Chapter 23
Circuits

Topics:

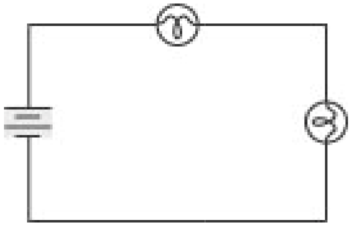
- Circuits containing multiple elements
- Series and parallel combinations
- *RC* circuits
- Electricity in the nervous system

Sample question:

An electric eel can develop a potential difference of over 600 V. How do the cells of the electric eel's body generate such a large potential difference?

Reading Quiz

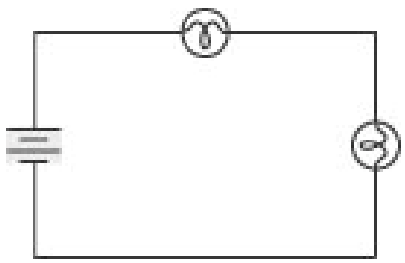
1. The bulbs in the circuit below are connected_________.
   A. in series
   B. in parallel



Answer

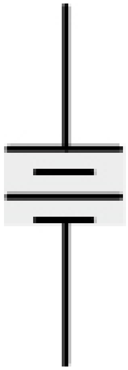
1. The bulbs in the circuit below are connected_________.

   B. in parallel



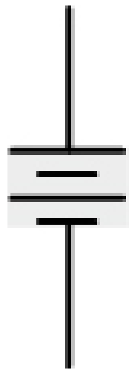
Reading Quiz

2. Which terminal of the battery has a higher potential?
   A. the top terminal
   B. the bottom terminal



Answer

2. Which terminal of the battery has a higher potential?
   A. the top terminal



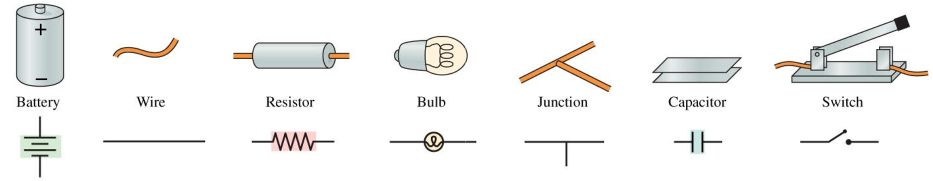
Reading Quiz

3. When three resistors are combined in series the total resistance of the combination is
   A. greater than any of the individual resistance values.
   B. less than any of the individual resistance values.
   C. the average of the individual resistance values.

Answer

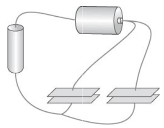
3. When three resistors are combined in series the total resistance of the combination is
   A. greater than any of the individual resistance values.

Drawing Circuit Diagrams

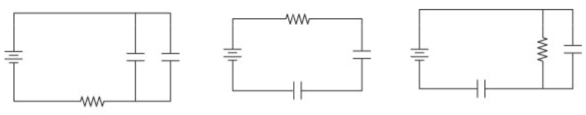


Checking Understanding

The following circuit has a battery, two capacitors and a resistor.

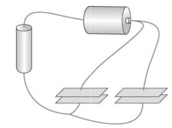


Which of the following circuit diagrams is the best representation of the above circuit?

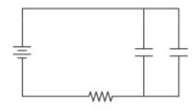


Answer

The following circuit has a battery, two capacitors and a resistor.



Which of the following circuit diagrams is the best representation of the above circuit?



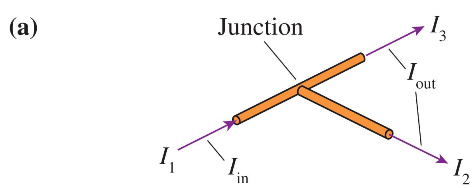
Kirchhoff's Laws

$$\sum I_{in} = \sum I_{out}$$

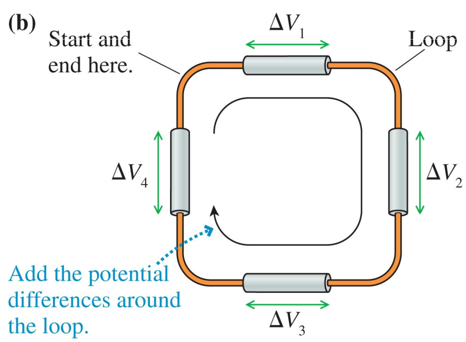
Kirchhoff's junction law

$$\Delta V_{loop} = \sum_i \Delta V_i = 0$$

Kirchhoff's loop law



Junction law: $I_1 = I_2 + I_3$



Loop law: $\Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 = 0$

Using Kirchhoff's Laws

MP **TACTICS BOX 23.1 Using Kirchhoff's loop law** Exercises 5,6

1. **Draw a circuit diagram.** Label all known and unknown quantities.
2. **Assign a direction to the current.** Draw and label a current arrow I to show your choice.
   - If you know the actual current direction, choose that direction.
   - If you don't know the actual current direction, make an educated guess. All that will happen if you choose wrong is that your value for I will end up negative.
3. **"Travel" around the loop.** Start at any point in the circuit, then go all the way around the loop in the direction you assigned to the current in step 2. As you go through each circuit element, ΔV is interpreted to mean

   $$\Delta V = V_{downstream} - V_{upstream}$$

   - For a battery with current in the negative-to-positive direction:

     $$\Delta V_{bat} = +\mathcal{E}$$

   - For a battery in the positive-to-negative direction (i.e., the current is going into the positive terminal of the battery):

     $$\Delta V_{bat} = -\mathcal{E}$$

   - For a resistor:

     $$\Delta V_R = -IR$$

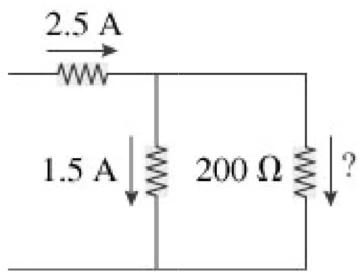
4. **Apply the loop law:**

   $$\sum \Delta V_i = 0$$

Clicker Question

The diagram below shows a segment of a circuit. What is the current in the 200Ω resistor?

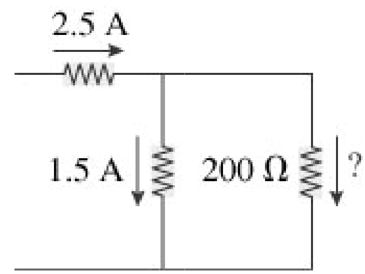
A. 0.5 A
B. 1.0 A
C. 1.5 A
D. 2.0 A
E. There is not enough information to decide.



Answer

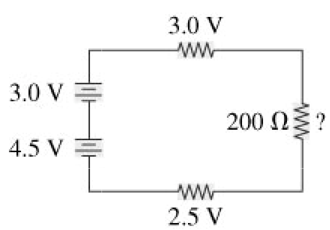
The diagram below shows a segment of a circuit. What is the current in the 200Ω resistor?

B. 1.0 A



Clicker Question

The diagram below shows a circuit with two batteries and three resistors. What is the potential difference across the 200 Ω resistor?

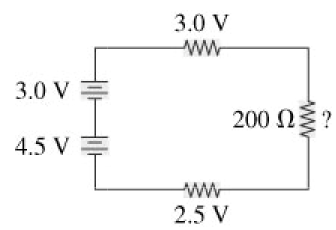


A. 2.0 V
B. 3.0 V
C. 4.5 V
D. 7.5 V
E. There is not enough information to decide.

Answer

The diagram below shows a circuit with two batteries and three resistors. What is the potential difference across the 200 Ω resistor?

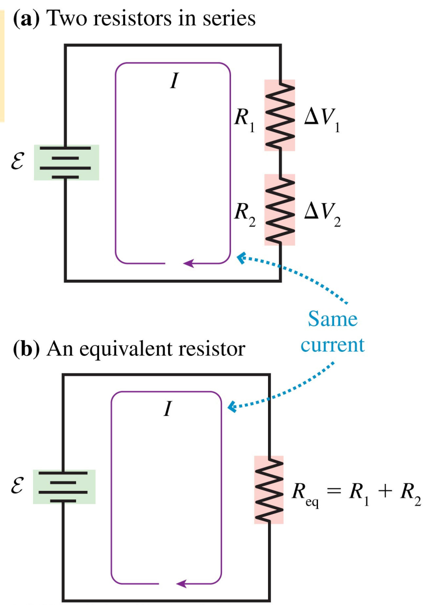
A. 2.0 V



Series Resistors

$$R_{eq} = R_1 + R_2 + \cdots + R_N$$

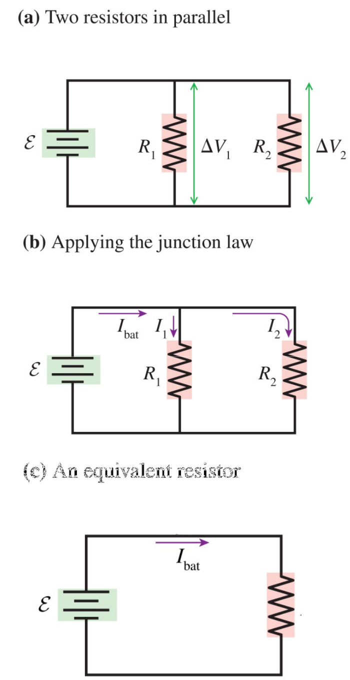
Equivalent resistance of N series resistors



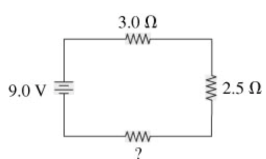
Parallel Resistors

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}\right)^{-1}$$

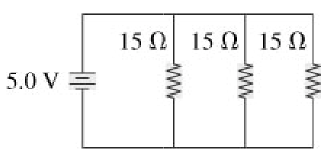
Equivalent resistance of N parallel resistors



There is a current of 1.0 A in the circuit below. What is the resistance of the unknown circuit element?



What is the current out of the battery?



Analyzing Complex Circuits

PROBLEM-SOLVING STRATEGY 23.1 Resistor circuits

PREPARE Draw a circuit diagram. Label all known and unknown quantities.

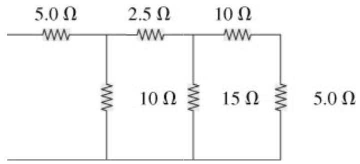
SOLVE Base your mathematical analysis on Kirchhoff's laws and on the rules for series and parallel resistors:

- Step by step, reduce the circuit to the smallest possible number of equivalent resistors.
- Determine the current through and potential difference across the equivalent resistors.
- Rebuild the circuit, using the facts that the current is the same through all resistors in series and the potential difference is the same across all parallel resistors.

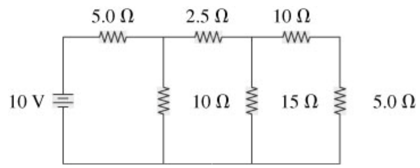
ASSESS Use two important checks as you rebuild the circuit.

- Verify that the sum of the potential differences across series resistors matches ΔV for the equivalent resistor.
- Verify that the sum of the currents through parallel resistors matches I for the equivalent resistor.

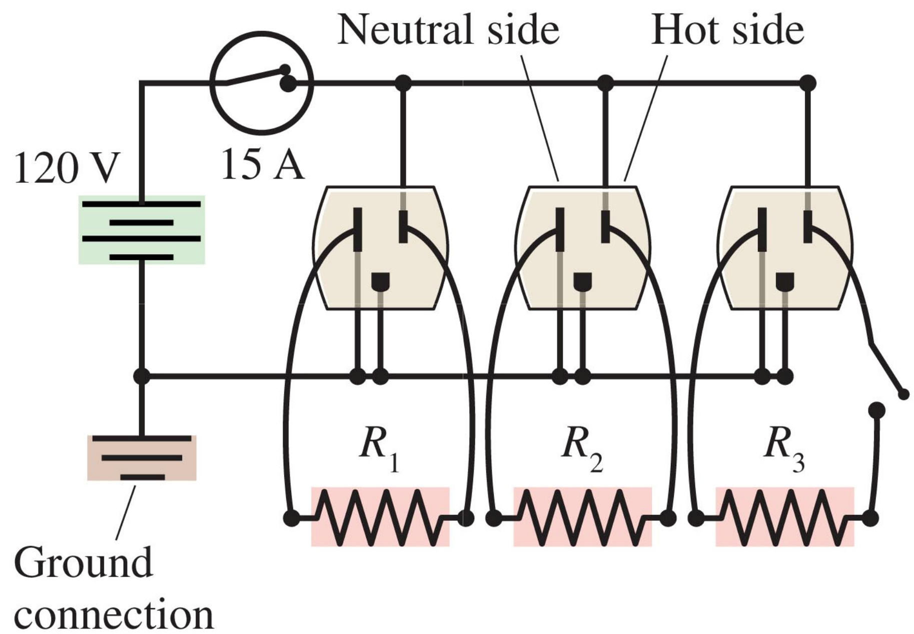
What is the equivalent resistance of the following circuit?



Find the current in and the potential difference across each element in the following circuit.



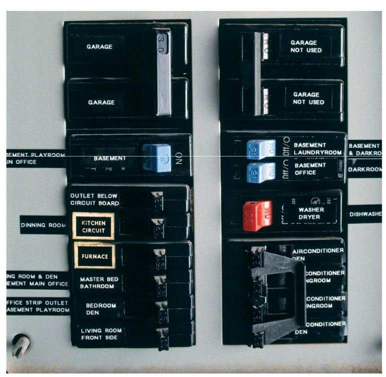
Household Electricity



The following devices are plugged in to outlets on the same 120 V circuit in a house. This circuit is protected with a 15 A circuit breaker.

Device	Power
Computer	250 W
Heater	900 W
Lamp	100 W
Stereo	120 W

Is there too much current in the circuit—does the circuit breaker blow?

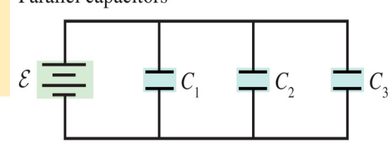


Capacitor Combinations

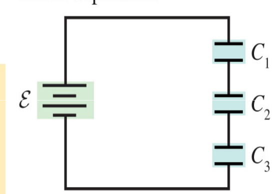
$$C_{eq} = C_1 + C_2 + C_3 + \cdots + C_N$$

Equivalent capacitance of N parallel capacitors

Parallel capacitors



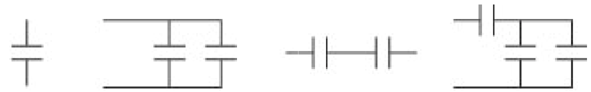
Series capacitors



$$C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_N}\right)^{-1}$$

Equivalent capacitance of N series capacitors

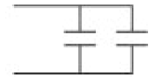
Which of the following combinations of capacitors has the highest capacitance?



A B C D

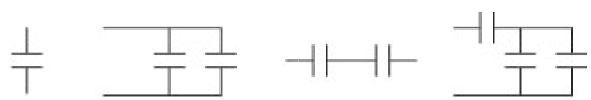
Answer

Which of the following combinations of capacitors has the highest capacitance?



B

Which of the following combinations of capacitors has the lowest capacitance?



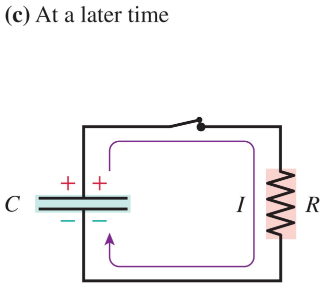
A B C D

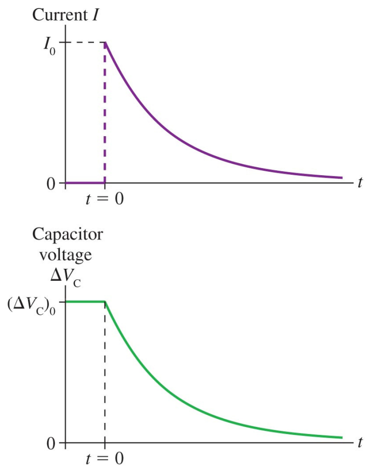
Answer

Which of the following combinations of capacitors has the lowest capacitance?

C

RC Circuits

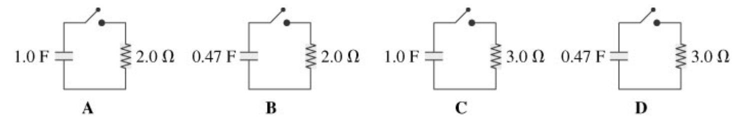




$$\tau = RC$$

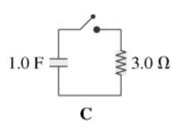
Additional Clicker Questions

The following circuits contain capacitors that are charged to 5.0 V. All of the switches are closed at the same time. After 1 second has passed, which capacitor is charged to the highest voltage?

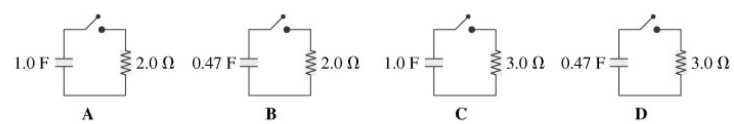


Answer

The following circuits contain capacitors that are charged to 5.0 V. All of the switches are closed at the same time. After 1 second has passed, which capacitor is charged to the highest voltage?

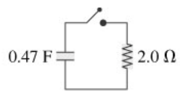


The following circuits contain capacitors that are charged to 5.0 V. All of the switches are closed at the same time. After 1 second has passed, which capacitor is charged to the lowest voltage?



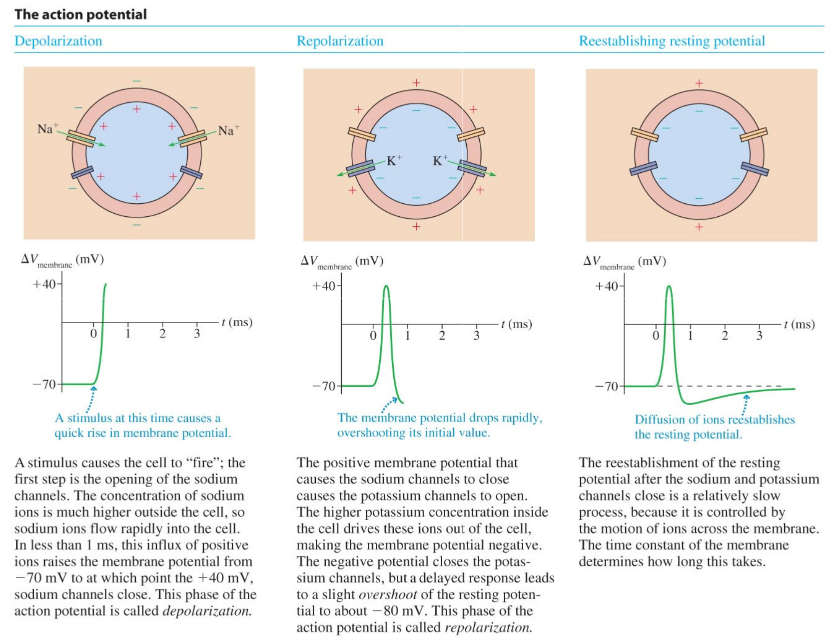
Answer

The following circuits contain capacitors that are charged to 5.0 V. All of the switches are closed at the same time. After 1 second has passed, which capacitor is charged to the lowest voltage?

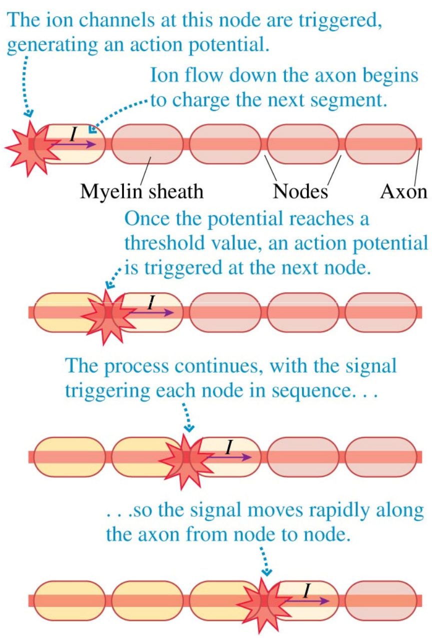


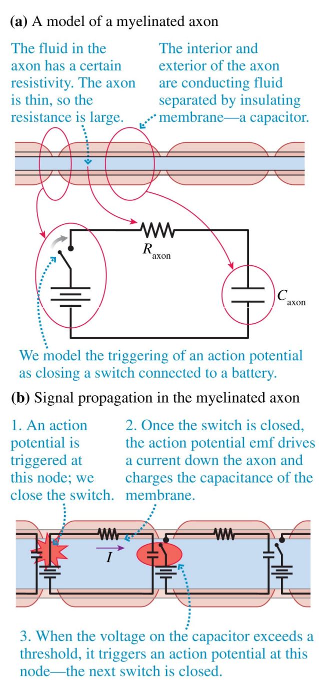
B

Electricity in the Nervous System

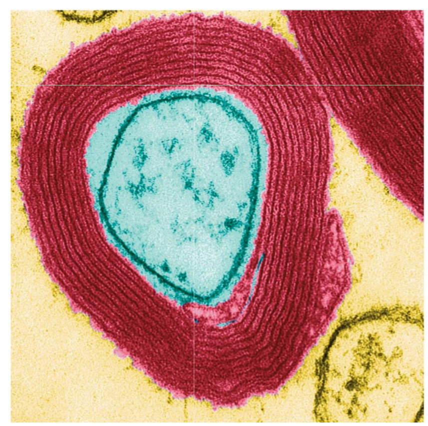


Saltatory Conduction



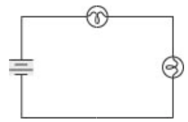


There are some diseases that result in a thinning of the myelin sheath that surrounds peripheral neurons—those that carry signals between the spinal cord and the limbs. How will this thinning affect nerve conduction speed? Explain this using the model for nerve conduction developed in the chapter.



Additional Clicker Questions

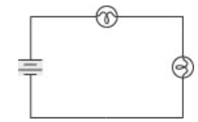
1. In the circuit below, the switch is initially open and bulbs A and B are of equal brightness. When the switch is closed, what happens to the brightness of the two bulbs?



A. The brightness of the bulbs is not affected.
B. Bulb A becomes brighter, bulb B dimmer.
C. Bulb B becomes brighter, bulb A dimmer.
D. Both bulbs become brighter.

Answer

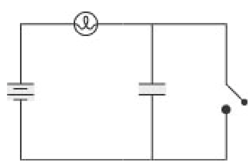
1. In the circuit below, the switch is initially open and bulbs A and B are of equal brightness. When the switch is closed, what happens to the brightness of the two bulbs?



B. Bulb A becomes brighter, bulb B dimmer.

Additional Clicker Questions

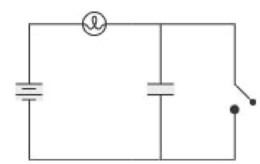
2. In the circuit shown below, the switch is initially closed and the bulb glows brightly. When the switch is opened, what happens to the brightness of the bulb?



A. The brightness of the bulb is not affected.
B. The bulb gets dimmer.
C. The bulb gets brighter.
D. The bulb initially brightens, then dims.
E. The bulb initially dims, then brightens.

Answer

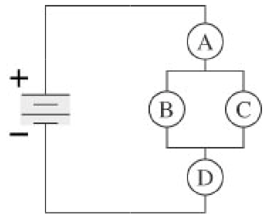
2. In the circuit shown below, the switch is initially closed and the bulb glows brightly. When the switch is opened, what happens to the brightness of the bulb?



B. The bulb gets dimmer.

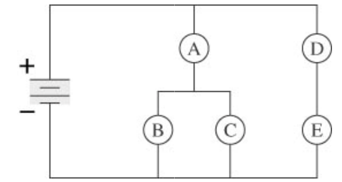
Additional Examples

1. In the circuit shown below:
   A. Rank in order, from most to least bright, the brightness of bulbs A–D. Explain.
   B. Describe what, if anything, happens to the brightness of bulbs A, B, and D if bulb C is removed from its socket. Explain.



Additional Examples

2. In the circuit shown below, rank in order, from most to least bright, the brightness of bulbs A–E. Explain.



Additional Examples

3. In the circuit shown below:
   A. How much power is dissipated by the 12 Ω resistor?
   B. What is the value of the potential at points a, b, c, and d?