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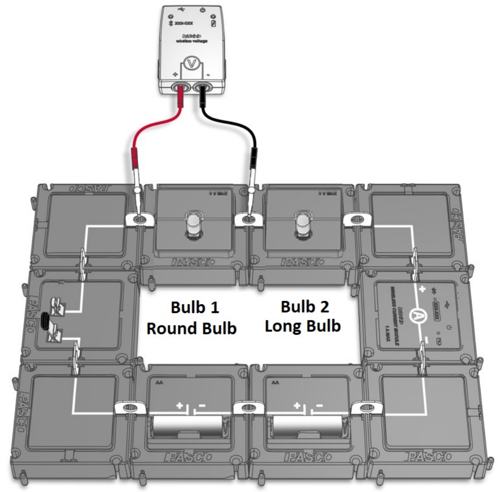
Activity – Understanding Complex Circuits and Capacitors

Part 1a: Essential question: What is power in Series?

What determines how bright a light bulb will light or how much heat a burner will create from electricity? In the previous activity, we found is included factors of Current, Resistance, and Voltage. However, no single of the quantities will determine how bright the light bulb becomes. With large current, but no resistance, comes not light. With large resistance but no potential difference (voltage) comes no current and therefore no light. So, what truly determines the brightness?



1. Begin by creating the circuit shown in the diagram on the right.
2. Close the switch and observe the brightness of each light bulb. Since both bulbs are arranged in series, we know they must have the same current as each other, but which bulb shines brighter?

The long bulb shines brighter.

3. Now, in the table on the right, record the Potential Difference, ΔV, across each bulb and the two batteries with the Voltmeter and the Current, I, through the two light bulbs with the Ammeter. Then, use Ohm's Law: $\Delta V = IR \rightarrow R = \frac{\Delta V}{I}$ to evaluate the resistance of the two light bulbs and equivalent resistance of the circuit (and record that equivalent resistance value in the "Source" column). You will refer to the values from this table in questions found later in this section.

	Bulb 1	Bulb 2	Source
ΔV	0.219 V	1.711 V	2.822 V
I	0.050 A	0.050 A	0.050 A
R	4.38 ohms	34.22 ohms	56.44 ohms
P	0.0109 watts	0.0855 W	0.1411 W

4. Consider the following definitions discussed earlier in this Unit:
   a. **Electric Potential**, V, is defined to be the amount of electric potential energy each charge carries (Energy per Charge). Therefore, the Electric Potential Difference, ΔV, would be the amount of electric potential energy each charge drops across a resistor: $\Delta V = \frac{\Delta U_{el}}{q}$
   b. **Electric Current**, I, is defined to be the amount of charge, q, that passes by a point each second: $I = \frac{q}{\Delta t}$.
   c. **Power** is defined to be the rate in which energy changes, as discussed in AP Physics 1's Unit 4 – Energy. Therefore, Electric Power would be the rate of change of electric potential energy of charges moving through the light bulb: $P = \frac{\Delta U_{el}}{\Delta t}$
5. With these definitions laid out, what algebraic expression could P be expressed in terms of I, and ΔV? Are there alternative versions of this equation if you integrate Ohm's Law into the mix? Once your know this, please calculate the P values and record them in the table above.

P = IV
P = I^2R

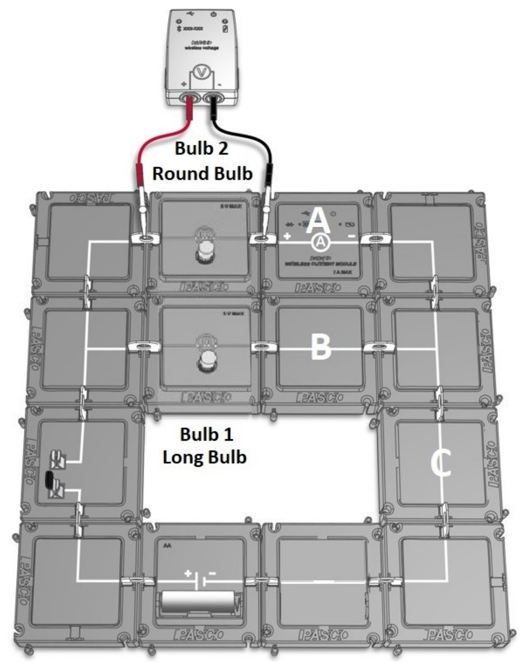
6. If we are claiming that electric potential energy is dropping each time a charge goes through a resistor, then by the law of conservation of energy, that potential energy must be transferred to some other form of energy. In the case of a lightbulb, what type of energy(ies) is this transforming into? With This in mind, which factor is the true contributor to the brightness of a lightbulb?

It is transformed into light and heat energy. The true contributor to the brightness of a lightbulb is the friction from the electrons moving through the resistor. The brightness also depends on the power of the lightbulb, the rate in which energy changes.

Part 1b: Essential question: What is power in Parallel?

1. Create the circuit depicted in the image on the right side, with both a long bulb and round bulb present in the circuit. Please Note: Remove one of your batteries.
2. Close the switch and measure the same quantities as measured in Part 1a. You will need to reposition the ammeter to the locations marked A, B, and C on the diagram to measure the currents of the three positions on the table.
3. Record your values in the table below the image on the right.
4. Evaluate Power for each column using the same principles used on the previous page.
5. Why type of similarities exist between Power in Series and Power in Parallel?

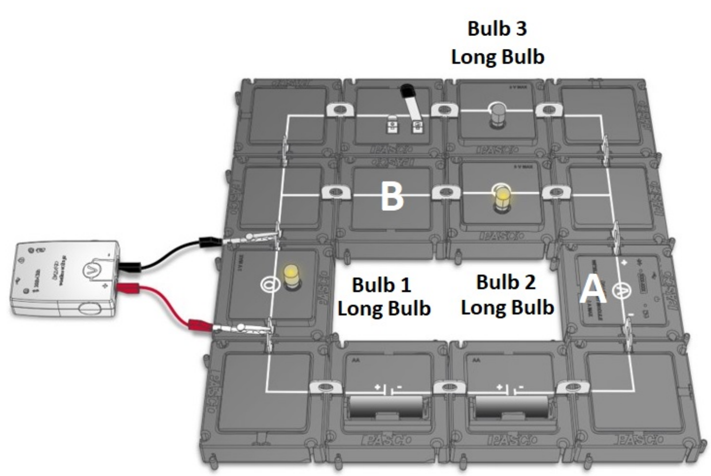
They are both linearly proportional to V, R, and I^2.



	Bulb 1	Bulb 2	Source
ΔV	1.245 V	1.233 V	1.356 V
I	0.046 A	0.092 A	0.141 A
R	27.065 ohms	13.402 ohms	9.617 ohms
P	0.0572 W	0.1134 W	0.1912 W

Part 1c: Essential question: What is power in a Compound Circuit?

A Compound Circuit is a Circuit which exhibits both properties of Series and Parallel. The diagram on the right is an example in which Bulbs 2&3 are parallel to each other, but whose equivalent resistance is in Series to Bulb 1. In other words, no individual charge can go through <u>both</u> Bulbs 2&3. However, any charge that goes through Bulb 1, <u>must</u> go through the Bulb 2&3 parallel system.



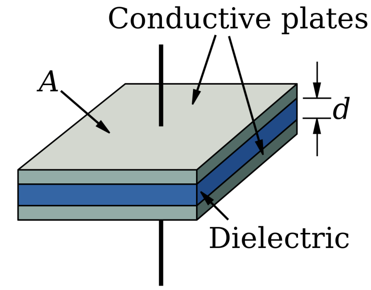
1. Open and close the switch and note the values of each quantity with either circuit. What are some changes that occur when the switch changes from opened to closed? Record your values in the table below and justify your findings with these quantitative measurements.

The values for bulb 1 and the source are approximately the same when the switch is both open and closed, but the values for bulb 2 and bulb 3 are different when the switch is closed versus when it is open. This makes sense as when the switch is closed, the current is able to flow into either branch,

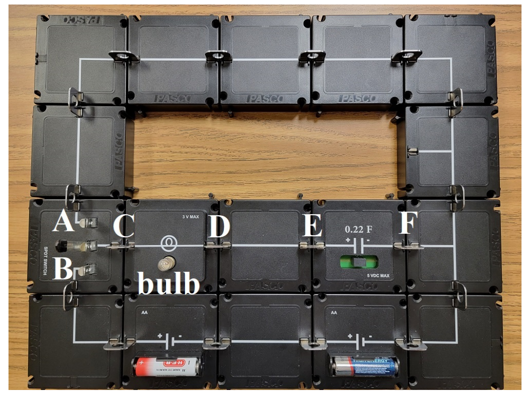
Open Switch	Closed Switch

	Bulb 1	Bulb 2	Bulb 3	Source	Bulb 1	Bulb 2	Bulb 3	Source
ΔV	2.457 V	0.289 V	0.005 V	2.762 V	2.578 V	0.159 V	0.061 V	2.760 V
I	0.062 A	0.053 A	0 A	0.062 A	0.062 A	0.045 A	0.038 A	0.062 A
R	39.629 ohms	5.453 ohms	undefined	44.548 ohms	41.581 ohms	3.533 ohms	1.605 ohms	44.516 ohms
P	0.152 W	0.015 W	0 W	0.171 W	0.160 W	0.001 W	0.002 W	0.171 W

Part 2a: Essential Question: What is a Capacitor?



A capacitor is an electrical device containing 2 parallel conductors that are spaced apart via an insulator. They are usually rolled up into small cylinders to save space, as seen in the diagram to the right. The sole purpose of a capacitor is to store charge within a circuit, so as to provide backup power to electrical components whose power supply has become unavailable (even for a fraction of a second) and modern circuitry simply would not be possible without them. We will try to understand the applications and behaviors of these capacitors in this section.



1. Begin by setting up the circuit depicted in the diagram to the right, using a long bulb in place of the lightbulb and with the 3-way switch placed in the position marked "A".
2. Flip the switch to the position marked "B" and note what happens below:

It lights up and then dims right after.

3. After waiting about 10 seconds, flip the switch back to the position marked "A" and note what happens below:

It lights up but then dims again.

4. Replace the Long Bulb with a Round Bulb and repeat the same two steps above. What are some similarities/differences with what happens now?

It shines brighter but then dims down faster.

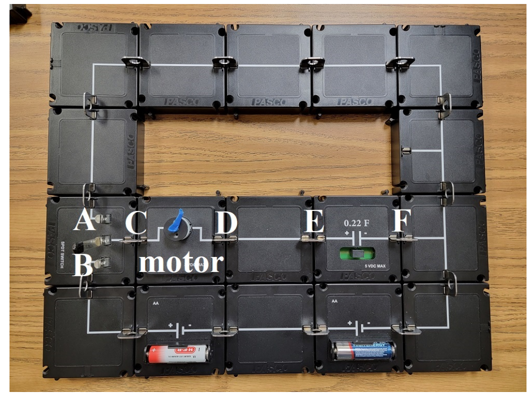
5. Next, use your Voltmeter to record the potential difference of different pairs of points when the switch has been at either position for at least 10 seconds.

Switch at Location A		Switch at Location B	
ΔV_{CD}	ΔV_{EF}	ΔV_{CD}	ΔV_{EF}
Voltage (V) [Digits title here] Run #1 0.008V	Voltage (V) [Digits title here] Run #1 4.733E-4V	Voltage (V) [Digits title here] Run #1 0.001V	Voltage (V) [Digits title here] Run #1 2.876V

6. What do you notice happens to the potential differences of these locations when the switch is held at each location? How do these potential differences compare to that of your two batteries (roughly 3V)?

The voltage decreases as it flows through the circuit when the switch is at location A, but it increases when the switch is at location B. The sum of the voltages when the switch is at location A is less than the total potential given by the battery, but the sum of the voltages when the switch is at location B is approximately equal to the voltage of the battery.

Next, replace the Bulb Module with the Motor Module, as shown in the diagram to the right.



1. Repeat the experiment and note the direction of the motor during the two states. What do you think this indicates about the current through the motor during the two states?

The motor spins clockwise at location B and counterclockwise at location A.

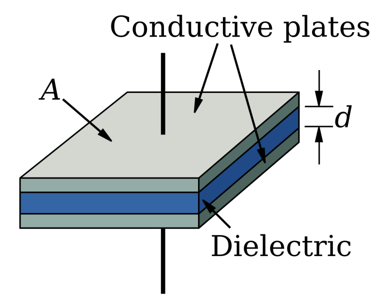
Compare

A balloon is a device that can <u>store air</u>. A student realized that when he inflates the balloon, the air travels to the right through the mouthpiece. He also notices that the rate of airflow through the mouthpiece slows down as the pressure inside of the balloon reaches the pressure of his lungs. But when he removes the balloon from his mouth and lets the air our, the air moves to the left through the mouthpiece, and the rate of airflow through the mouthpiece also slows as the pressure inside the balloon approaches the pressure of the environment. How can the principles of this observation be related to the capacitor?

As a capacitor will run out of potential, the flow will slow down just as it does with the balloon.

What is Capacitance?

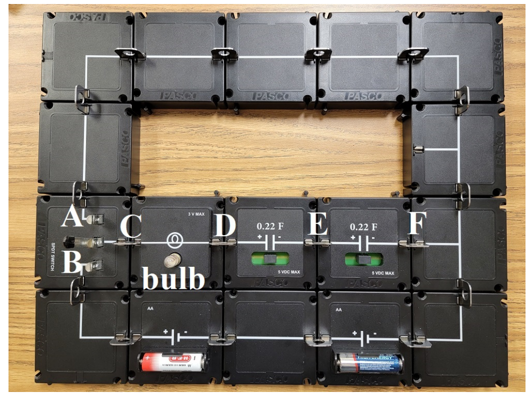
1. Consider the following definitions discussed earlier in this Unit:
   a. **<u>Charge</u>**, Q, is a collection of electrons (or positive charges in the conventional model) that move through a circuit. As an analogy, consider the number of charges to be comparable to the number of air molecules in this classroom.
   b. **<u>Electric Potential</u>**, V, is defined to be the amount of electric potential energy each charge carries (Energy per Charge). However, in this analogy, consider the electric potential as being comparable the "pressure" of the air in this classroom.
   c. **<u>Capacitance</u>**, C, is the amount of "available space" for charges to gather inside a capacitor. In this analogy of this classroom, it would serve as the "size" of the classroom. A "large classroom" does not necessarily have to have more air molecules than a "small classroom", if the pressures (voltage) are not the same.



      i. The capacitance of a capacitor is set at the moment of construction of the capacitor and is dependent upon the area of the plates and distance of separation between them by the equation: $C = \kappa\varepsilon_0 \frac{A}{d}$
      ii. The amount of charge a capacitor can store is directly related to both the size (capacitance) of the capacitor and the electric potential difference (voltage) placed across it: $Q = C\Delta V$
         1. Imagine, if you doubled the pressure (voltage) of this room but kept its size the same, you would double the amount of air stored inside of this room. Alternatively, if you were to double the size of the room and keep the same pressure, you would have double the air molecules due to the Ideal Gas Law.
         2. **<u>Important note</u>**: Applying a difference potential difference across a capacitor **<u>does not</u>** change its capacitance! That would be like saying squeezing air into this classroom would change the "size" of the classroom.
         3. The unit of capacitance is a $\frac{Coulomb}{Volt}$ or a *Farad*.

Part 2b: Capacitors in Series?

Next, replace the Motor Module with the Long Bulb and place a 2nd capacitor in series to the other, as shown in the diagram to the right.



1. Repeat the experiment by flipping the switch between locations A and B again and note any differences to the time the light bulb remains lit when compared to the single capacitor from part 2a.

It is not as bright and it dims much faster.

2. Next, use your Voltmeter to record the potential difference of different pairs of points when the switch has been at either position for at least 10 seconds.

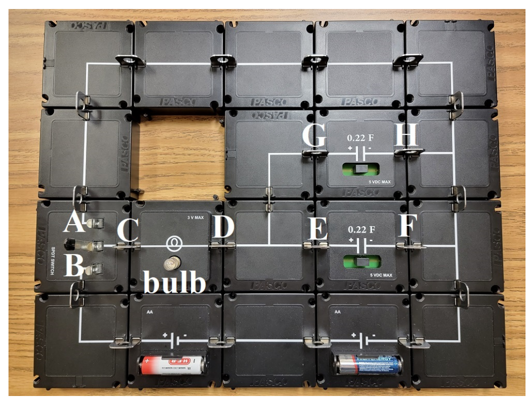
Switch at Location A			Switch at Location B		
ΔV_{CD}	ΔV_{DE}	ΔV_{EF}	ΔV_{CD}	ΔV_{DE}	ΔV_{EF}
0.001V	1.215V	1.212V	-4.733E-4V	2.789V	-0.051V

3. What do you notice happens to the potential differences of these locations when the switch is held at each location? How do these potential differences compare to that of your two batteries (roughly 3V)?

The sum of the voltages is approximately equal to the total voltage given to the circuit by the battery, 3V.

Part 2c: Capacitors in Parallel?

Next, reposition the 2 capacitors to a parallel arrangement as seen in the figure to the right.



1. Repeat the experiment by flipping the switch between locations A and B again and note any differences to the time the light bulb remains lit when compared to the single capacitor from part 2a.

It is still dim but it takes longer to go out fully.

2. Next, use your Voltmeter to record the potential difference of different pairs of points when the switch has been at either position for at least 10 seconds.

Switch at Location A			Switch at Location B		
ΔV_{CD}	ΔV_{EF}	ΔV_{GH}	ΔV_{CD}	ΔV_{EF}	ΔV_{GH}
0.006V	9.466E-4V	2.877V	-9.466E-4V	0.004V	0.004V

3. What do you notice happens to the potential differences of these locations when the switch is held at each location? How do these potential differences compare to that of your two batteries (roughly 3V)?

The potential difference increases. The sum of the potential differences is equal to the total voltage of the battery when the switch is at location A, but it is less than the battery when the switch is at