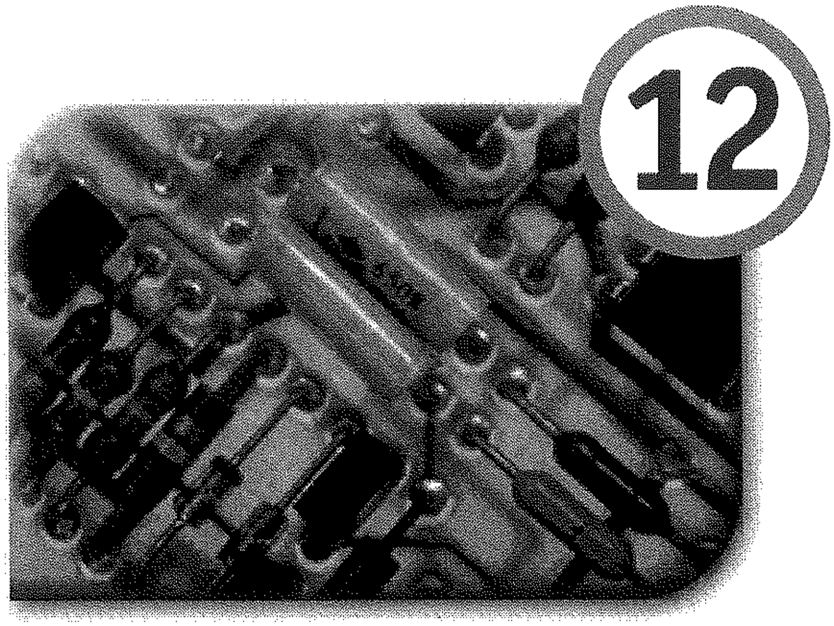


12

dc CIRCUITS

Hints for Using the Electric Circuit Construction Tools

- To add one of the elements to the circuit, click on it in the toolbox. Release the mouse and move the mouse between two dots in the circuit-building area. Then click and the element should appear between the dots.
- To remove an element, click on it.

The simulation has tools on the right side that can be used to construct an electric circuit. The tools, starting at the top, are

The Wire Tool makes a wire.

The Switch Tool produces an open switch. The switch can be closed and opened by clicking on it only while the simulation is running.

The Bulb Tool creates a 1.0-ohm resistance bulb.

The Capacitor Tool has two equally long parallel vertical lines and produces the capacitors used in Activities 12.6 and 12.7.

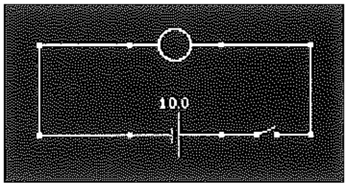
The Battery Tool is a source of potential difference. You can adjust the potential difference (often called voltage) across the battery terminals with a slider.

The Ammeter and Voltmeter Tools create meters that measure the current along a circuit and the potential difference (voltage) across a circuit element, respectively.

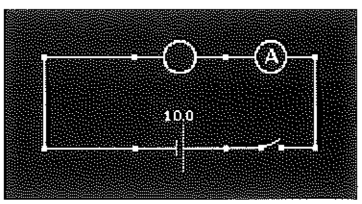
The Grounding Tool has an elbow and can set the electric potential in the circuit to zero at some point of your choice.

The Pointer Tool (an arrow) selects some element to adjust its value. The pointer can also indicate the voltage at different points in a circuit if the circuit is grounded with the Grounding Tool. Just click the pointer down at points in the circuit and the voltage is shown in the bottom-right panel of the simulation screen.

Question 1 First circuit. Consider the circuit as shown below. Adjust the battery voltage across the bulb to 10.0 V and observe the brightness of the bulb. How does the bulb brightness change as the voltage across the bulb is decreased?

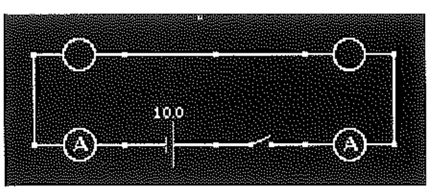


Question 2 Bulb resistance. Adjust the battery voltage and observe the brightness of the bulb and the electric current through the bulb. Complete the following table showing the voltage V across the bulb (for this circuit, the same as the voltage across the battery) and the electric current I passing through the bulb. Use this data to determine the electric resistance R in ohms of the bulb: $R = V/I$.

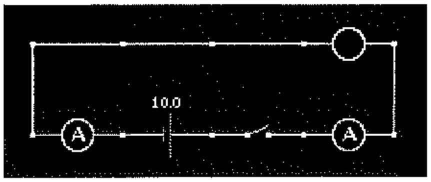


Voltage (V)	10	8	6	4	2	0
Current (A)						

Question 3 Two bulbs in series. Consider the circuit shown below. Which bulb will be brightest when the switch is closed? Add more bulbs in series, and compare the brightnesses of each bulb with others in the circuit. What do your observations tell you?



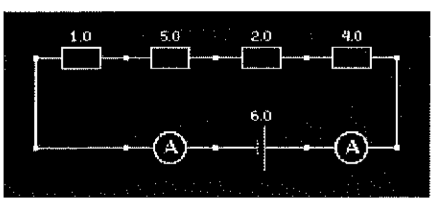
Question 4 Equivalent resistance for series resistors. With the circuit shown below, keep the potential difference across the battery at 10 V. In the table, record the current through the circuit as you replace wires with more 1.0-Ω bulbs in series. Based on your observations, state a rule for the equivalent resistance of a group of series resistive elements (like the bulbs).



Number of bulbs	1	2	3	4
Current (A)				

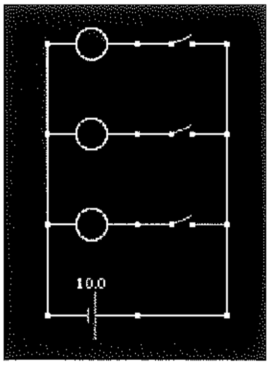
The **equivalent resistance** of the bulbs is $R_{eq} = V / I$ where V is the potential difference across all of the resistive elements (the bulbs in this case) and I is the current through them. A single resistor with this equivalent resistance would have the same current passing through it if the same potential difference was placed across it.

Question 5 More series resistors. Use the idea for the equivalent resistance of series resistors to predict the current through the circuit shown below for different potential differences across the resistors. The resistors in this case have different resistances. You will have to adjust the resistances in the simulation.

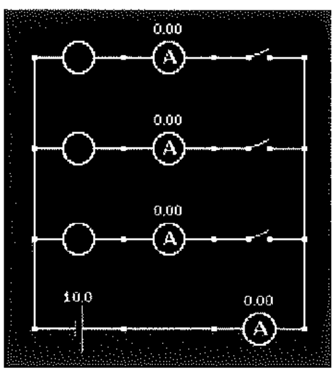


Voltage (V)	10	5	0
Current (A)			

Question 1 Parallel bulbs. With one switch closed, note the brightness of the bulb. How will the brightness of that bulb change if the switch for the second bulb is closed? Compare their brightnesses. How will the brightnesses of the two lower bulbs change if the switch for the third bulb is closed? How do the brightnesses of the three bulbs compare?



Question 2 Current through different branches.



Predict the current through all ammeters when the switch for the lowest bulb is closed. After your prediction, close the switch to see how you did.

Predict the current through all the ammeters when the switches for the two lowest bulbs are closed. After your prediction, close the switches to see how you did.

Finally, predict the current through all the ammeters when the switches for all three bulbs are closed. After your prediction, close the switches to see how you did.

Question 3 Junction rule.

Turn on the switch for the lowest bulb. Look at the two middle junctions along the right side of the circuit (middle two dots on the right side of the circuit), How does the current flowing into each junction compare to the current flowing out of each junction?

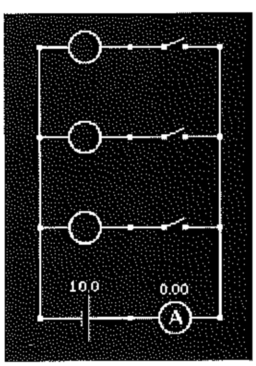
Turn on the switches for the two lowest bulbs. How does the current flowing into each of the middle two junctions on the right side of the circuit compare to the current flowing out of each of these junctions?

Turn on the switches for all three bulbs. How does the current flowing into each of the middle two junctions on the right side of the circuit compare to the current flowing out of each of these junctions?

Question 3 Junction rule continued.

Write a general rule that seems to be consistent with your observations for the two junctions just analyzed.

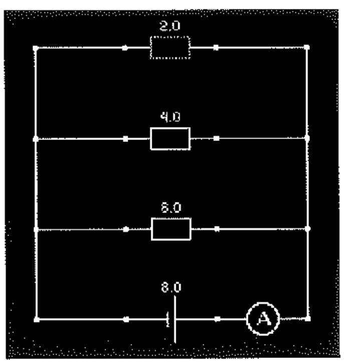
Question 4 Equivalent resistance of parallel resistors. Complete the following table, which shows the current through the 5.0-V battery when placed in parallel across one or more 1.0-Ω bulbs. Use these numbers to write an equation for the equivalent resistance of the parallel resistors. In general equivalent resistance is defined as $R_{eq} = V / I$ where V is the voltage across the resistors and I is the total current flowing through them.



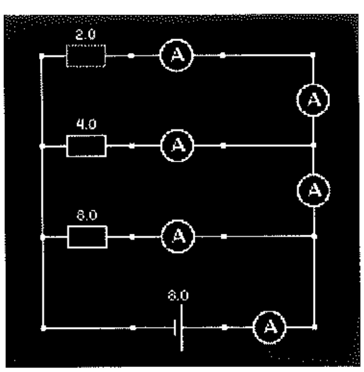
Bulbs in circuit	1	2	3
Voltage (V)	10	10	10
Current (A)			
$R_{equivalent}$ (Ω)			

Question 5 The battery—a constant current source or a constant voltage source? Based on your observations in this and the previous activity, would you say that the battery is a constant potential difference (constant voltage) source or a constant current source? Provide an example to support your choice.

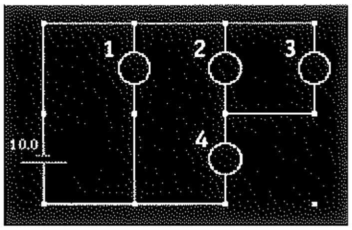
Question 6 Using the equivalent resistance and junction rules. Apply the equivalent resistance rule you developed in Question 4 to predict the total current through the circuit shown below.



Question 7 Junction rule. Is the junction rule consistent with the current readings for the circuit shown here? Provide two examples.



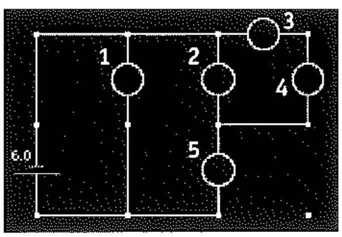
Puzzle 1 Rate the bulbs in this circuit according to brightness, listing the brightest bulb first. Indicate whether any bulbs are equally bright.



_______ _______ _______ _______

Brightest Dimmest

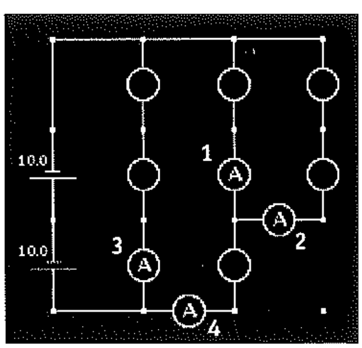
Puzzle 2 Rate the bulbs in this circuit according to brightness, listing the brightest bulb first. Indicate whether any bulbs are equally bright.



_______ _______ _______ _______ _______

Brightest Dimmest

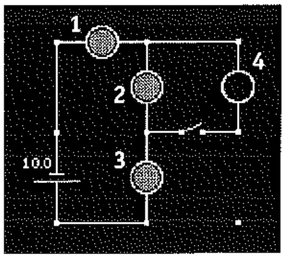
Puzzle 3 Rate the ammeters in this circuit according to current flowing through them, the largest current ammeter first. The ammeters have zero resistance. Indicate whether any currents are equal. (**Hint.** It might be easier to visualize the circuit if you redraw it without the ammeters.)



_______ _______ _______ _______

Largest Smallest

Puzzle 4 When the switch is open, three bulbs shine with equal brightness. Indicate how the brightness of each bulb changes when the switch is closed. Justify your choices.

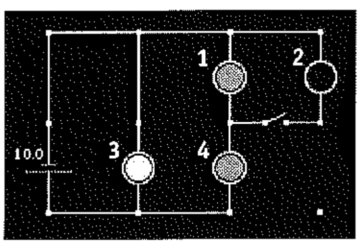


Bulb 1: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer

Bulb 2: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer

Bulb 3: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer

Puzzle 5 Indicate how the brightness of each bulb changes when the switch is closed. Justify your choices.



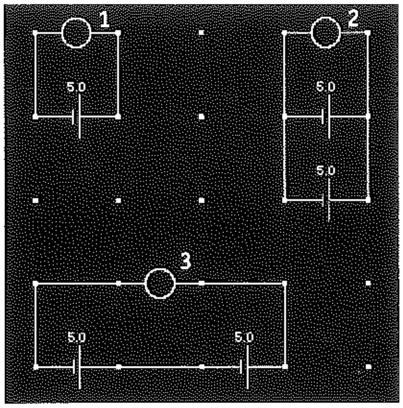
Bulb 1: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer
Explanation:

Bulb 2: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer
Explanation:

Bulb 3: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer
Explanation:

Bulb 4: _______ Becomes brighter
_______ Remains same
_______ Becomes dimmer
Explanation:

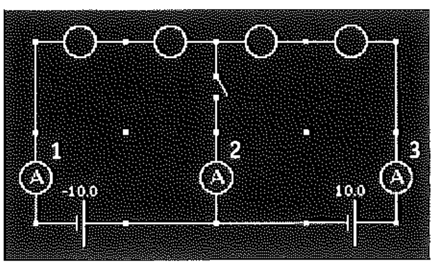
Puzzle 6 Three separate circuits each have one bulb. Rate the circuits according to the brightness of the bulb in the circuit, listing the brightest bulb circuit first. Indicate whether any bulbs are equally bright.



_______ _______ _______

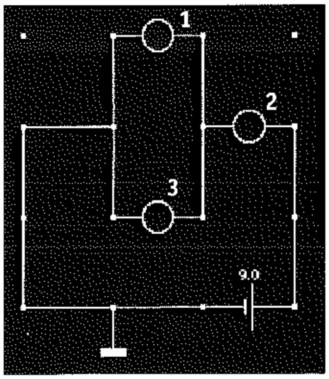
Brightest Dimmest

Puzzle 7 (a) Determine the current in each ammeter and the relative brightness of the four 1-Ω bulbs when the switch is open. Be sure to note that the left battery has a potential difference of –10 V.



(b) Determine the current in each ammeter and the relative brightness of the four 2-Ω bulbs when the switch is closed. Note that the left battery has a potential difference of –10 V.

Puzzle 8 (a) Rate the relative brightnesses of the 1-Ω bulbs.

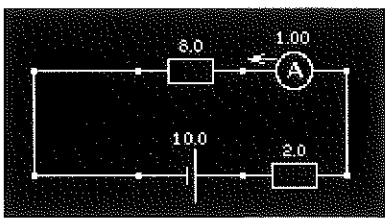


(b) Determine the voltage at each point in the circuit. The circuit is grounded (zero volts) on the left side of the battery.

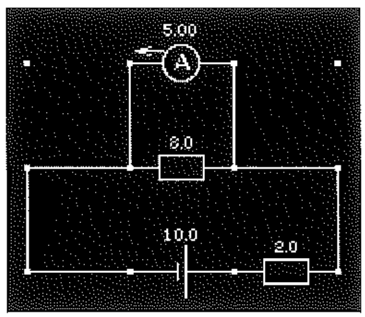
Measuring Electric Current with an Ammeter

- An ammeter measures the flow of electric charge.
- To measure the current in a branch of a circuit, it must be inserted in series into the circuit branch so that all of the current passing through that branch must also pass through the ammeter.
- If inserted in the branch of a circuit through which we want to measure the electric current, the ammeter must not affect that current flow. Consequently, the ammeter has very low electric resistance (ideally, zero resistance).
- Both the correct and incorrect ways to insert the ammeter in the circuit are shown here. If used as shown on the right, a very large current will flow through the low resistance ammeter and possibly damage it (or blow its fuse).

Correct Ammeter



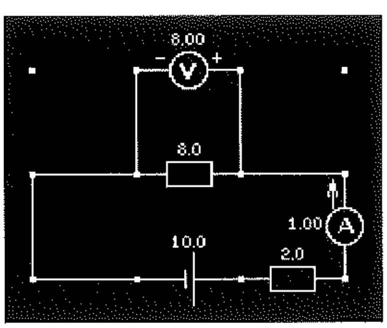
Incorrect Ammeter



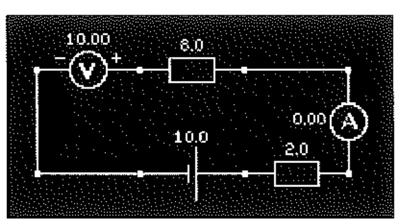
Measuring Potential Difference with a Voltmeter

- A voltmeter measures the potential difference between two points in an electric circuit.
- To measure the potential difference, the voltmeter terminals are touched to the two points. The voltmeter is in parallel with the circuit elements across which the potential difference is being measured.
- If placed in parallel across some part of the circuit, we do not want the voltmeter to provide an alternative path for the circuit's electric current. Consequently, the voltmeter should have somewhat higher electric resistance than the circuit elements across which the terminals are placed—ideally, the voltmeter has infinite resistance.
- Both the correct and incorrect ways to use a voltmeter to measure potential difference are shown here.

Correct Ammeter



Incorrect Ammeter

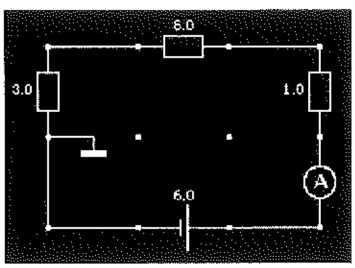


SUMMARY: Kirchhoff's Laws

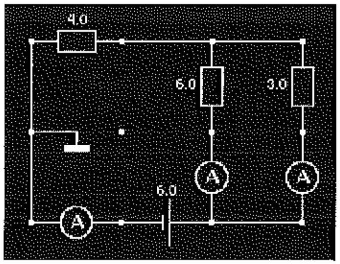
Loop rule. The net change in electric potential (the voltage change) around any closed loop is zero. This is because the electric potential at every point in the circut can have only one value. A charged particle returns to the same electric potential if it returns to the same point in a circuit after a trip around a loop.

Junction rule. The electric current entering any point in a direct-current (dc) electric circuit equals the electric current leaving that point. If this were not true, electric charge would accumulate or dissipate at that point. This happens on capacitor plates but not at dc circuit junctions.

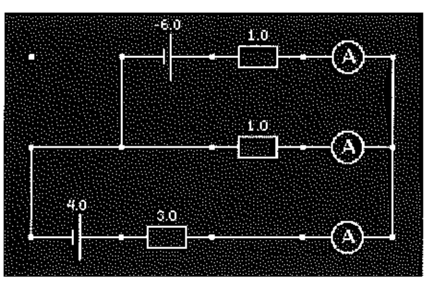
Question 1 The loop rule. (a) Use the loop rule to predict the electric current through the circuit shown below. **(b)** Then, determine the electric potential (voltage) at each point in the circuit.



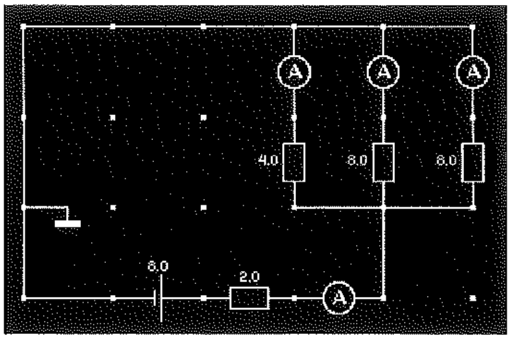
Question 2 (a) Apply the loop rule twice and the junction rule once to get three equations that can be used to determine the ammeter current readings for the circuit shown below. **(b)** Then, determine the electric potential at each point in the circuit.



Question 3 (a) Apply the loop rule twice and the junction rule once. Be sure to note that the top battery produces −6.0 V (the left side is the positive terminal). **(b)** Use the three independent equations developed in part (a) to determine the current in each branch of the circuit.



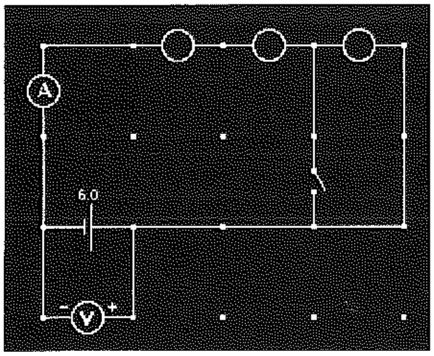
Question 4 The circulatory system. Here, we use a very simple electric circuit as an analog for the heart (the battery) and the vessels in the circulatory system (the resistors). The electron current is the "blood flow."



(a) Predict the equivalent resistance of this circuit. Then calculate the battery current and the current through each resistor. Also, determine the electric potential at every position in the circuit.

(b) Suppose the "person's" aorta (the large vessel that leaves the heart—it has a 2-Ω resistance in our simulation) becomes clogged, causing its resistance to blood flow to quadruple (to 8.0 Ω in the simulation). Now, determine the current flow (blood flow) in the other parts of the circuit.

Question 5 A circuit with three identical bulbs is shown below. Run the simulation with the switch open. Then answer the following questions before closing the switch.



After you have answered the questions, run the simulation and turn the switch on and off to see how you did.

(a) What happens to the brightness of each bulb when the switch is closed?

(b) What happens to the current through the battery when the switch is closed?

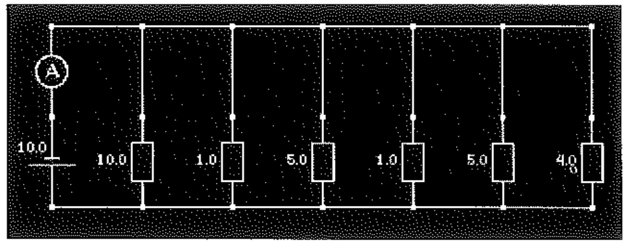
(c) What happens to the potential difference across the battery?

(d) What happens to the total power use of the bulbs when the switch is closed?

Question 6 Blowing a fuse. The circuit shown here is analogous to a line in your home that is connected to a fuse that blows if the current exceeds 25.0 A.

As you prepare dinner, you have the following items connected across a 10-V potential difference:

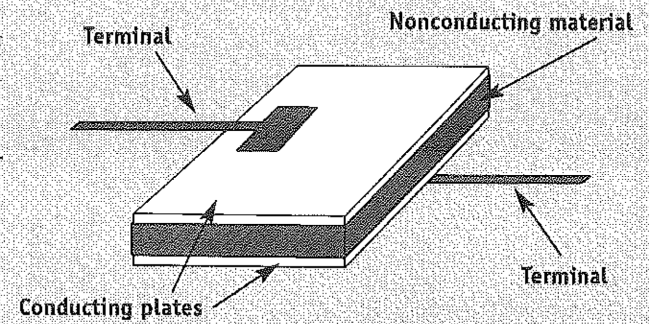
10-Ω light
1-Ω burner
5-Ω mixer
1-Ω oven
5-Ω crock
4-Ω light



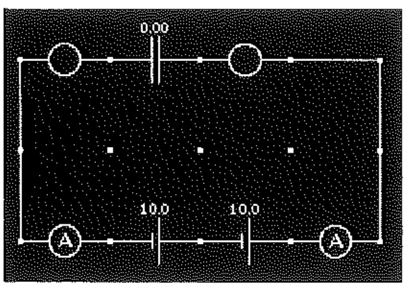
(a) Will you blow the fuse?

(b) If the current does exceed 25 A, remove one or more of the appliances so that the current is 25 A or less but as close to 25 A as possible. Which appliances will you remove?

Capacitance *C* A capacitor consists of two conducting surfaces separated by a nonconducting region. The capacitance C of the capacitor is a measure of its ability to store opposite electric charge ($+q$ and $-q$) on the conducting surfaces when a potential difference V is placed across the surfaces. In particular, $C = q/V$.



Question 1 Capacitor in an electric circuit. Predict how the brightness of each bulb, the current reading in each ammeter, and the voltage across the capacitor change with time as you run the simulation. Remember that the capacitor has two very large metal plates that do not touch. Thus there is a gap in the circuit—the space between the plates. After your predictions, run the simulation.



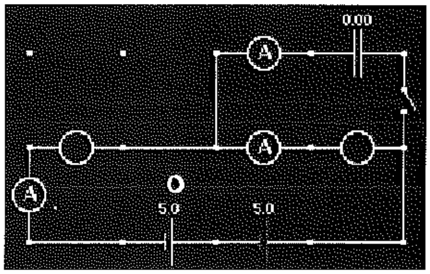
Question 2 Review questions.

(a) Does an open gap between the conducting plates of a capacitor mean that current cannot flow in other parts of the circuit or in that branch of the circuit?

(b) What happens on the capacitor plates when this current flows?

(c) Why does the current flow decrease over time in this particular situation (but not in general)?

Question 3 A capacitor in parallel with a bulb. With the switch open in the circuit below, note in the simulation the ammeter readings and bulb brightnesses for each bulb. If you were to close the switch, there would now be a capacitor in parallel with the bulb on the right (don't close the switch yet).



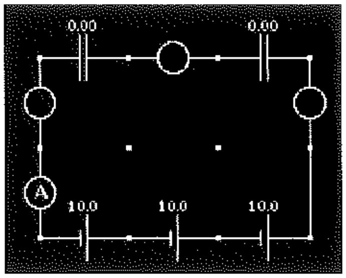
Immediately after closing the switch, would the brightness of the bulb on the right in parallel with the capacitor increase, decrease, or remain the same? Explain.

Immediately after closing the switch, would the brightness of the bulb on the left increase, decrease, or remain the same? Explain.

A long time after closing the switch, predict the relative brightnesses of the bulbs. Explain your reasoning.

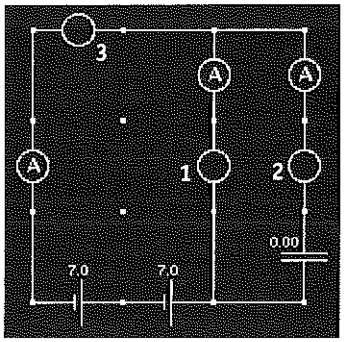
After your preditions, close the switch and see what happens. You may have to open the switch, reset the simulation, and try the experiment again while focusing on one bulb at a time.

Question 4 Bulb between two capacitors. This circuit has three bulbs and two capacitors all in series across a 30-V potential difference (three 10-V batteries in series). Predict what happens to each bulb immediately after the simulation begins to run. Justify your predictions.



Predict what happens to each bulb 10 or 20 s after the simulation starts. Justify your predictions, then run the simulation to check your reasoning.

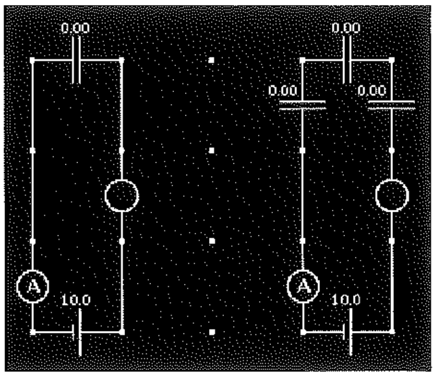
Question 5 Three bulbs and a capacitor. Predict the relative brightnesses of the three bulbs and the approximate voltage across the capacitor shown below immediately after the simulation starts to run. Justify your predictions.



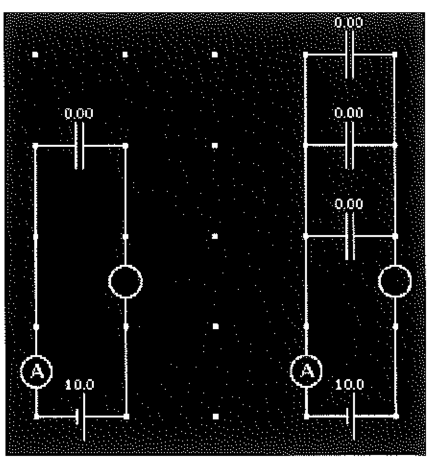
Repeat your predictions, only this time about 3 s after the simulation starts to run. Justify your predictions.

Repeat your predictions, only this time after the simulation has run 10 or 20 s. Justify your predictions.

Question 1 Series capacitors. Run the simulation and decide whether the group of three capacitors in series has more, the same, or less capacitance than the circuit with a single capacitor. All capacitors have the same capacitance, the bulbs the same resistance, and the ammeters zero resistance. Justify your conclusion.

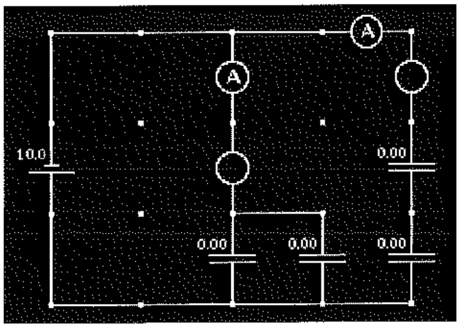


Question 2 Parallel capacitors. Run the simulation and decide whether the group of three capacitors in parallel has more, the same, or less capacitance than the circuit with a single capacitor. All capacitors have the same capacitance, the bulbs the same resistance, and the ammeters zero resistance. Justify your conclusion.



12.7 Series and Parallel Capacitors continued

Question 3 Answer the following questions about the circuit shown below.

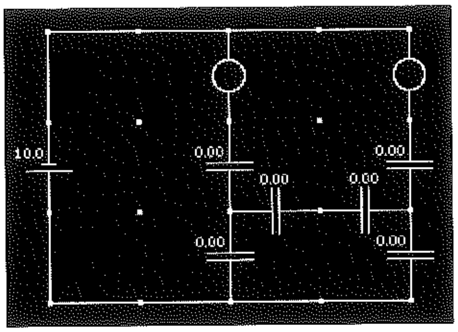


(a) Compare the relative brightness of the two bulbs shortly after the switch is closed. Explain your reasoning.

(b) Compare the relatve brightness of the two bulbs after the capacitors are completely charged. Explain why the brightnesses are as observed.

(c) Determine the potential difference across each capacitor after it becomes fully charged.

Question 4 Answer the following questions about the circuit shown below.

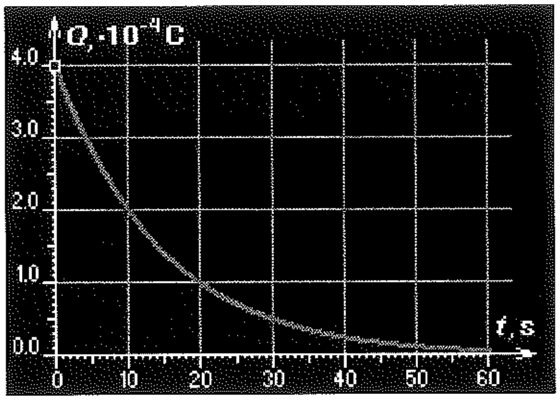


(a) Compare the relative brightness of the two bulbs shortly after the switch is closed.

(b) Compare the relative brightness of the two bulbs after the capacitors are completely charged.

(c) Determine the potential difference across each capacitor after it becomes fully charged.

Question 1 Discharging a capacitor. Set the initial charge on the capacitor to 4.0×10^{-4} C, the resistor resistance to 1.5 MΩ, and the capacitor's capacitance to 9.6 μF. Run the simulation and record the charge on the capacitor each 10 s starting at time zero. State in the form of a rule any systematic variation that you observe in the charge on the capacitor.



Question 2 Effect of *R* and *C* on half-life. With the resistor resistance at 1.5 MΩ and the capacitor's capacitance at 9.6 μF, the half-life for the discharge of the capacitor is 10 s.

(a) Increase the resistance to 3.0 MΩ. Find a value for the capacitance so that the half-life is again 10 s.

(b) Adjust the capacitance again to get a 10-s half-life, only this time with the resistor resistance at 6.0 MΩ.

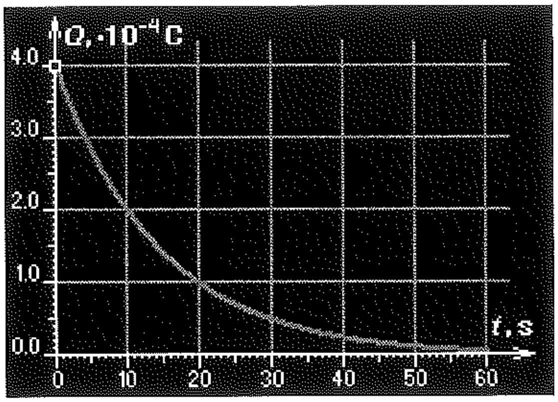
(c) Return the resistance to 3.0 MΩ and the capacitance to 4.8 μF. Increase the resistance and observe the graph. Does the half-life increase or decrease as the resistance increases? If you double the resistance, how does the half-life change?

(d) Return the resistance to 3.0 MΩ and the capacitance to 4.8 μF. Increase the capacitance and observe the graph. Does the half-life increase or decrease when the capacitance increases? If you double the capacitance, how does the half-life change?

(e) Now, write an equation that indicates how the half-life for capacitor discharge depends on the values of the resistance and the capacitance in the *RC* circuit.

(f) Does the half-life depend on the initial charge on the capacitor?

Question 3 Charge and current. Start with an initial charge of 4.0×10^{-4} C, a resistance of 3.0 MΩ, and a capacitance of 4.8 μF. The half-life is 10 s and the equation for the charge on the capacitor as a function of time is $Q = Q_0 e^{-0.693\, t / RC}$. Determine the current ($I = dQ/dt$) through the resistor as a function of time. Then, determine the value of the current at times 0, 10, 20, and 30 s. Run the simulation to check your work.



Question 4 Loop rule during discharge. Start with an initial charge of 4.0×10^{-4} C, a resistance of 3.0 MΩ, and a capacitance of 4.8 μF. In the space below, draw a series *RC* circuit. Assume that the capacitor is initially charged. Use the numbers on the simulation screen to see whether Kirchhoff's loop rule applies to the discharge of this *RC* circuit at times 10, 20, and 30 s after the discharge starts.