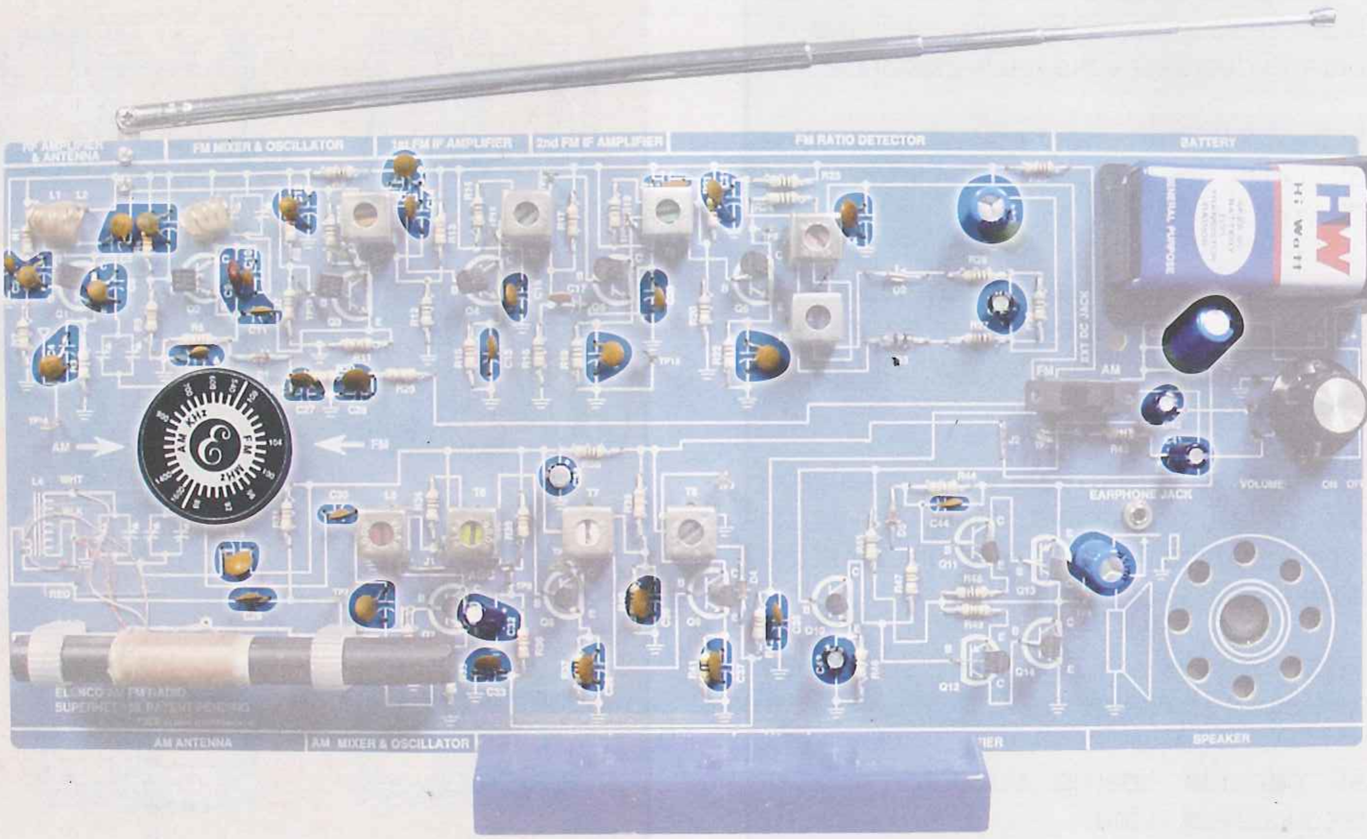
CHAPTER 4: CAPACITORS

Learn By Doing®

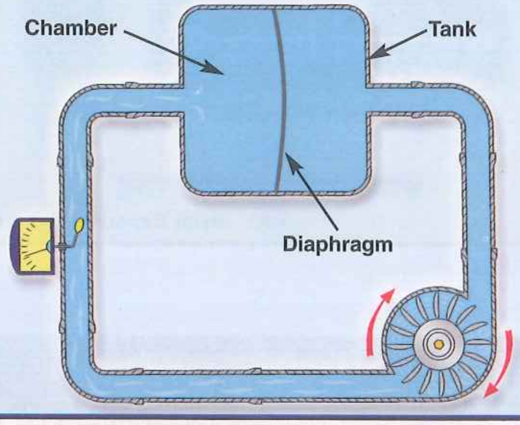
Capacitors are components, which can store electric charge, an ability that makes them useful in many types of circuits. They can delay changes to a circuit, allowing things to happen slowly or in sequence. They are essential to filtering and tuning circuits, and in many electronic products they are the most common component. As an example of how important capacitors are in electronics, consider a typical AM/FM radio (shown below). It contains 41 capacitors, which are highlighted.



In this chapter you will learn about the different types of capacitors, how they work, and how they are used in circuits. It will be fascinating to see how these simple components make electronics work.

4-1 Capacitors

Capacitors are electrical components that can store electricity for periods of time. When a capacitor has a difference in voltage (electrical pressure) across it, it is "**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. A capacitor may be thought of as a water tank that has a strong rubber diaphragm sealing off each side of the tank, as shown below:



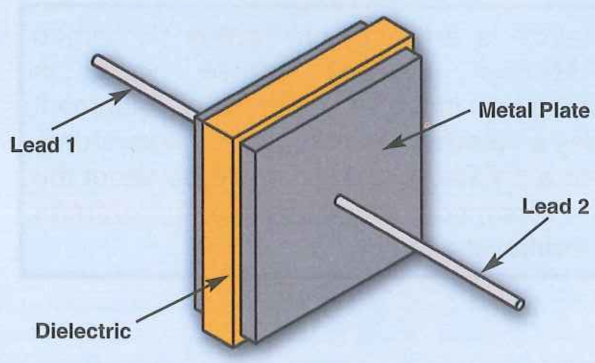
The pipe might have a plunger on one end (or a pump somewhere else in the piping circuit) that pushes water against the diaphragm. The water in the pipe would then force the rubber to stretch out until the force of the rubber pushing back on the water was equal to the force of the plunger. The rubber would be charged and ready to push the plunger back. If the plunger is released the rubber will discharge and move back to its original position, until there is no more pressure on it.

Capacitors act the same as the rubber diaphragm just described. When a voltage (electrical pressure) is placed on one side, electrical charge "piles up" on that side of the capacitor until the voltage pushing back matches the voltage applied. The capacitor is then charged to that voltage. If the charging voltage were 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).

Because of their ability to store electric charge, capacitors can block slow changing voltages and pass fast changing ones. This allows capacitors to isolate parts of a circuit from each other while letting signals move between them.

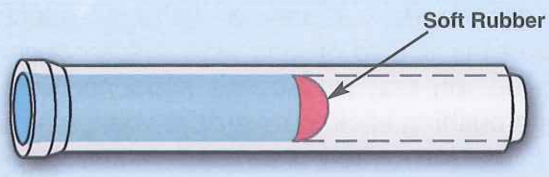
What would happen if the plunger in the drawing above was wiggled in and out many times each second? The water in the pipe would be pushed by the diaphragm and then sucked back by the diaphragm. Since the movement of the water (current) is back and forth (alternating) it is called an alternating current 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.

There are many different types of capacitors made using many different materials, but 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. Dielectric materials include air, paper, mylar, and thin films of oxides.

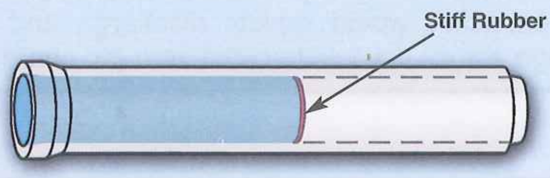


A rubber diaphragm in a pipe could be made with different size and stiffness depending on how much water it was to hold and how much pressure it could handle without bursting.

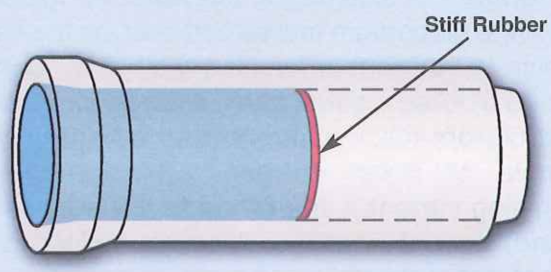
Similarly, capacitors are described for their capacity for holding electric charge, called their capacitance, and their ability to withstand electrical pressure (voltage) without damage. Capacitor characteristics are controlled by varying the number and size of the metal-dielectric layers, the thickness of the dielectric layers, and the type of material used.



Large Capacity, Low Pressure



Low Capacity, but can withstand High Pressure

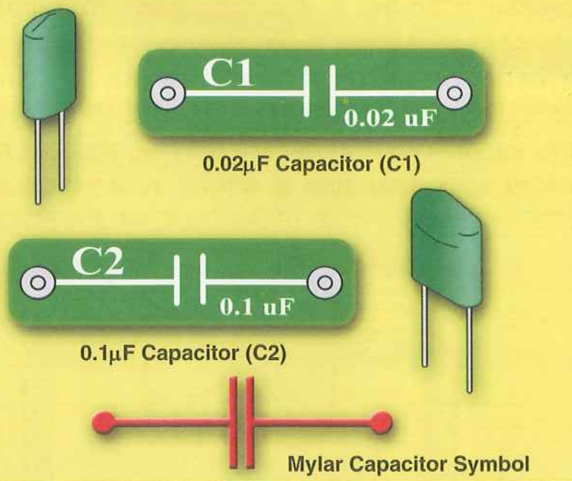


High Capacity and can withstand High Pressure

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). However a 1 Farad capacitor would be about the size of a room, so electronics uses **microfarads** (µF, millionths of a farad).

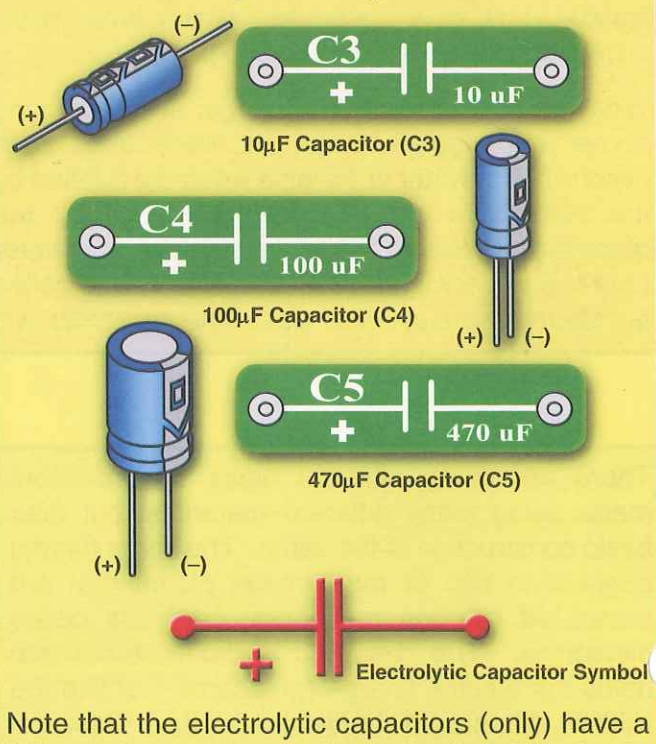
Introducing New Parts

Snap Circuits® includes two mylar or ceramic capacitors (0.02µF and 0.1µF). Take them out and look at them if they are with you.



Introducing New Parts

Snap Circuits® also includes three electrolytic capacitors (10µF, 100µF, and 470µF). These parts use special dielectrics to get high capacitance into a small part. Take them out and look at them if they are with you.

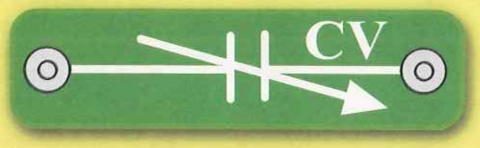


Note that the electrolytic capacitors (only) have a "+" polarity marking on them, the "+" side should always be connected to the higher voltage.

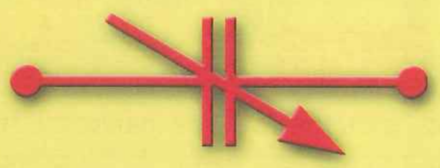
Introducing New Parts

Snap Circuits® also includes one variable capacitor. Take it out and look at it if the parts are with you.

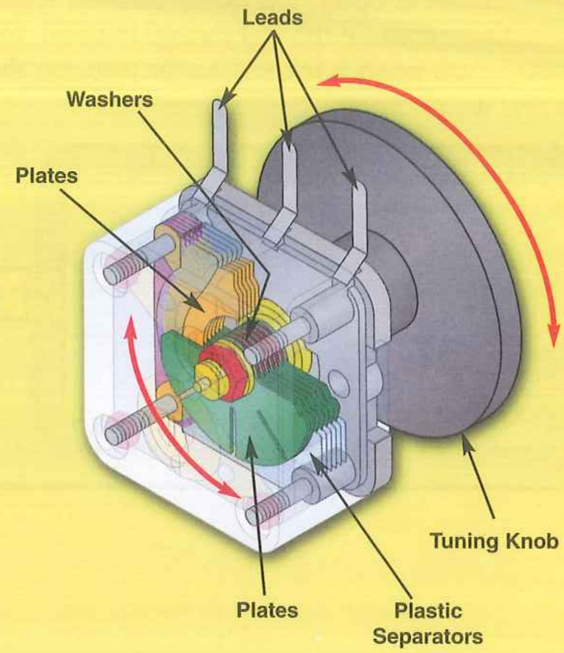
This capacitor has movable plates, so the capacitance can be adjusted between 0.00004 and 0.00022μF. It is only used in high frequency radio circuits for tuning.



Variable Capacitor (CV)



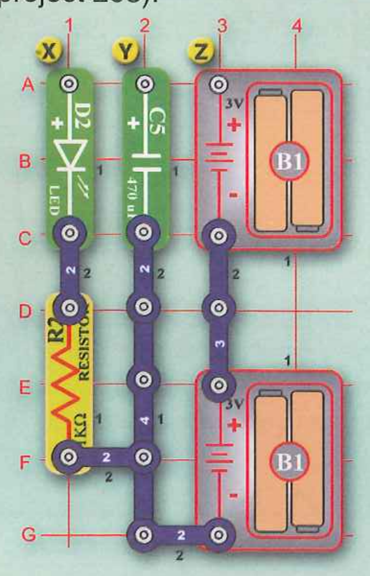
Variable Capacitor Symbol



4-2 Capacitor Circuits

Experiments

With the help of Snap Circuits®, capacitors will be easy to understand. Consider the circuit below (which is project 203).



If points Y and Z in this circuit were connected for a moment, then the 470μF capacitor would be filled up with electricity from the batteries. If points X and Y were then connected (instead of points Y and Z), the green LED would be lit for a few seconds and then go dim. The electricity stored in the capacitor gets discharged, creating a current through the LED and resistor.

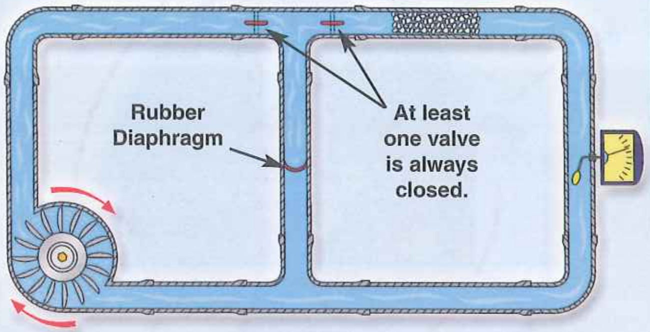
Electricity was stored in the capacitor, and then used to light the LED. Because of this ability, capacitors may be thought of as rechargeable batteries. But capacitors are not very efficient at storing electricity - the 470μF lit the LED for only a few seconds while the batteries are used to run all your projects! That is because capacitors store electrical energy while batteries store chemical energy.

If the 470μF capacitor was replaced with the 100μF capacitor in the preceding circuit (as per project 204), the circuit would work the same way but the LED would go out much faster. Lower value capacitors cannot store as much electrical energy as larger value parts.

If the 1KΩ resistor was replaced with the 100Ω resistor (as per project 205), the LED would get brighter but go out faster. The lower resistance allows a higher current to flow, which discharges the capacitor faster.

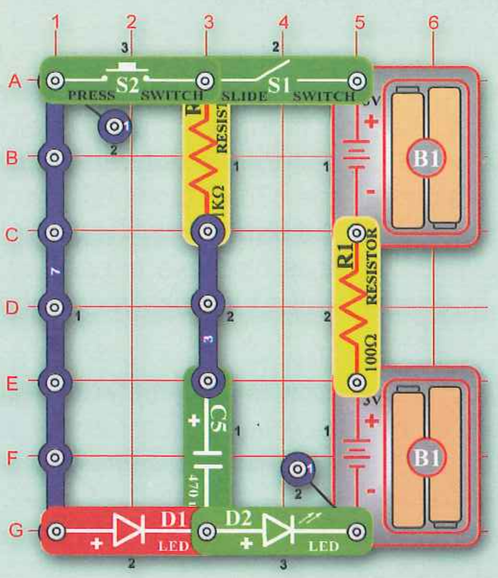
You can also imagine the preceding circuit as if it were water flowing through pipes, as shown.

If the left valve is open, the pump pushes water into the diaphragm. If the right valve is open, the diaphragm will push back the water through the rocks and water meter.



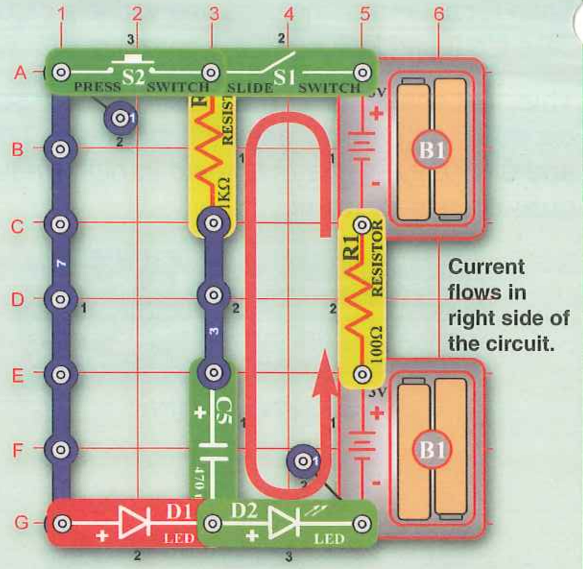
Experiments

As another example, consider this circuit (which is project 235):

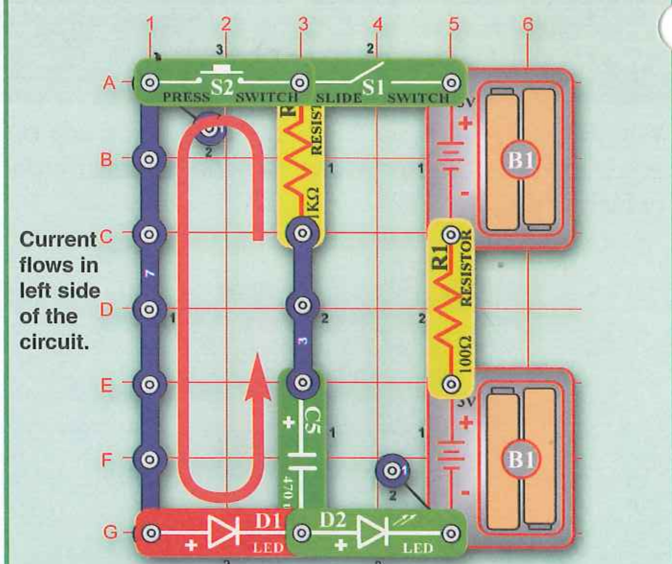


If the slide switch was turned on for a few seconds and then turned off, a current would flow through the right side of the circuit. The green LED would be bright for a moment and then go dim as the capacitor charges up.

Experiments



With both switches off, the capacitor holds its charge but no current flows. If the press switch were pressed, a current would then flow through the left side of the circuit. The red LED would be bright for a moment and then go dim as the capacitor discharges through it.



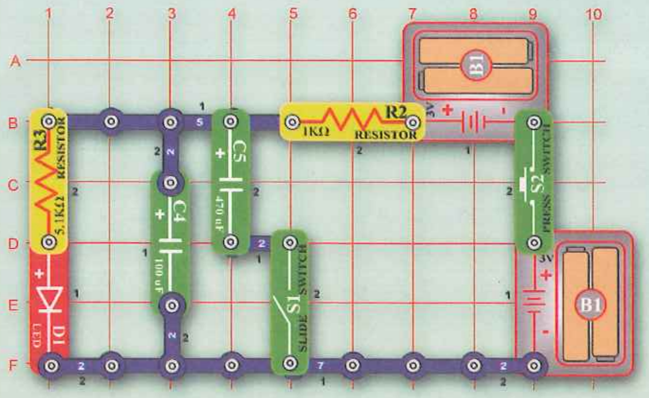
The capacitor value (470μF) sets how much electrical charge can be stored, and the resistor value (1KΩ) sets how quickly that charge can be stored or released.

There is a 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 paths!**

4-3 Capacitors in Series & Parallel

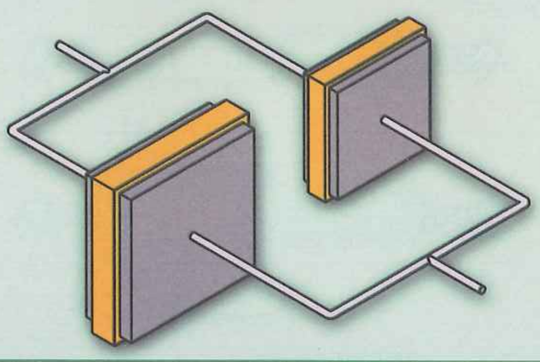
Experiments

Now consider this circuit (which is project 165):

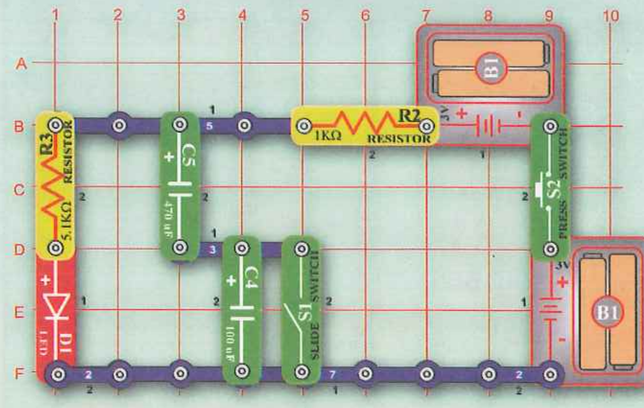


When the press switch is pressed there is a small delay before the LED gets bright, as the capacitor charges up. When the press switch is released there is a delay before the LED goes off, as the capacitor discharges. If the capacitors were removed from this circuit, the LED would be bright whenever the press switch is on. The capacitors slow down this circuit, by delaying the full effects of the press switch.

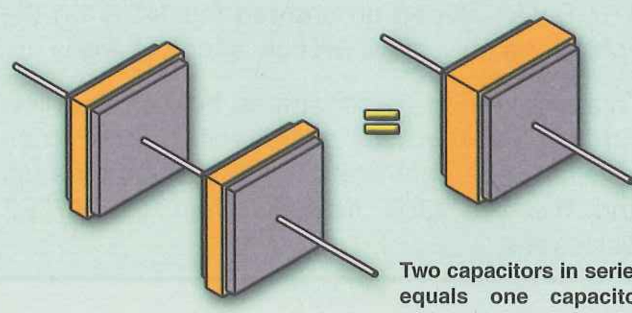
The LED delays will be much longer and easier to see if the slide switch is on, because then the larger 470μF capacitor is also in the circuit. When capacitors are placed in parallel like this, the overall capacitance is increased because there is more room to store electric charge in.



Now consider this circuit (which is project 164):



If the slide switch is off, both capacitors are in the circuit. This circuit is just like the last one except that now the slide switch is used to place the two capacitors in series. When capacitors are in series like this, the overall capacitance is decreased because this is like increasing the dielectric thickness. In terms of water pipes, you could think of capacitors in series as adding together the stiffness of their rubber diaphragms.



Two capacitors in series equals one capacitor with a thicker dielectric.

Notice that how capacitors combine is opposite to how resistors combine. **When parts are placed in series, resistance increases but capacitance decreases. When parts are placed in parallel, resistance decreases but capacitance increases.**

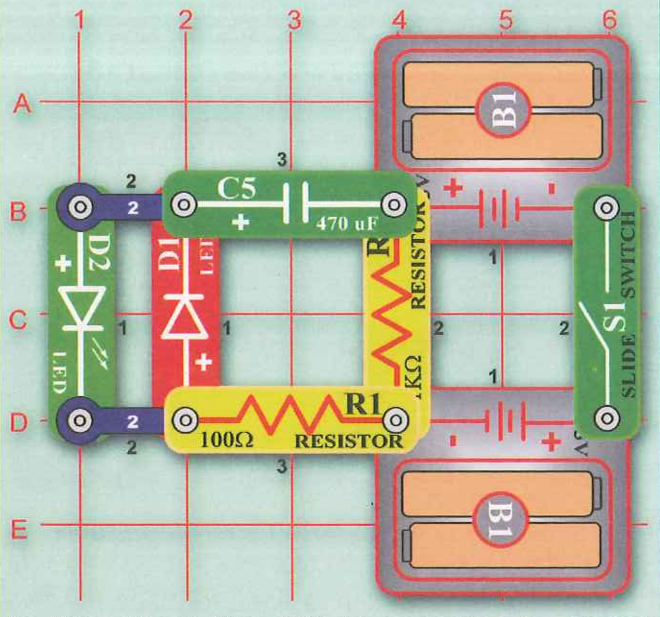
Advanced students can compute the total capacitance as follows:

$$C_{parallel} = C1 + C2 + C3 + \ldots \quad = \frac{1}{C_{Series}} + \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \ldots\ldots$$

For example, a 100μF and a 470μF in parallel act like a 570μF. A 100μF and a 470μF in series act like an 82μF.

Experiments

Now consider this circuit (which is project 296):



In this circuit the 470μF capacitor is placed backwards, its "+" side should normally be towards the higher voltage at the batteries. While the switch is on, current will flow and light the green LED even after the 470μF is charged up. This is because high-value capacitors "leak" when they are placed in a circuit backwards. The lower value parts will leak much less or not at all. If the 470μF was flipped around (so the "+" is on the right), then no current will flow after it charges up.

This circuit also demonstrates how LEDs allow current to flow in only one direction. The green LED flashes bright when the 470μF charges up, and the red LED flashes when the 470μF discharges.

Summary

Summary of Chapter 4:

1. Capacitors are components that can store electricity for periods of time.
2. Capacitance measures how much electrical charge may be stored in a capacitor, and is usually expressed in microfarads (μF).
3. Capacitors block slow changing voltages and pass fast changing ones.
4. Capacitor charge/discharge times are proportional to the resistance and capacitance in the charge/discharge paths.
5. Placing capacitors in series reduces the capacitance, and placing capacitors in parallel increases the capacitance.

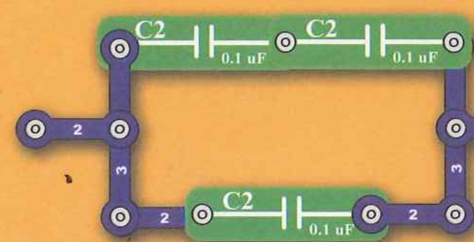
Quiz

Chapter 4 Practice Problems

1. A __________ is charged by having a one-way current flow through it.
   A. Faraday
   B. Capacitor
   C. Resistor
   D. Dielectric
2. Capacitor characteristics are controlled by . . .
   A. the material used.
   B. the number of metal-dielectric layers.
   C. the thickness of the dielectric layers.
   D. all of the above.
3. Which of these sub-circuits will have the highest total capacitance?

A

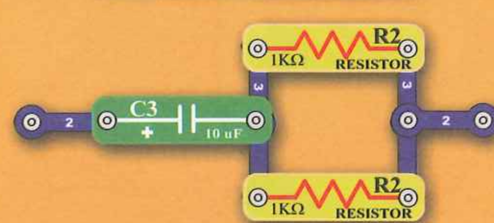

B

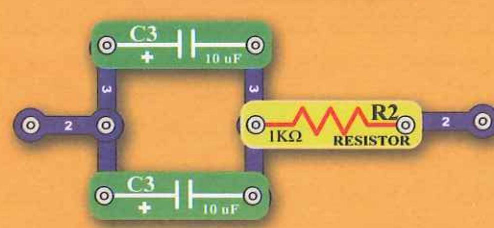

C


D


4. Which of these sub-circuits will charge up the fastest?

A


B


C


D


Answers: 1.B, 2.D, 3.C, 4.B