit). How bright do you think the LED will be? Press the switch and see if you are right. The LED is bright, so most of the current must be flowing through the smaller 3.3kΩ resistor. This makes perfect sense when we look at the water diagram, with most of the water flowing through the pipe with less rocks. In general, **the more** water pipes (or **resistors**) **there are in parallel, the lower the total resistance is** and the more water (or current) will flow. The relationship is more complicated than for resistors in series and is given here for advanced students:

$$R_{\text{Parallel}} = \frac{R_1 \times R_2}{R_1 + R_2}$$

For two 10kΩ resistors in parallel, the result would be 5kΩ. The 3.3kΩ and 100kΩ in parallel in our circuit now give the same LED brightness as a single 3.2kΩ resistor.

To demonstrate this, remove the 100kΩ resistor and replace it with the 10kΩ (in the same holes); press the switch and the LED should be just as bright. The total resistance is now only 2.5kΩ, but your eyes probably won't notice much difference in LED brightness. Now remove the 10kΩ and replace it with the 1kΩ; press the switch. The total resistance is now only 770Ω, so the LED should now be much brighter.

Parts Needed:

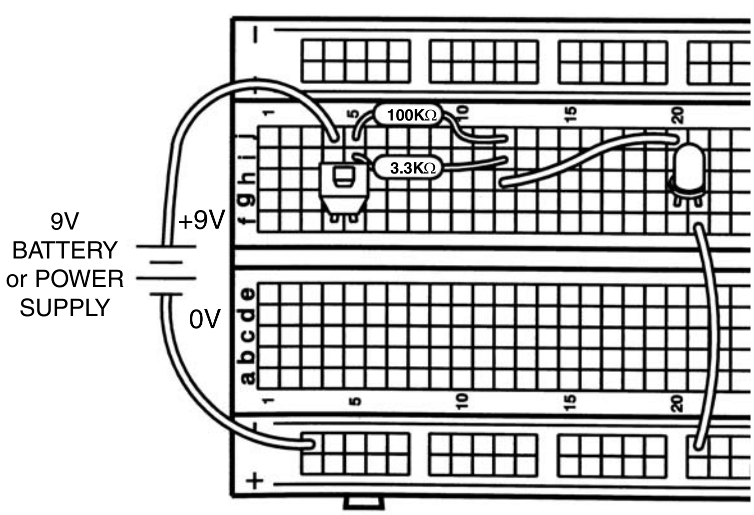
- a 9V battery or power supply
- Switch
- one 1kΩ resistor (brown-black-red-gold)
- one 3.3kΩ resistor (orange-orange-red-gold)
- one 10kΩ resistor (brown-black-orange-gold)
- one 100kΩ resistor (brown-black-yellow-gold)
- one LED
- 2 wires

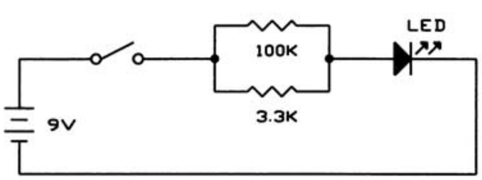
Wiring Checklist (✓ indicates same position as last experiment):

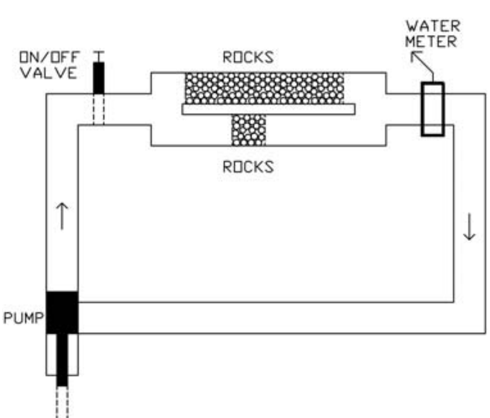
☑ Insert red battery wire or positive power supply (P. S.) into j4 and black battery wire or negative power supply (ground) into (–)3.
☑ Insert switch into f4 and f5.
☑ Insert the LED into g20 and g21 ("flat" side goes into g21).
☑ Insert a short wire between f21 and (–)21.
☑ Insert the 3.3kΩ resistor into i5 and i12.
☐ Insert the 100kΩ resistor into j5 and j12.
☐ Insert a short wire between h12 and j20.

WIRING DIAGRAM

Note: From now on there will be less description for frequently used parts.







EXPERIMENT 5: COMPARISON OF PARALLEL CURRENTS

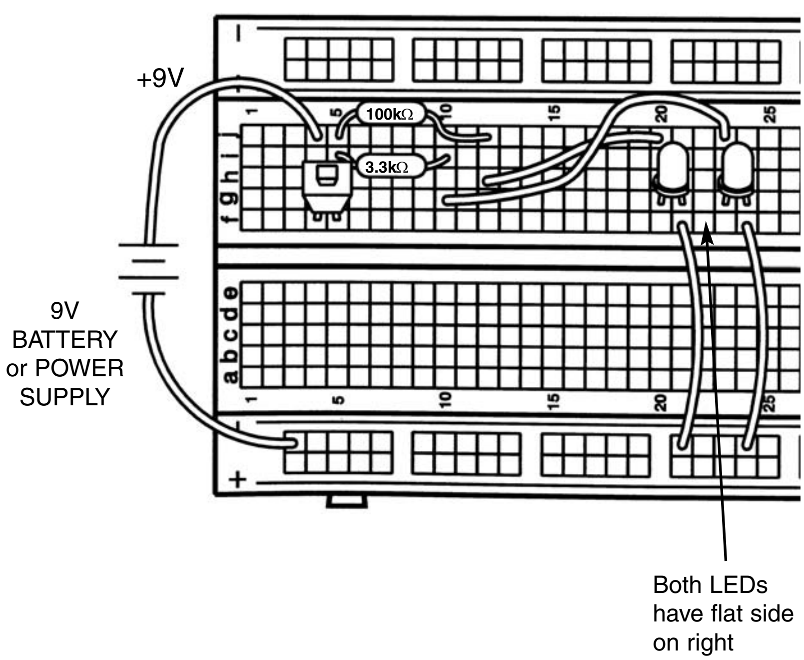
Since we have two resistors in parallel and a second LED that is not being used, let's modify the last circuit to match the schematic below. It's basically the same circuit but instead of just parallel resistors there are parallel resistor-LED circuits. Remove the resistors used in Experiment #4; the other parts are used here. Insert the new parts according to the Wiring Checklist. Replace the 100kΩ resistor with several values as before (such as 1kΩ, 10kΩ, and others if you wish), pressing the switch and observing the LEDs each time. The brightness of the right LED will not change, but the brightness of the left LED will depend on the resistor value you placed in series with it.

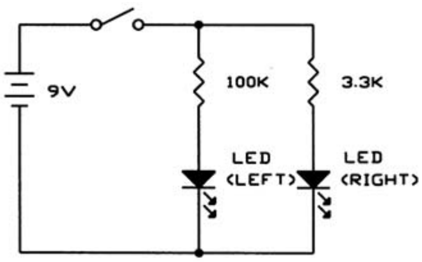
Parts Needed:

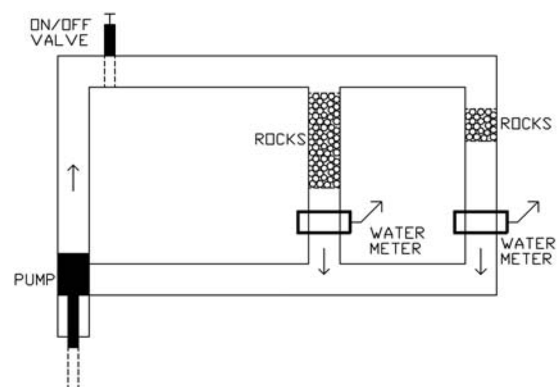
- a 9V battery or power supply
- Switch
- one 3.3kΩ resistor (orange-orange-red-gold)
- one 100kΩ resistor (brown-black-yellow-gold)
- 2 LEDs
- 4 wires

Wiring Checklist (☑ indicates same position as last experiment):

☑ Insert red battery wire or positive P. S. into j4 and black battery wire or negative P. S. (ground) into (–)3.
☑ Insert switch into f4 and f5. The switch may be a tight fit, carefully press it in slowly.
☑ Insert an LED into g20 and g21 ("flat" side goes into g21).
☑ Insert a short wire between f21 and (–)21.
☑ Insert the 100kΩ resistor into j5 and j12.
☑ Insert a short wire between h12 and j20.
☐ Insert the 3.3kΩ resistor into i5 and j10.
☐ Insert a short wire between g10 and j23.
☐ Insert an LED into g23 and g24 ("flat" side goes into g24).
☐ Insert a short wire between f24 and (–)24.







EXPERIMENT #6: COMBINED CIRCUIT

Let's combine everything we've done so far. Remove the resistors used in Experiment #3; the other parts are used here. Insert the new parts and wires according to the Wiring Checklist. Before pressing the switch, take a look at the schematic and think about what will happen as you turn the dial on the variable resistor (we'll abbreviate this to VR). Now press the switch with one hand and turn the dial with the other to see if you were right. As you turn the VR dial from left to right the left LED will go from bright to very dim and the right LED will go from very dim to visible.

What's happening is this: With the dial turned all the way to the left the VR is 0Ω (much smaller than the 10kΩ) so nearly all of the current passing through the 3.3kΩ will take the VR-LED(left) path and very little will take the 10kΩ-LED(right) path. When the VR dial is turned 1/5 to the right the VR is 10kΩ (same as the other path) and the current flowing through the 3.3kΩ will divide equally between the two LED paths (making them equally bright). As the VR dial is turned all the way to the right the VR becomes a 50kΩ (much larger than the 10kΩ) and LED(left) will become dim while LED(right) gets brighter.

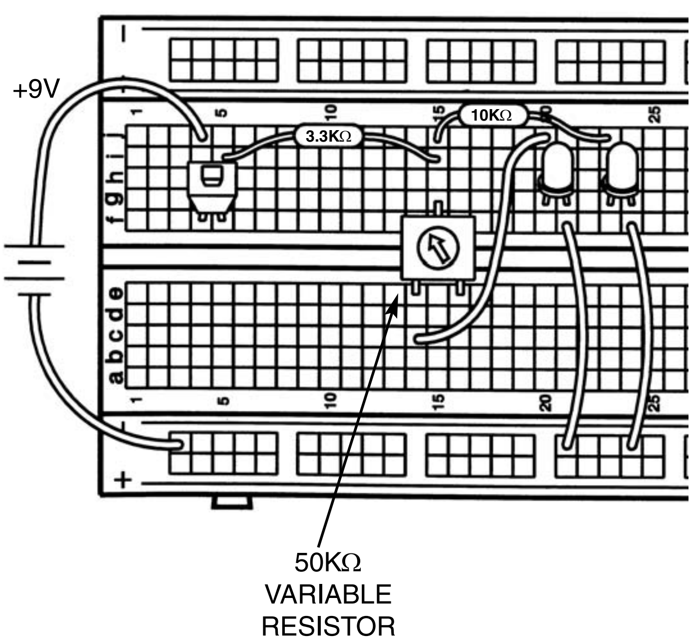
Now is a good time to take notes on how resistors work in series and in parallel. All electronic circuits are much larger combinations of series and parallel circuits such as these. It's important to understand these ideas because soon we'll apply them to capacitors and inductors!

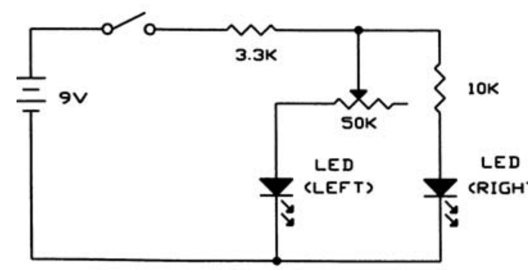
Parts Needed:

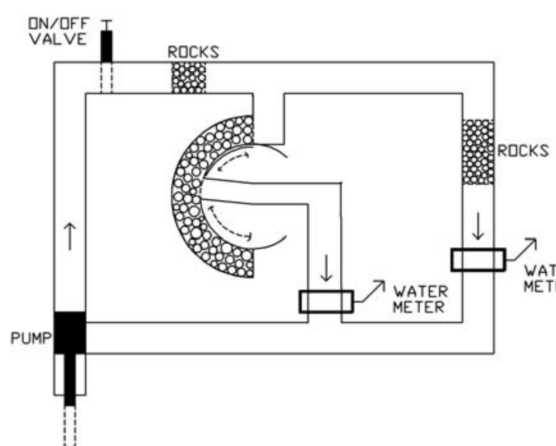
- a 9V battery or power supply
- Switch
- one 3.3kΩ resistor (orange-orange-red-gold)
- one 10kΩ resistor (brown-black-orange-gold)
- 50kΩ variable resistor
- 2 LEDs
- 3 wires

Wiring Checklist (✓ indicates same position as last experiment):

☑ Insert red battery wire or positive P. S. into j4 and black battery wire or negative P. S. (ground) into (–)3.
☑ Insert switch into f4 and f5.
☑ Insert an LED into g20 and g21 ("flat" side goes into g21).
☑ Insert a short wire between f21 and (–)21.
☑ Insert an LED into g23 and g24 ("flat" side goes into g24).
☑ Insert a short wire between f24 and -24.
☐ Insert the 50kΩ variable resistor into holes e14, g15, and e16. It may be a tight fit, carefully press it in slowly.
☐ Insert the 3.3kΩ resistor into i5 and i15.
☐ Insert the 10kΩ resistor into j15 and j23.
☐ Insert a short wire between c14 and j20.







EXPERIMENT #7: WATER DETECTOR

You've seen how electricity flows through copper wires easily and how carbon resists the flow. How well does water pass electricity? Let's find out.

Connect the parts and wires according to the Wiring Checklist and take a look at the schematic. There isn't a switch this time, so just disconnect one of the wires if you want to turn the circuit off. Notice that the Wiring Checklist leaves 2 wires unconnected. The LED will be off initially (if you touch the two loose wires together then it will be on). Now take a small cup (make sure it isn't made of metal), fill it half way with water, and place the two unconnected wires into the water without touching each other. The LED should now be dimly lit, but the brightness could vary depending on your local water quality. You are now seeing a demonstration of how water conducts (passes) electricity. (A small cup of water like this may be around 100kΩ, but depends on the local water quality). Try adding more water to the cup and see if the LED brightness changes (it should get brighter because we are "making the water pipe larger"). Since the LED only lights when it is in water now, you could use this circuit as a water detector!

Now adjust the amount of water so that the LED is dimly lit. Now, watching the LED brightness, add some table salt to the water and stir to dissolve the salt. The LED should become brighter because water has a lower electrical resistance when salt is dissolved in it. Looking at the water pipe diagram, you can think of this as a strong cleaner dissolving paintballs that are mixed in with the rocks. You could even use this circuit to detect salt water like in the ocean!

Wiring Checklist (✓ indicates same position as last experiment):

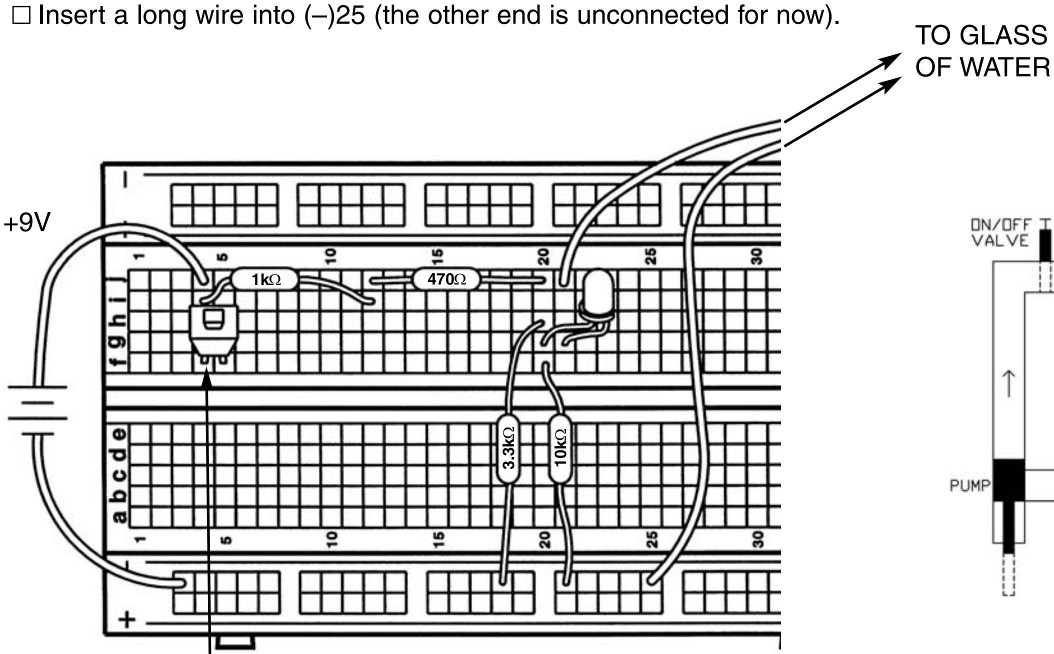
- ☑ Insert red battery wire or positive P. S. into j4 and black battery wire or negative P. S. (ground) into (–)3.
- ☑ Insert an LED into g20 and g21 ("flat" side goes into g21).

Note: Keep the switch in the breadboard (unconnected) until later experiments, as it can be difficult to remove and insert.

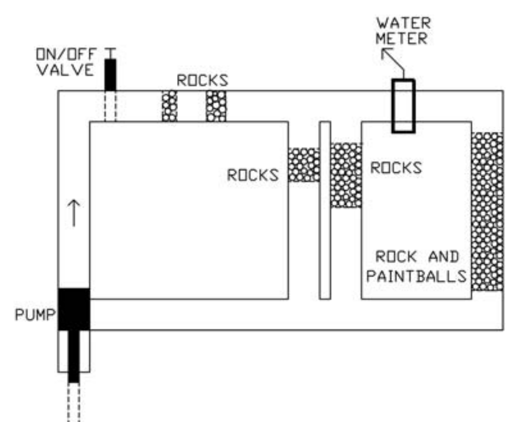
- ☐ Insert the 470Ω resistor into j12 and j20.
- ☐ Insert the 1kΩ resistor into i4 and i12.
- ☐ Insert the 3.3kΩ resistor into h20 and (–)18.
- ☐ Insert the 10kΩ resistor into f20 and (–)21.
- ☐ Insert a long wire into j21 (the other end is unconnected for now).
- ☐ Insert a long wire into (–)25 (the other end is unconnected for now).

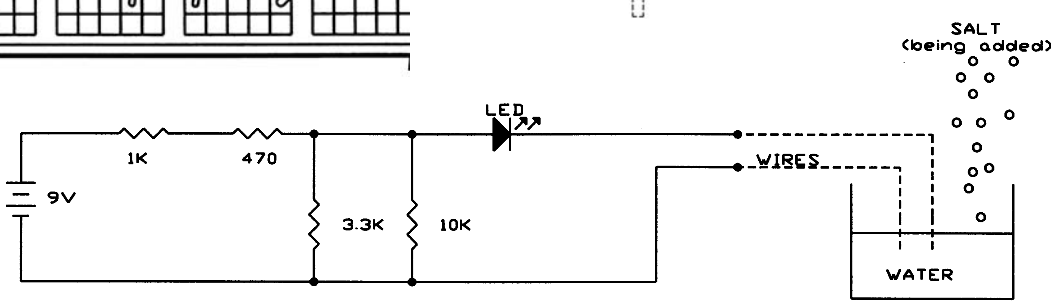
Parts Needed:

a 9V battery or power supply
one 470Ω resistor (yellow-violet-brown-gold)
one 1kΩ resistor (brown-black-red-gold)
one 3.3kΩ resistor (orange-orange-red-gold)
one 10kΩ resistor (brown-black-orange-gold)
one LED
2 long wires
a glass of water and salt



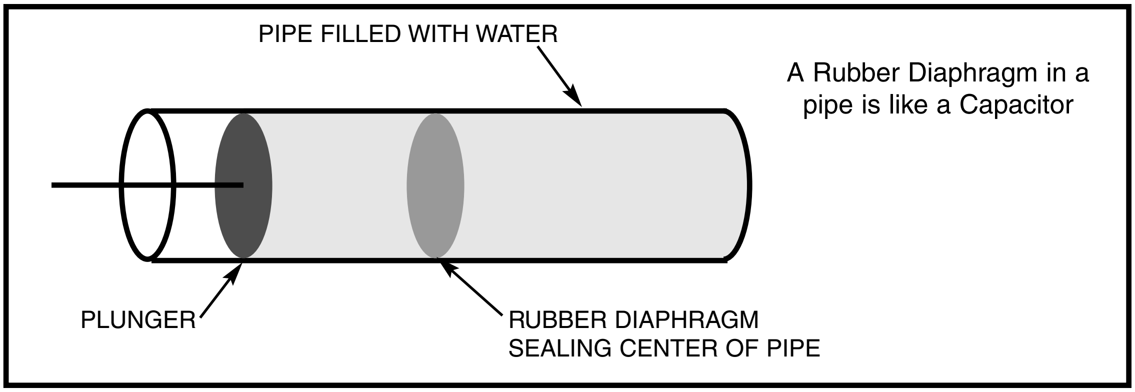
Note: Switch is not used here but leave in for future experiments.





INTRODUCTION TO CAPACITORS

Capacitors: Capacitors are electrical components that can store electrical pressure (voltage) for periods of time. When a capacitor has a difference in voltage (electrical pressure) across it, it is said to be charged. A capacitor is charged by having a one-way current flow through it for a short period of time. It can be discharged by letting a current flow in the opposite direction out of the capacitor. In the water pipe analogy, you may think of the capacitor as a water pipe that has a strong rubber diaphragm sealing off each side of the pipe as shown below:



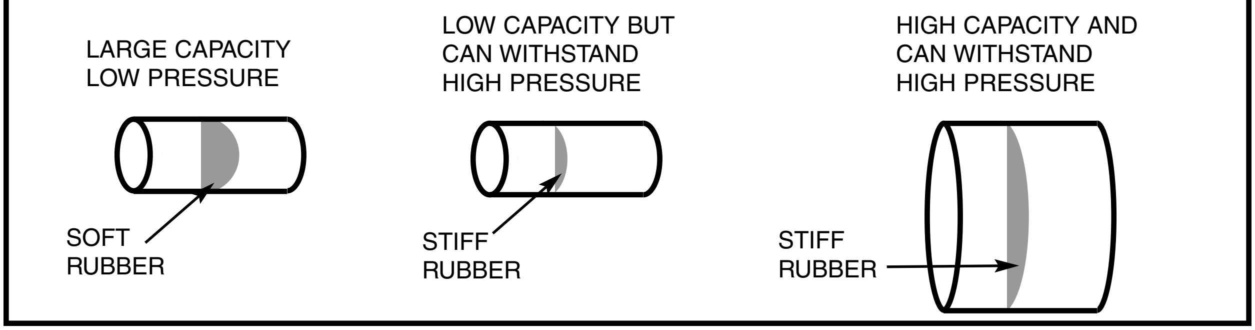
If the pipe had a plunger on one end (or a pump elsewhere in the piping circuit), as shown above, and the plunger was pushed toward the diaphragm, the water in the pipe would force the rubber to stretch out until the force of the rubber pushing back on the water was equal to the force of the plunger. You could say the pipe is charged and ready to push the plunger back. In fact if the plunger is released it will move back to its original position. The pipe will then be discharged or with no pressure on the diaphragm.

Capacitors act the same as the pipe just described. When a voltage (electrical pressure) is placed on one side with respect to the other, electrical charge "piles up" on one side of the capacitor (on the capacitor "plates") until the voltage pushing back equals the voltage applied. The capacitor is then charged to that voltage. If the charging voltage was then decreased the capacitor would discharge. If both sides of the capacitor were connected together with a wire then the capacitor would rapidly discharge and the voltage across it would become zero (no charge).

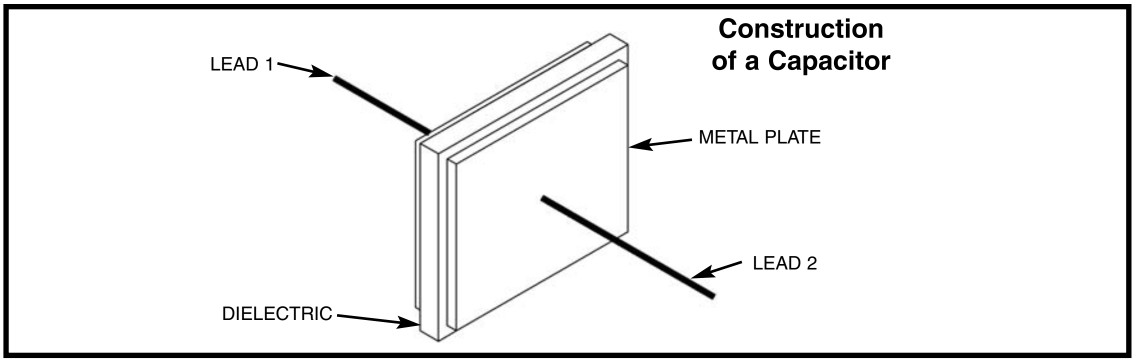
What would happen if the plunger in the drawing above was wiggled in and out many times each second? The water in the pipe would be pushed by the diaphragm and then sucked back by the diaphragm. Since the movement of the water (current) is back and forth (alternating) it is called an **alternating current** or **AC**. The capacitor will therefore pass an alternating current with little resistance. When the push on the plunger was only toward the diaphragm, the water on the other side of the diaphragm moved just enough to charge the pipe (a transient or temporary current). Just as the pipe blocked a direct push, a capacitor blocks a **direct current** (**DC**). Current from a battery is an example of direct current. An example of alternating current is the 60 cycle (60 wiggles per second) current from the electrical outlets in the walls of your house.

Construction of Capacitors: If the rubber diaphragm is made very soft it will stretch out and hold a lot of water but will break easily (large capacitance but low working voltage). If the rubber is made very stiff it will not stretch far but will be able to withstand higher pressure (low capacitance but high working voltage). By making the pipe larger and keeping the rubber stiff we can achieve a device that holds a lot of water and withstands high pressure (high capacitance, high working voltage, large size). So the pipe size is determined by its capacity to hold water and the amount of pressure it can handle. These three types of water pipes are shown below:

TYPES OF WATER PIPES



Similarly, capacitors are described by their capacity for holding electric charge, called their **Capacitance**, and their ability to withstand electric pressure (voltage) without damage. Although there are many different types of capacitors made using many different materials, their basic construction is the same. The wires (leads) connect to two or more metal plates that are separated by high resistance materials called **dielectrics**.



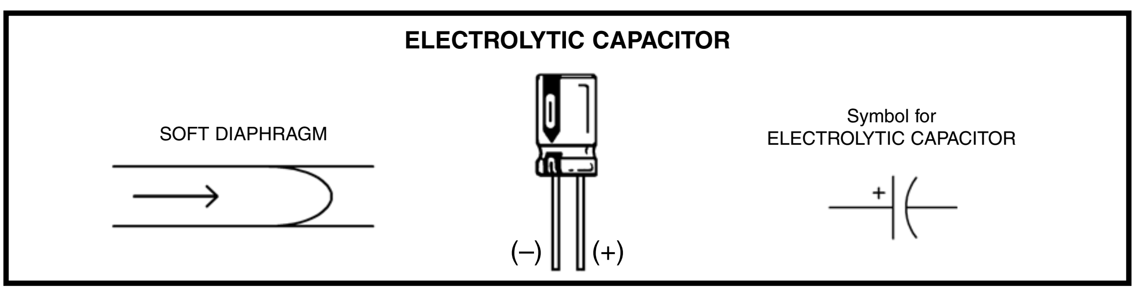
The dielectric is the material that holds the electric charge (pressure), just like the rubber diaphragm holds the water pressure. Some dielectrics may be thought of as stiff rubber, and some as soft rubber. The capacitance and working voltage of the capacitor is controlled by varying the number and size of metal-dielectric layers, the thickness of the dielectric layers, and the type of dielectric material used.

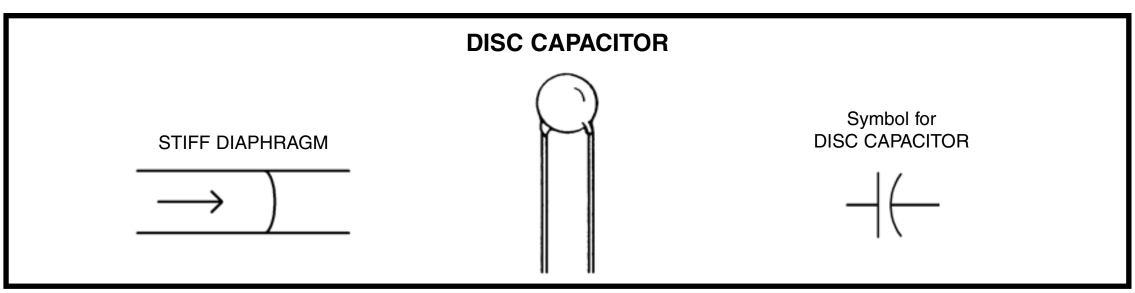
Capacitance is expressed in **farads** (F, named after Michael Faraday whose work in electromagnetic induction led to the development of today's electric motors and generators), or more commonly in microfarads (μF, millionths of a farad) or picofarads (pF, millionths of a microfarad). Almost all capacitors used in electronics vary from 1pF to 1,000μF.

Your PK-101 includes two electrolytic (10μF and 100μF) and two disc (0.005μF and 0.047μF) capacitors. (Mylar capacitors may have been substituted for the disc ones, their construction and performance is similar). Electrolytic capacitors (usually referred to as lytics) are high capacitance and are used mostly in power supply or low frequency circuits. Their capacitance and voltage are usually clearly marked on them. Note that these parts have "+" and "–" **polarity** (orientation) markings, the lead marked "+" should always be connected to a higher voltage than the "–" lead (all of your Wiring Diagrams account for this).

Disc capacitors are low capacitance and are used mostly in radio or high frequency applications. They don't have polarity markings (they can be hooked up either way) and their voltage is marked with a letter code (most are 50V). Their value is usually marked in pF with a 3 digit code similar to the stripes used on resistors. The first 2 digits are the first 2 digits of the capacitor's value and the third digit tells the power of 10 to multiply by (or the number of zeros to add). For example, the 0.005μF (5,000pF) and .047μF (47,000pF) disc capacitors in your PK-101 are marked 502 and 473.

Capacitors have symbols as follows:

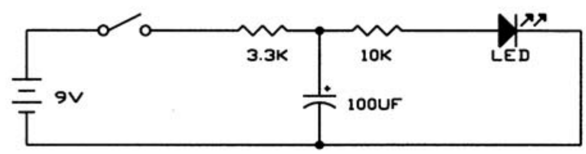


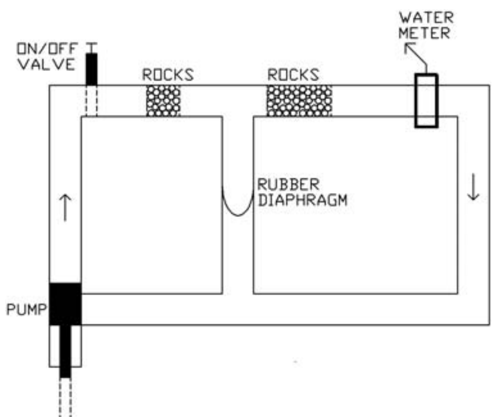


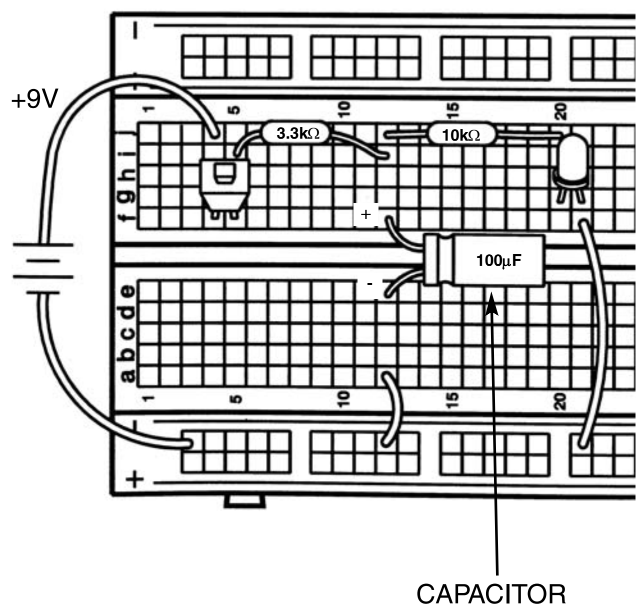
EXPERIMENT #8: SLOW LIGHT BULB

Starting with this experiment, we will no longer show you the Parts List or the Wiring Checklist. Refer back to the previous experiments if you feel you need more practice in wiring the circuits. Refer back to page 10 if you need to review the resistor color code. Connect the circuit according to the schematic and Wiring Diagram and press the switch several times. You can see it takes time to charge and discharge the large capacitor because the LED lights up and goes dim slowly. Replace the 3.3kΩ resistor with the 1kΩ resistor; now the charge time is faster but the discharge time is the same. Do you know why? When the switch is closed the battery charges the capacitor through the 1kΩ resistor and when the switch is opened the capacitor discharges through the 10kΩ, which has remained the same. Now replace the 100μF capacitor with the 10μF. Both the charge and discharge times are now faster since there is less capacitance to charge up. If you like you may experiment with different resistors in place of the 1kΩ and 10kΩ. If you observe the LED carefully, you might start to suspect the relationship between the component values and the charging and discharging times - **the charge/discharge times are proportional to both the capacitance and the resistance in the charge/discharge path!**

A simple circuit like this is used to slowly light or darken a room, such as a movie theater.





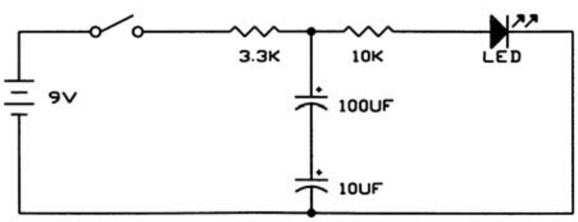


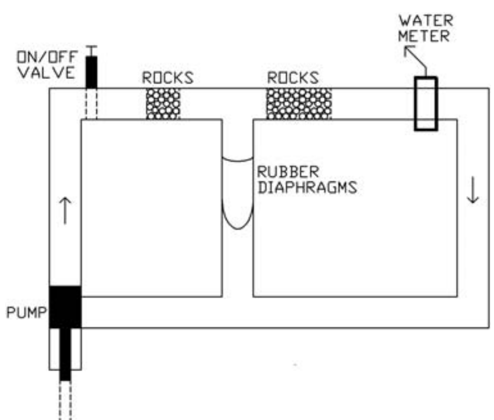
EXPERIMENT #9: SMALL DOMINATES LARGE - CAPACITORS IN SERIES

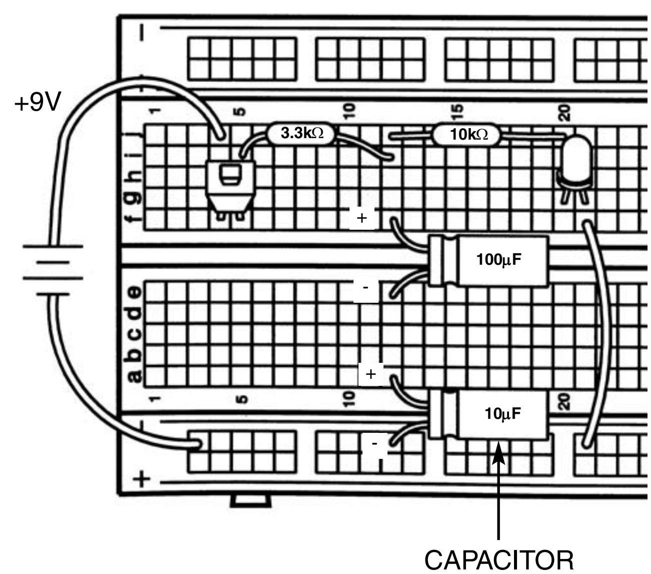
Take a look at the schematic, it is almost the same circuit as the last experiment except that now there are two capacitors in series. What do you think will happen? Connect the circuit according to the schematic and Wiring Diagram and press the switch several times to see if you are right.

Looking at the water diagram and the name of this experiment should have made it clear - the smaller 10µF will dominate (control) the response since it will take less time to charge up. As with resistors, you could change the order of the two capacitors and would still get the same results (try this if you like). Notice that while resistors in series add together to make a larger circuit resistance, capacitors in series combine to make a smaller circuit capacitance. Actually, capacitors in series combine the same way resistors in parallel combine (using the same mathematical relationship given in Experiment 4). For this experiment, 10µF and 100µF in series perform the same as a single 9.1µF.

In terms of our water pipe analogy, you could think of capacitors in series as adding together the stiffness of their rubber diaphragms.



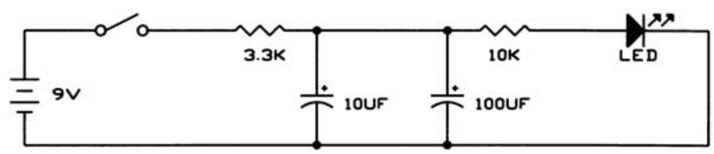


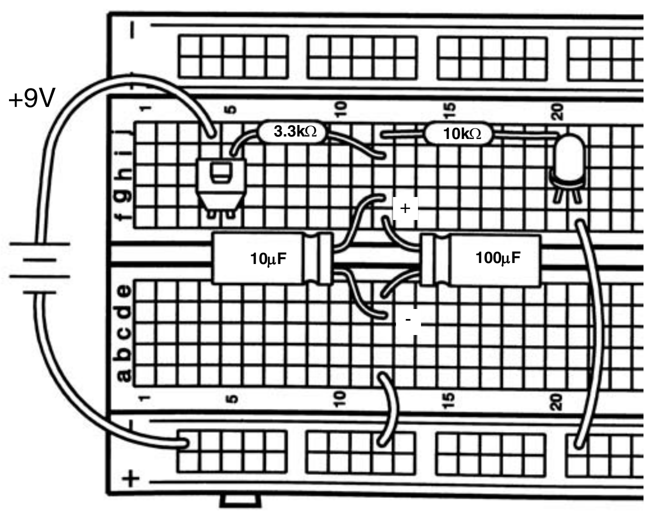


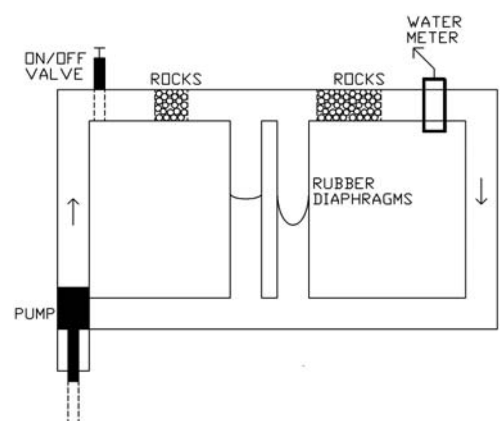
EXPERIMENT #10: LARGE DOMINATES SMALL - CAPACITORS IN PARALLEL

Now you have capacitors in parallel, and you can probably predict what will happen. If not, just think about the last experiment and about how resistors in parallel combine, or think in terms of the water diagram again. Connect the circuit according to the schematic and Wiring Diagram and press the switch several times to see.

Capacitors in parallel add together just like resistors in series, so here 10μF + 100μF = 110μF total circuit capacitance. In the water diagram, we are stretching both rubber diaphragms at the same time so it will take longer than to stretch either one by itself. If you like you may experiment with different resistor values as you did in experiment #8. Although you do have two disc capacitors and a variable capacitor (which will be discussed later) there is no point in experimenting with them now, their capacitance values are so small that they would act as an open switch in any of the circuits discussed so far.





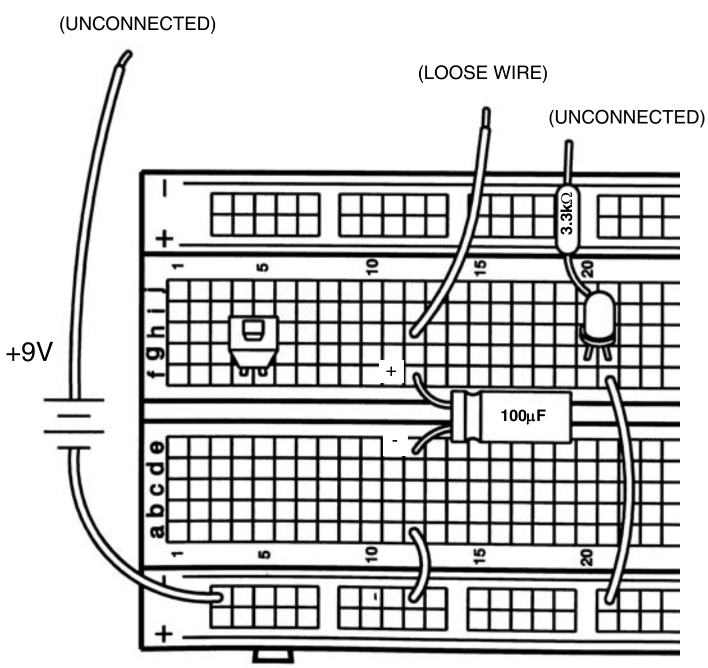


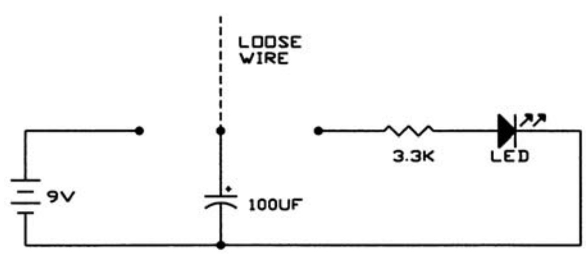
EXPERIMENT #11: MAKE YOUR OWN BATTERY

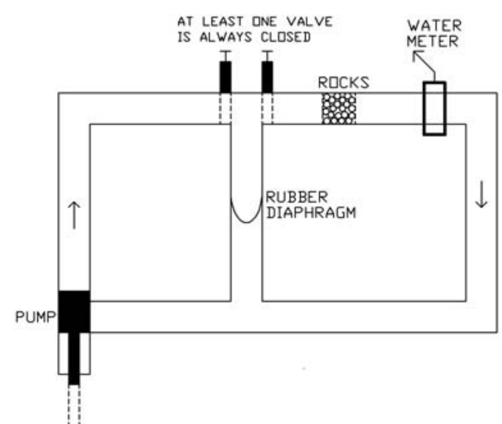
Connect the circuit according to the schematic and Wiring Diagram. Note that one side of the battery and resistor are unconnected and there is a wire connected only to the 100µF capacitor. At this time no current will flow because nothing is connected to the battery. Now hold the loose wire and touch it to the positive battery wire and then remove it, the battery will instantly charge the capacitor since there is no resistance (actually there is some internal resistance in the battery and some in the wires but these are very small). The capacitor is now charged and is storing the electricity it received from the battery. It will remain charged as long as the loose wire is kept away from any metal. Now touch the loose wire to loose side of the 3.3kΩ resistor and watch the LED. It will initially be very bright but diminishes quickly as the capacitor discharges. Repeat charging and discharging the capacitor several times. You can also discharge the 100µF in small bursts by only briefly touching the 3.3kΩ. If you like you can experiment with using different values in place of the 3.3kΩ; lower values will make the LED brighter but it will dim faster while with higher resistor values the LED won't be as bright but it will stay on longer. You can also put a resistor in series with the battery when you charge the capacitor, then it will take time to fully charge the capacitor. What do you think would happen if you used a smaller capacitor value?

When the capacitor is charged up it is storing electricity which could be used elsewhere at a later time - it is like a battery! However, an electrolytic capacitor is not a very efficient battery. Storing electric charge between the plates of a capacitor uses much more space than storing the same amount of charge chemically within a battery - compare how long the 100µF lit the LED above with how your 9V battery runs all of your experiments!

Now is a good time to take notes for yourself on how capacitors work, since next we introduce the diode.







TEST YOUR KNOWLEDGE #1

1. __________ are the particles that flow between atoms as part of an electric current.

2. A __________ circuit occurs when wires or components from different parts of the circuit accidentally connect.

3. A __________ produces electricity using a chemical reaction.

4. To decrease the current in a circuit you may decrease the voltage or __________ the resistance.

5. Materials which have very high resistance are called __________ and materials which have very low resistance are called __________.

6. Adding resistors in parallel __________ the resistance while adding resistors in series _________ the resistance.

7. The electrical resistance of water __________ when salt is dissolved in it.

8. Capacitors are components that can store __________ for periods of time.

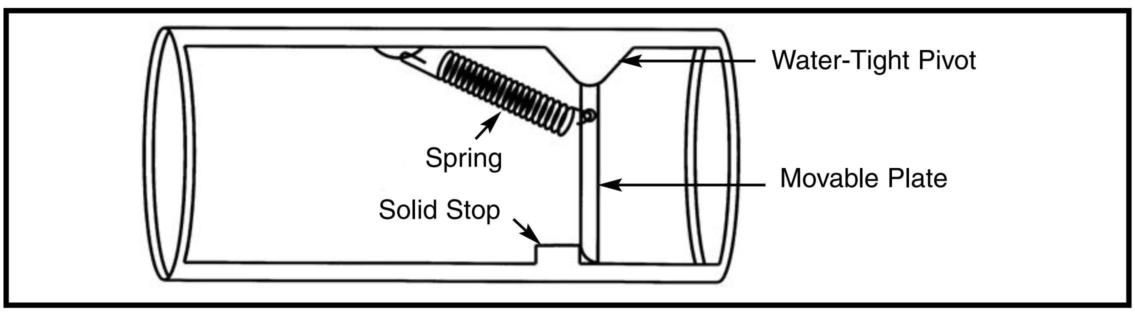
9. Capacitors have low resistance to __________ current and high resistance to __________ current.

10. Adding capacitors in parallel __________ the capacitance while adding capacitors in series __________ the capacitance.

(Answers are on page 3)

INTRODUCTION TO DIODES

The Diode: The **diode** is an electronic device that allows current to flow in only one direction. In our water pipe analogy it may be thought of as the check valve shown here:



The check valve only allows water to flow in one direction, to the right in this drawing. There is a small spring and if the water pressure exceeds a certain level then the spring will be stretched and the valve opened. If the pressure is to flow to the left then the plate will be pressed against the solid stop and no water will flow.

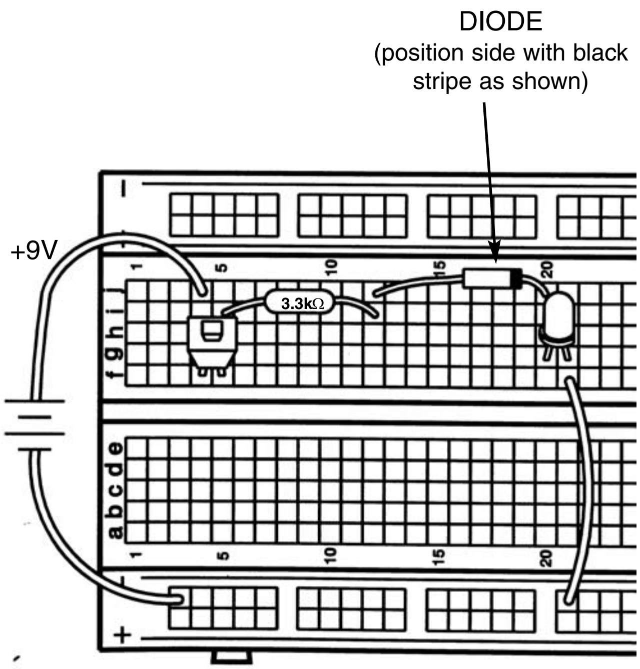
Electronic diodes are made from materials called **semiconductors**, so-called because they have more resistance than metal conductors but less than insulators. Most semiconductors are made of Silicon but Gallium Arsenide and Germanium are also used. Their key advantage is that by using special manufacturing processes their resistance is decreased under certain operating conditions. The manufacturing processes create two regions of permanent electrical charge, quite different from charging a capacitor. While the physics of how this works is quite complicated, the effect is that once the voltage across the diode exceeds a small turn-on level (0.7V for Silicon) the resistance of the diode becomes very low in one direction (so low in fact that the current flow must be limited by other resistances in the circuit to prevent damage to the diode). When the diode is turned on like this we refer to it as being **forward-biased**. In the other direction the diode is always a very high resistance, we call this **reverse-biased**. The schematic symbol, shown below, indicates that the diode will allow current to flow from left to right but block current flow from right to left.

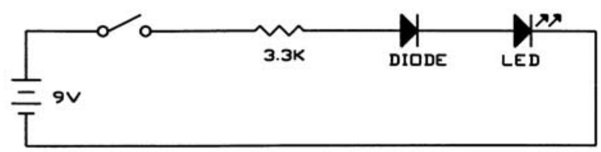
EXPERIMENT #12: ONE - WAY CURRENT

Your PK-101 includes one diode, a 1N4148, which is a standard diode widely used in industry. Connect the circuit and press the switch, the LED lights up. The diode's turn-on voltage of 0.7V is easily exceeded and the diode has little effect on the circuit. Now reverse the wires to the diode and try again, nothing happens. The diode is now reverse-biased and blocks current flow through the circuit, just like the plate and solid stop block the water flow in the drawing shown above.

You've probably noticed a similarity between the schematic symbols for the diode and the LED. Re-wire the diode back to forward-biased or remove it from the circuit and then reverse the wires to the LED. Press the switch and LED doesn't light, do you know why?

Starting now, the equivalent water diagrams will no longer be presented.



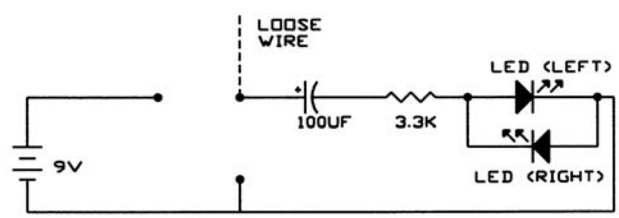


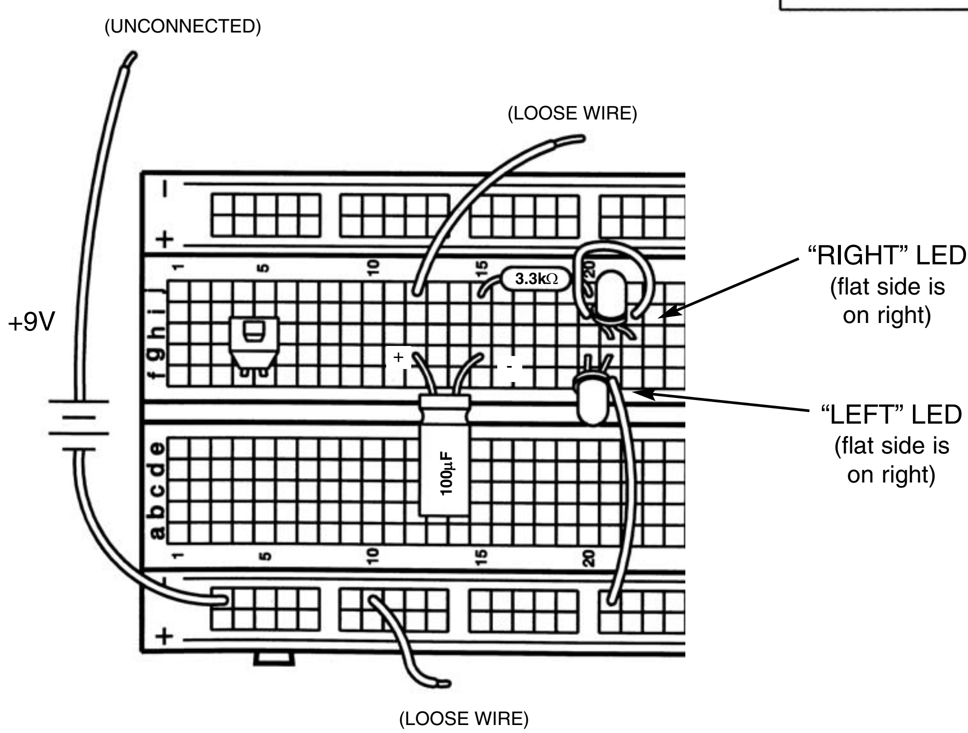
EXPERIMENT #13: ONE-WAY LIGHT BULBS

Diodes made of Gallium Arsenide need a higher voltage across them to turn on, usually about 1.5V This turn-on energy is so high that light is generated when current flows through the diode. These diodes are the light emitting diodes that you have been using.

To demonstrate this, connect the circuit below (note that the two LEDs will be referred to as "left" and "right"). Touch the loose wire to the battery and watch the left LED. It will be bright initially as a current flows to charge up the 100µF capacitor and then will dim as the capacitor voltage reaches the battery voltage. The right LED will not light since it is reverse-biased. Then touch the loose wire to the negative side of the battery ("ground") and watch the right LED. It will be bright initially as a current flows to discharge the 100µF capacitor and then will dim as the capacitor voltage drops to zero. The left LED will not light since now it is reverse-biased.

As in Experiment #11, you may try different resistor values in this circuit if you like.



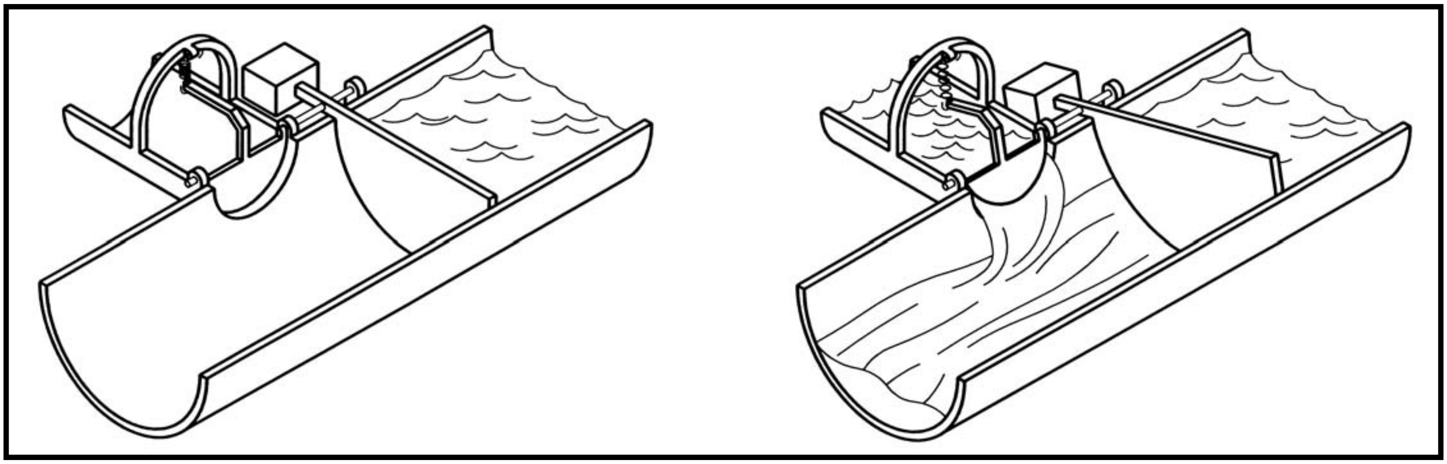


INTRODUCTION TO TRANSISTORS

The Transistor: The **transistor** was first developed in 1949 at Bell Telephone Laboratories, the name being derived from "transfer resistor". It has since transformed the world. Did you ever hear of something called a vacuum tube? They are large and can be found in old electronic equipment and in museums. They are seldom used today and few engineers even study them now. They were replaced by transistors, which are much smaller and more reliable.

The transistor is best described as a current amplifier - it uses a small amount of current to control a large amount of current. There are many different families of transistors but we will only discuss the type included in your PK-101, called the NPN Bipolar Junction Transistor or BJT and made of the semiconductor silicon. It has three connection points, called the emitter, base, and collector.

In our water pipe analogy the BJT may be thought of as the lever pivot shown here:

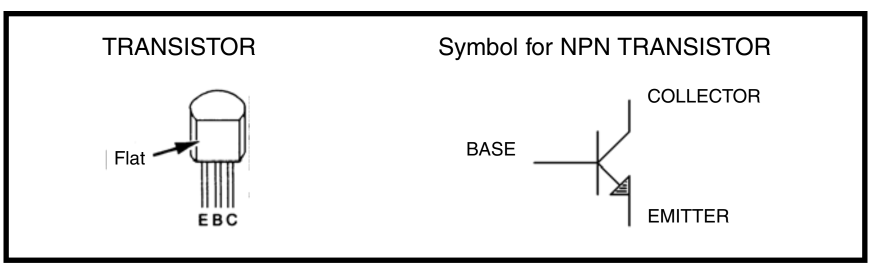


Notice that it includes a check valve that is connected to a lever arm. A small amount of "base current" pushes on the check valve which turns and opens the lever arm. But before this base current can start to flow though it must have enough water pressure to overcome the spring in the check valve (usually 0.7V). If the base pipe is much smaller than the collector and emitter pipes, then a small base current I_B flowing in will cause a large collector current I_C to flow in, these will combine and exit the device as emitter current I_E.

In transistors the emitter, base, and collector are different regions of permanent electrical charge, producing the effects described above for the lever pivot. The properties and uses of transistors may seem confusing at first but will become clear as you proceed through the experiments. All but one of the remaining experiments will use the transistor, so its importance to electronics should be apparent.

A key advantage of semiconductors is that several transistors can be manufactured on a single piece of silicon. This led to the development of **Integrated Circuit** (IC) technology, in which careful control of complex manufacturing processes has enabled entire circuits consisting of transistors, diodes, resistors, and capacitors to be constructed on a silicon base. Some ICs used in computers now have more than a million transistors on them. Spectacular improvements in cost, size, and reliability have been achieved as a result.

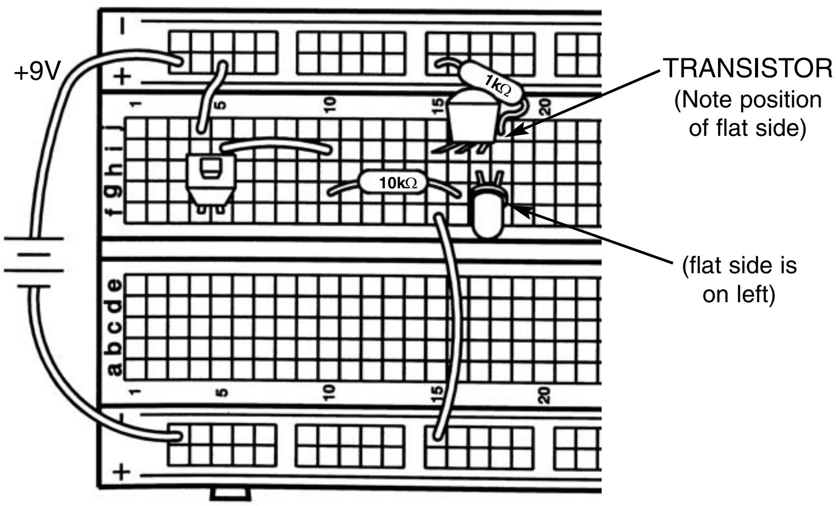
The schematic symbol for a transistor is shown below:

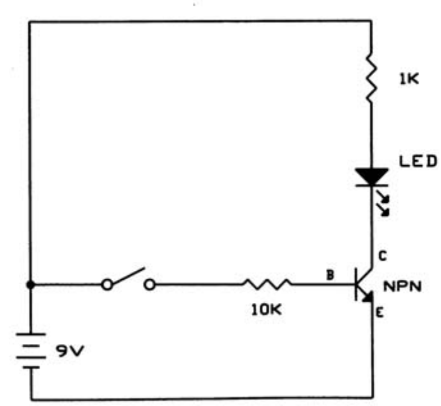


Note the small arrow in the emitter, this indicates which direction the current will flow through the device.

EXPERIMENT #14: THE ELECTRONIC SWITCH

Your PK-101 includes three transistors which are all type 2N3904 NPN Bipolar Junction Transistors. Connect the circuit according to the schematic and Wiring Diagram. Although there is a closed circuit with the battery, 1kΩ, LED, and transistor, no current will flow since the transistor is acting like an open circuit (with no base current the lever arm remains shut). Press the switch; a base current now flows and opens the lever arm, resulting in a large collector current which lights the LED. The transistor is being used as an electronic switch. Although there is still a normal switch in this circuit, there could be many electronic switches controlled by one normal switch.

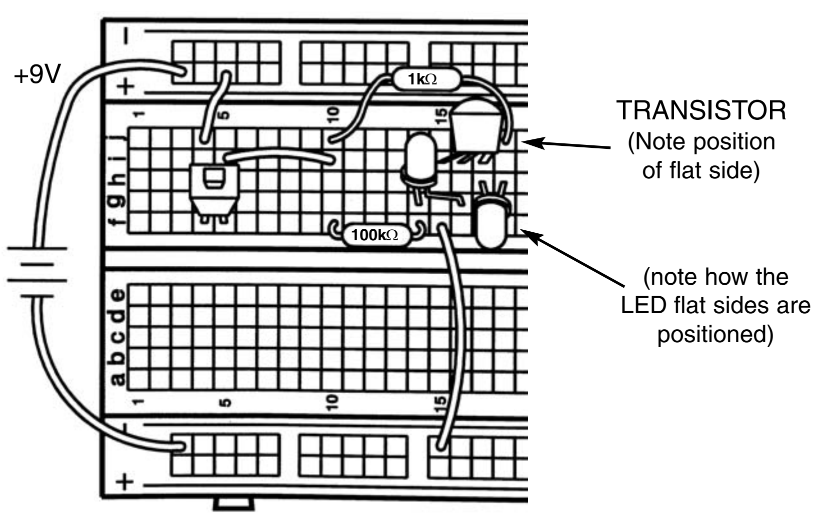


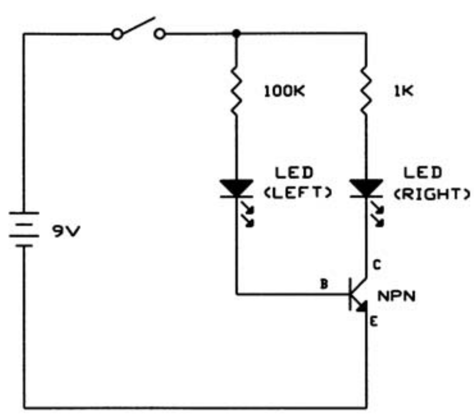


EXPERIMENT #15: THE CURRENT AMPLIFIER

Connect the circuit and press the switch. The right LED in the collector path is brighter than the left LED in the base path because the base current is amplified by the transistor. The current gain of a transistor varies anywhere from 10 to 1,000 depending on the type of transistor, the ones in your PK-101 have a gain of about 200.

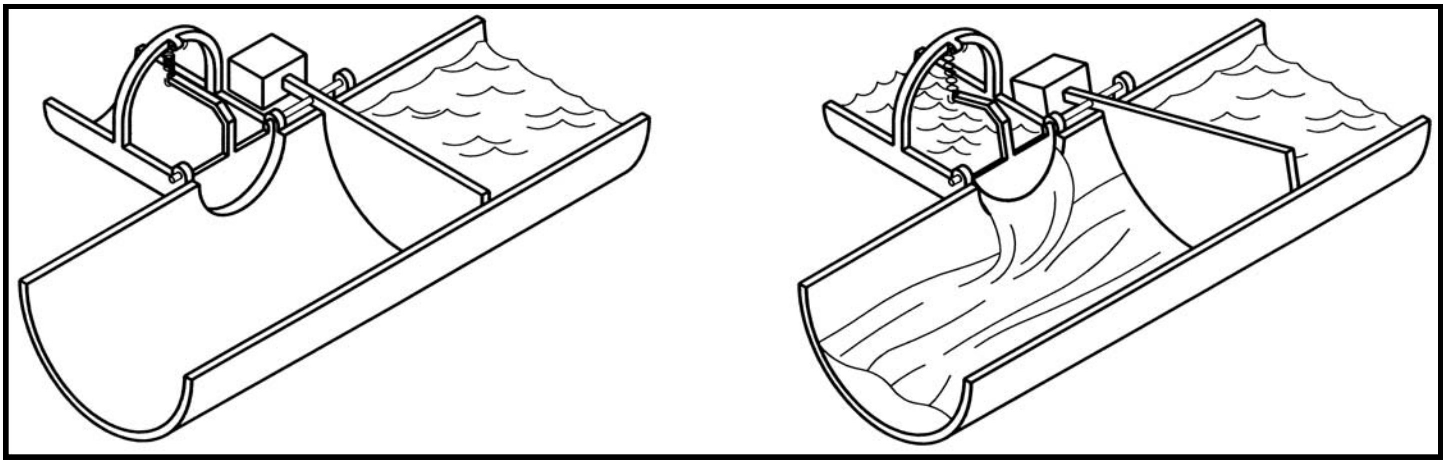
Note that the battery voltage and circuit resistance will limit the current gain. For example, if you replace the 1kΩ in this circuit with a 33kΩ then the current gain will only be about 3. The circuit resistances, not transistor itself, are limiting the current and the transistor is said to be **saturated**.





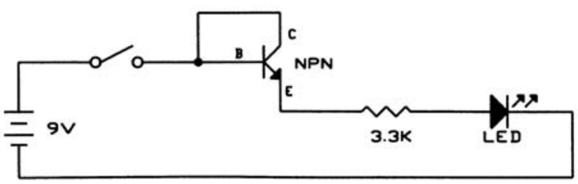
EXPERIMENT #16: THE SUBSTITUTE

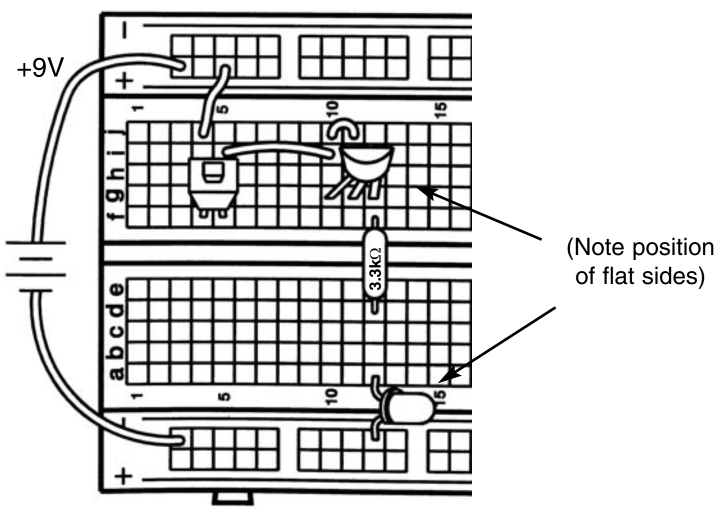
Look again at the water pipe analogy for the transistor, the lever pivot:



What would happen if the base and collector were connected together? Once there is enough pressure to overcome the spring in check valve DE (0.7V) there would be only slight resistance and no current gain. This situation should sound familiar since this is exactly how a diode operates. When the base and collector of a transistor are connected together the transistor becomes a diode.

Connect the circuit and press the switch, the LED lights. This is the same circuit as Experiment 12, One-Way Current. This demonstrates how transistors can be substituted for diodes, and this will occur in practice sometimes for manufacturing reasons.

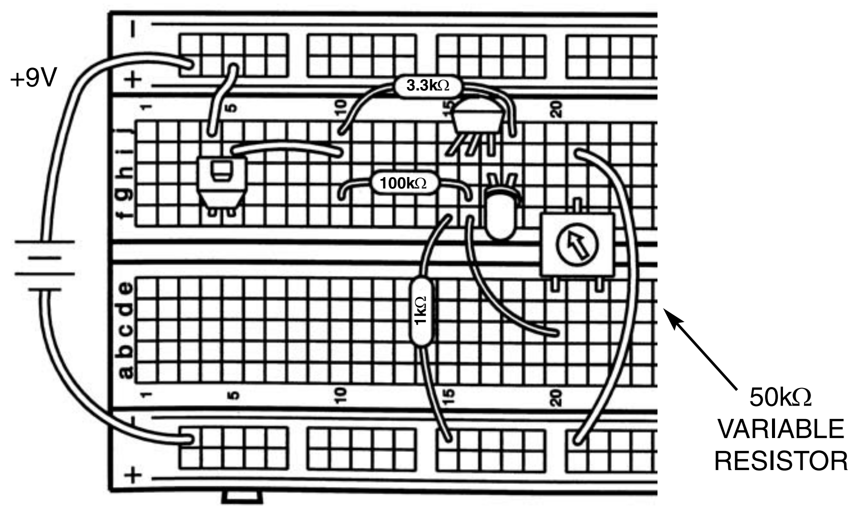


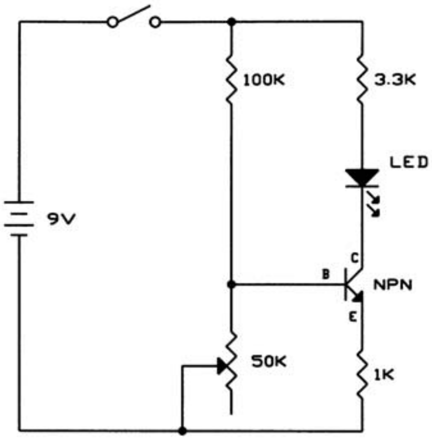


EXPERIMENT #17: STANDARD TRANSISTOR BIASING CIRCUIT

Connect the circuit and press the switch while turning the variable resistor from right to left (from 0Ω to 50kΩ). The 100kΩ and variable 50kΩ are a voltage divider that sets the voltage at the transistor base. If this voltage is less than 0.7V then the transistor will be off and no current will flow through the LED. As the base voltage increases above 0.7V a small base current starts to flow, which is amplified to produce a larger collector current that lights the LED. As the base voltage continues to increase the transistor becomes saturated and the LED brightness will not increase further.

This circuit will normally be used with the voltage divider set so that the transistor is turned on but is not saturated. Although this circuit does not have many applications by itself, when a small alternating current (AC) signal is applied to the base then a larger copy of the signal will appear at the collector - a small-signal amplifier!





EXPERIMENT #18: VERY SLOW LIGHT BULB

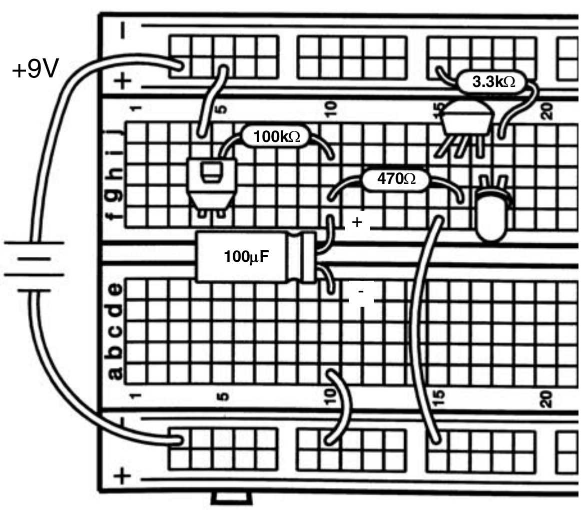
Connect the circuit and press the switch, hold it down for several seconds. The LED will slowly light up. Release the switch and the LED will slowly go dark.

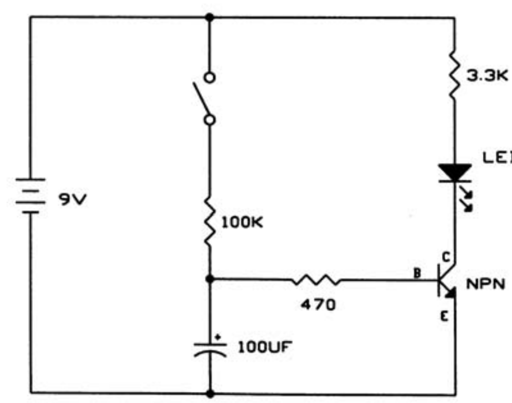
When you first press the switch all of the current flowing through the 100kΩ resistor goes to charge up the capacitor, the transistor and LED will be off. When the capacitor voltage rises to 0.7V the transistor will first turn on and the LED will turn on. As the capacitor voltage continues to rise the current flow through the 470Ω resistor and into the transistor base will increase. The current through the LED will then rise rapidly due to the transistor's current gain.

When the switch is released the capacitor will discharge through the 470Ω resistor and the transistor base, the LED will dim as this discharge current decreases. When the capacitor voltage drops below 0.7V the transistor will turn off. If you get impatient you may touch a wire between the two capacitor springs to discharge it instantly.

Do you know how to change the capacitor charge and discharge times? The 100kΩ resistor controls the charge time, the 470Ω controls the discharge, and the capacitor controls both the charge and discharge. Replace these parts with some different values and observe the effects.

Compare this circuit to the one you used in Experiment 8 when we first introduced the capacitor. By adding a transistor you can use a large resistor for a slow charge time and still have a bright LED!

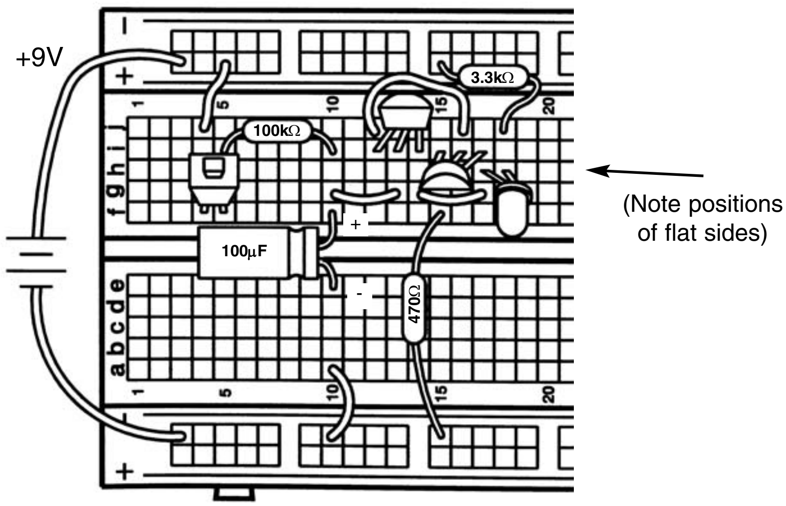


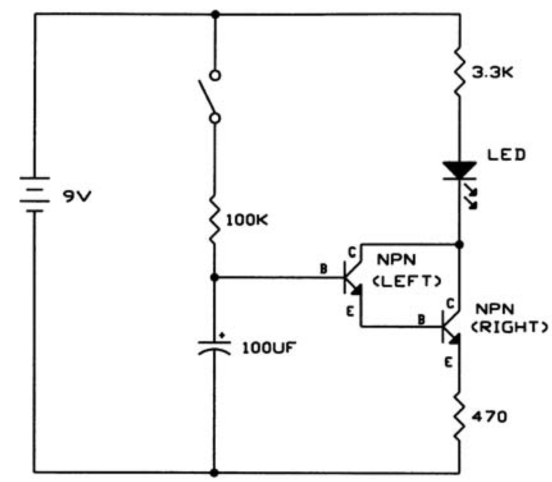


EXPERIMENT #19: THE DARLINGTON

This circuit is very similar to the last one. Connect the components and press the switch, hold it down for several seconds. The LED will slowly light up. Release the switch and the LED stays lit.

Take a look at the schematic. All the current flowing through the emitter of the left transistor will flow to the base of the right transistor. So the current flowing into the base of the left transistor will be amplified twice, once by each transistor. This configuration is called the **Darlington configuration**. It has very high current gain and very high input resistance at the base. Since there are now two transistors to turn on, the capacitor voltage must exceed 1.4V before the LED will start to light. And, since the input current to the base is so small, it will take much longer to discharge the capacitor. But the circuit is functionally the same as Experiment 18 and the LED will eventually go dark, though it may take a few minutes. You can experiment with changing some of the component values if you like.

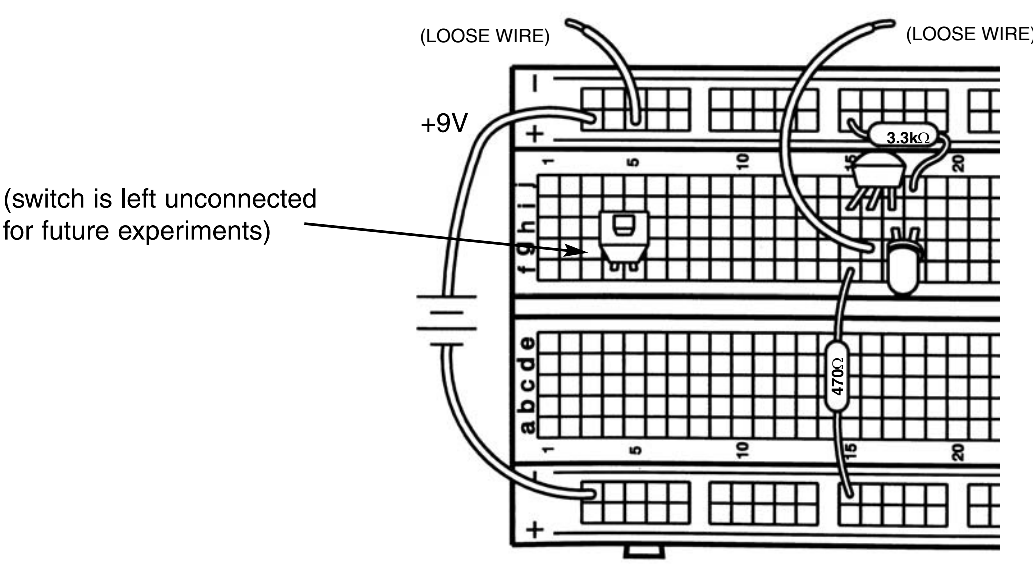


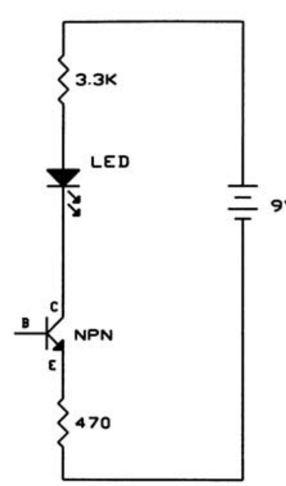


EXPERIMENT #20: THE TWO FINGER TOUCH LAMP

Take a look at the schematic. You're probably wondering how it can work, since nothing is connected to the transistor base. It can't, but there is another component that isn't shown in the schematic. That component is you.

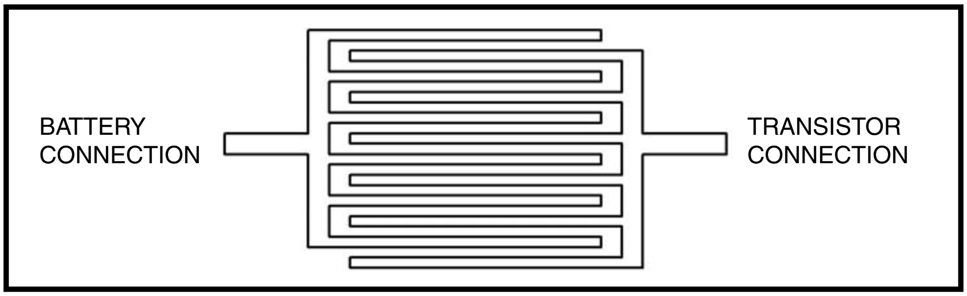
Connect the circuit according to the schematic and Wiring Diagram, including the two loose wires. Now touch the loose battery wire with one finger and the loose transistor wire with another. The LED may be dimly lit. The problem is your fingers aren't making good enough electrical contact with the springs. Wet your fingers with water or saliva and touch the springs again. The LED should be very bright now. You saw in Experiment 7 how water can conduct electricity and since your body is mostly water it shouldn't surprise you that your body can also conduct. Your body's resistance varies a lot, but is typically a few hundred kilohms. Think of this circuit as a touch lamp since when you touch it the LED lights. You may have seen such a lamp in the store or already have one in your home.



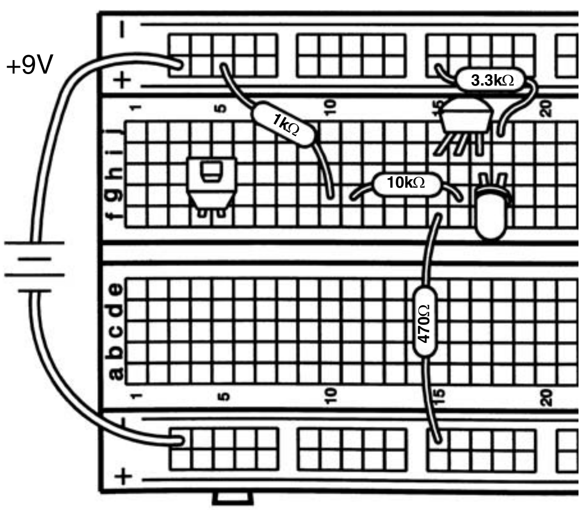


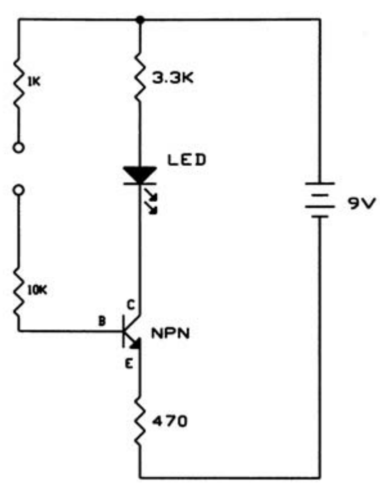
EXPERIMENT #21: THE ONE FINGER TOUCH LAMP

Actually, the touch lamps you see in stores only need to be touched by one finger to light, not two. So let's see if we can improve the last circuit to only need one finger. Connect the circuit, the only changes from the last experiment are the addition of the 1kΩ and 10kΩ resistors. These two resistors plug into adjacent (but not connected) holes g10 and g11. Wet a large area of one of your fingers and touch it to the resistor metal coming out of these two holes at the same time; the LED lights. To make it easier for one finger to touch the two contacts, touch lamps or other touch devices will have the metal contacts interweaved as shown below and will also be more sensitive so that you don't have to wet your finger to make good contact.



This circuit is still different from the touch lamps sold in stores because the LED goes dark if you remove your finger from it. We need a way of remembering when you've touched the lamp to turn it on or off - we need a memory, and we'll show you one in Experiment 45.





EXPERIMENT #22: THE VOLTMETER

Make sure you have a strong 9V battery for this experiment. Connect the circuit according to the Wiring Diagram and schematic, connect the battery last since this will turn on the circuit. And be sure to disconnect the battery (or turn off your power supply) when you're not using the circuit to avoid draining the battery. The part of the circuit to the left of the dashed line in the schematic is the voltmeter, the two resistors on the right produce a voltage that you will measure. Notice that the variable resistor (VR) will always act as a 50kΩ across the battery but by turning its knob you adjust the voltage at the base of the left transistor. By turning this knob you can make one LED brighter than the other, indicating that the voltages at the bases of the two transistors are not equal. Adjust the VR so that the two LEDs are equally bright. The transistor base voltages are now equal. To determine what voltage you have measured, simply subtract the percentage you turned your VR dial from 100 and multiply by 0.09.

If you like you can calculate what voltage you should have measured. Your measurement may differ from this due to the tolerances in the resistors and the VR dial, but you should be close. The resistors on the right are a voltage adjuster, just like the VR is, and the voltage you measured (at the base of the right transistor) is:

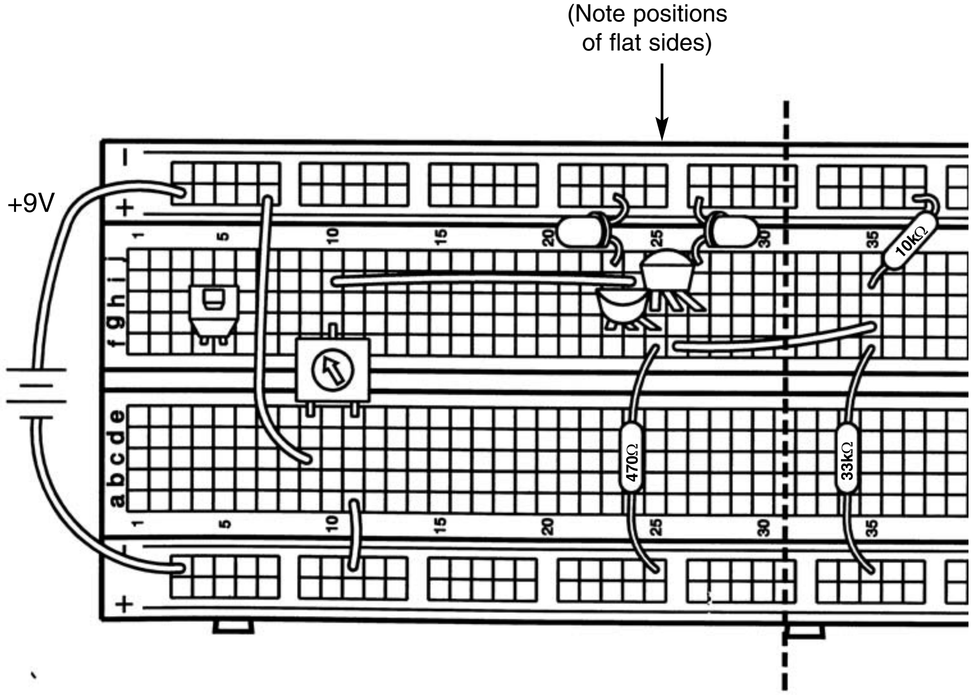
$$V_{Calculated} = \frac{R_{Lower}}{R_{Upper} + R_{Lower}} \times V_{Battery} = \frac{33k\Omega}{10k\Omega + 33k\Omega} \times 9V = 6.9V$$

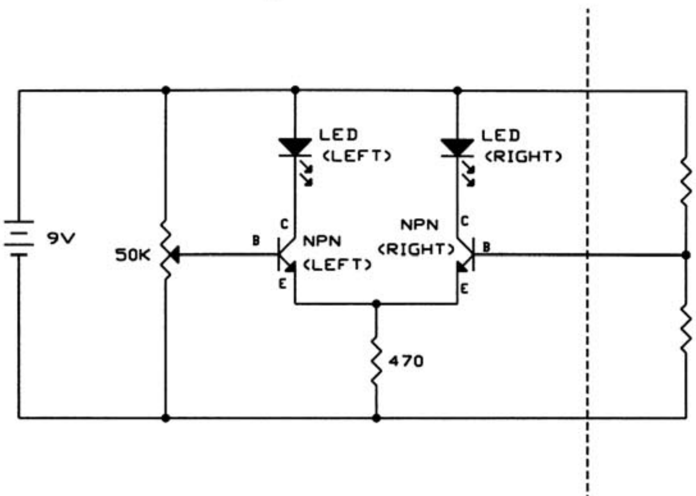
This circuit is a form of the **Differential Pair** transistor configuration, which is widely used in integrated circuits. If the transistor base voltages are equal then the currents through the LEDs and collectors will also be equal. If one base voltage is higher than the other then that transistor will have more current flowing through it's collector and associated LED.

You can now replace the two resistors on the right with a different combination and make a new voltage measurement. The table below lists different combinations of your PK-101 resistors that you can measure, but you don't have to measure them all. In some combinations resistors are placed in series or parallel to create new values.

Remember to disconnect the battery when you're not using the circuit to avoid draining the battery.

Upper Resistor	Lower Resistor	Measured Voltage	Calculated Voltage
10kΩ	33kΩ		6.9V
33kΩ	10kΩ		2.1
33kΩ	100kΩ		6.8
100kΩ	33kΩ		2.2
3.3kΩ	10kΩ		6.8
10kΩ	3.3kΩ		2.2
1kΩ	3.3kΩ		6.90
3.3kΩ	1kΩ		2.1
10kΩ	parallel 33kΩ, 100kΩ		6.4V
parallel 33kΩ, 100kΩ	10kΩ		2.6V
series 10kΩ, 33kΩ	100kΩ		6.3
100kΩ	series 10kΩ, 33kΩ		2.7
1kΩ	parallel 3.3kΩ, 10kΩ		6.4
parallel 3.3kΩ, 10kΩ	1kΩ		2.6
series 1kΩ, 3.3kΩ	10kΩ		6.3
10kΩ	series 1kΩ, 3.3kΩ		2.7


(Note positions
of flat sides)
+9V
10kΩ
470Ω
33kΩ
a b c d e
f g h i j


LED
(LEFT)
LED
(RIGHT)
10K
9V
50K
NPN
(LEFT)
NPN
(RIGHT)
33K
470

EXPERIMENT #23: 1.5 VOLT BATTERY TESTER

Make sure you have a strong 9V battery for this experiment. Connect the circuit, and connect the battery last since this will turn on the circuit. And be sure to disconnect the battery when you're not using the circuit to avoid draining the battery. This circuit is a variation of the differential pair configuration used in Experiment 22, you will use it to test your 1.5V batteries. Take any 1.5V battery you have (AAA, AA, A, B, C, or D cells) and hold it between the loose wires (the base of the right transistor and ground, be sure to connect to the (+) and (-) battery terminals as shown).

If the right LED is bright and the center LED is off then your 1.5V battery is good, otherwise your 1.5V 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, or if your 9V battery is weak.

This circuit uses two diodes (the left transistor is being used as a diode) to create a voltage reference. The turn-on voltage drops for the diodes are combined to produce a constant voltage of about 1.1V at the base of the center transistor. (We said earlier that a diode turn-on voltage is 0.7V, but it varies slightly depending on the current. In this application the drops will be about 0.55V for each). This is compared to the 1.5V battery voltage at the base of the right transistor, in the same manner as Experiment 21. A strong 1.5V battery will easily exceed 1.1V and only the right transistor and LED will be on, while the center transistor and left LED will be shut off. But if the 1.5V battery is weak then the base voltages will be nearly equal and NPN-center and LED-left will also be on. Diodes are often used to make voltage references like this in electronic circuits.

Remember to disconnect the battery when you're not using the circuit to avoid draining the battery.