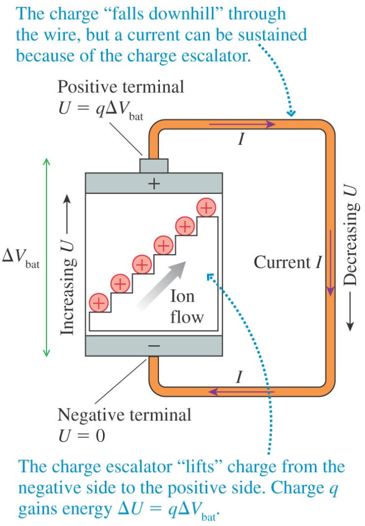
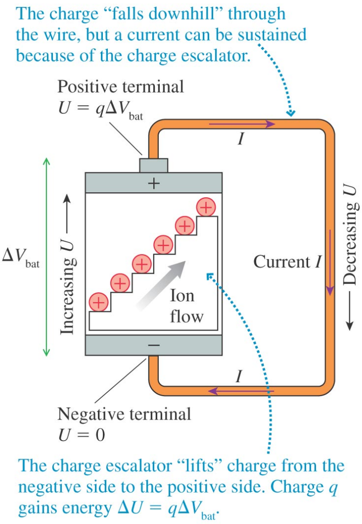
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- A battery is a source of potential. So, it can drive a current through a wire until it runs out of energy (unlike the quick discharge of a capacitor).

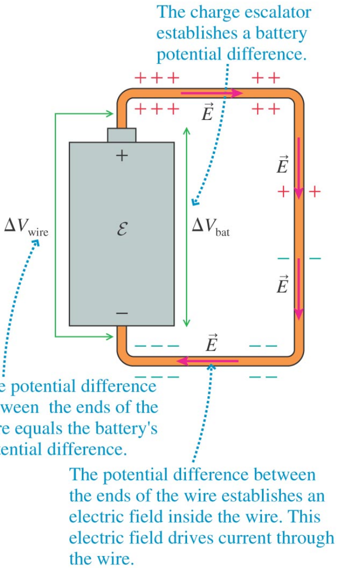
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- A battery is a source of potential. So, it can drive a current through a wire until it runs out of energy (unlike the quick discharge of a capacitor).
- The battery creates a potential difference by lifting postive charges from the negative to positive terminals.

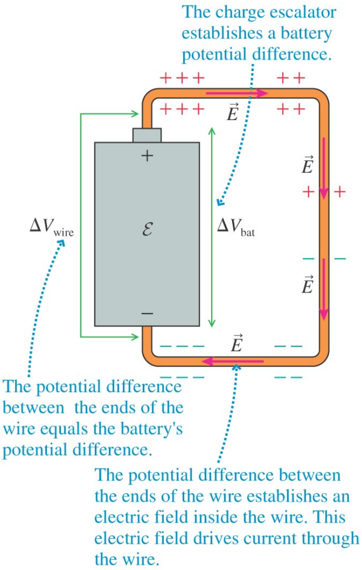
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- The battery creates excess charge on the outside of the wire which creates an internal electric field and drives current through.

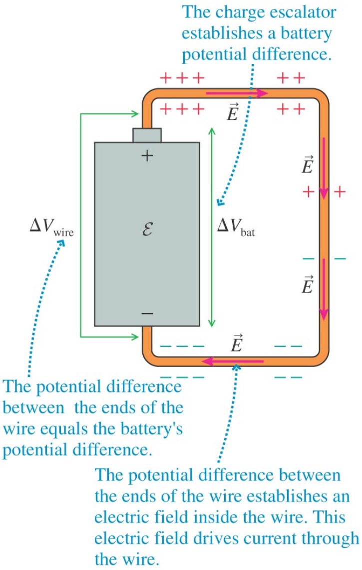
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- The battery creates excess charge on the outside of the wire which creates an internal electric field and drives current through.
- The potential difference is the same no matter what the path. So, the difference across the battery must be the same as across the wire.

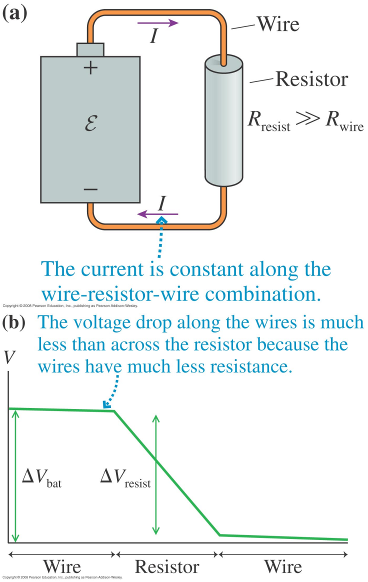
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

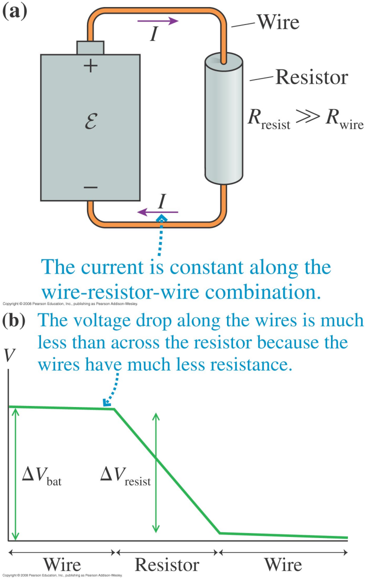
- The battery creates excess charge on the outside of the wire which creates an internal electric field and drives current through.
- The potential difference is the same no matter what the path. So, the difference across the battery must be the same as across the wire.
- The magnitude of the current is determined jointly by the resistance of the battery and the wire.

Batteries and Current



- Current must be conserved, so the *I* in through the resistor is the same as in the wire.

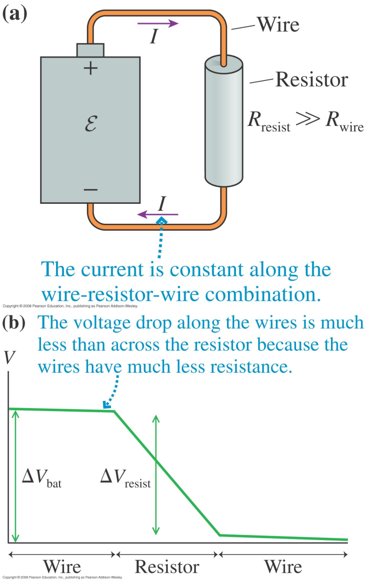
Batteries and Current



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- Current must be conserved, so the I in through the resistor is the same as in the wire.
- However, the resistance of the wire is small compared to the resistor, so the potential difference is much smaller ($\Delta V = IR$)

Batteries and Current



- Current must be conserved, so the I in through the resistor is the same as in the wire.
- However, the resistance of the wire is small compared to the resistor, so the potential difference is much smaller ($\Delta V = IR$)
- For an ideal wire there is no potential difference at all. The only potential drop is across the resistor.

Chapter 32 - Fundamentals of Circuits

- We are finally there! Time to apply our EM knowledge to something practical - electrical circuits.

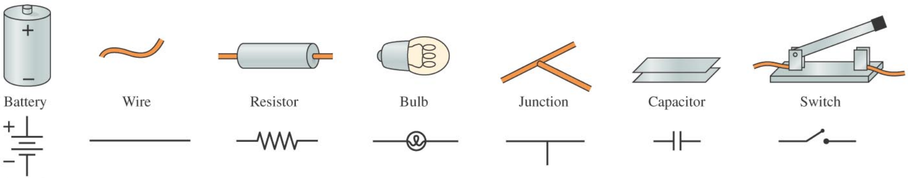
Chapter 32 - Fundamentals of Circuits

- We are finally there! Time to apply our EM knowledge to something practical - electrical circuits.
- This chapter presents circuit analysis - drawing of circuit diagrams and analyzing the current and potential difference across each element.

Chapter 32 - Fundamentals of Circuits

- We are finally there! Time to apply our EM knowledge to something practical - electrical circuits.
- This chapter presents circuit analysis - drawing of circuit diagrams and analyzing the current and potential difference across each element.
- We will also only be talking about DC circuits. In other words, we are talking about circuits with batteries in them providing a constant potential difference (unlike the wall-plug).

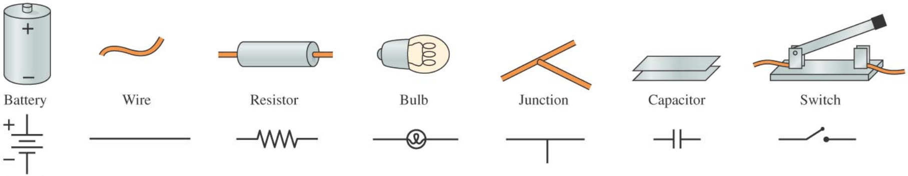
Circuit Elements and Diagrams (32.1)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We generally draw an abstract (logical) picture of a circuit known as a circuit diagram using the symbols above.

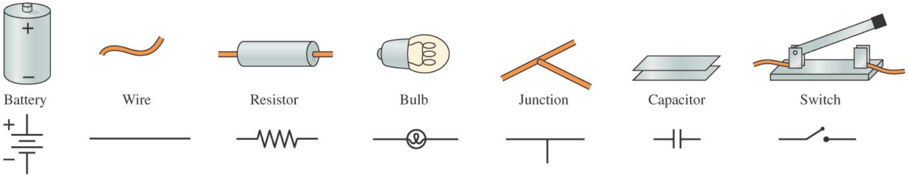
Circuit Elements and Diagrams (32.1)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We generally draw an abstract (logical) picture of a circuit known as a circuit diagram using the symbols above.
- A circuit diagram illustrates the electrical connections in a circuit rather than the physical locations of the circuit elements.

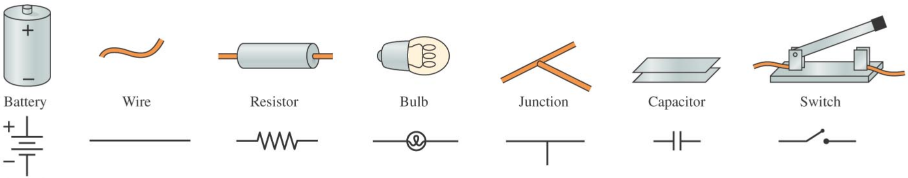
Circuit Elements and Diagrams (32.1)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

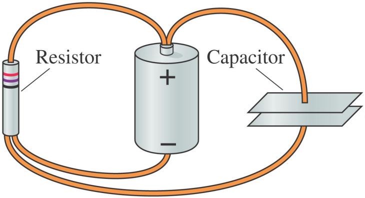
- We generally draw an abstract (logical) picture of a circuit known as a circuit diagram using the symbols above.
- A circuit diagram illustrates the electrical connections in a circuit rather than the physical locations of the circuit elements.

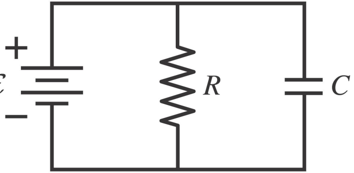
Circuit Elements and Diagrams (32.1)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We generally draw an abstract (logical) picture of a circuit known as a circuit diagram using the symbols above.
- A circuit diagram illustrates the electrical connections in a circuit rather than the physical locations of the circuit elements.





Kirchhoff's Laws and the Basic Circuit(32.2)

- Remember that we have seen two Kirchhoff's Laws already:

Kirchhoff's Laws and the Basic Circuit(32.2)

- Remember that we have seen two Kirchhoff's Laws already:
  1. Kirchhoff's Junction Law says that the total current into a junction must equal the total current leaving it:

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

Kirchhoff's Laws and the Basic Circuit(32.2)

- Remember that we have seen two Kirchhoff's Laws already:
  1. Kirchhoff's Junction Law says that the total current into a junction must equal the total current leaving it:

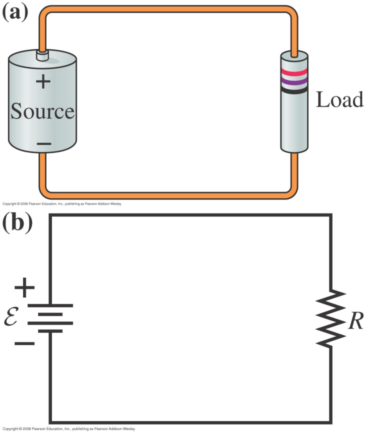
     $$\Sigma I_{in} = \Sigma I_{out}$$

  2. Kirchhoff's Loop Law says that the sum of the potential differences around any closed loop is zero:

     $$\Delta V_{loop} = \Sigma_i (\Delta V)_i = 0$$

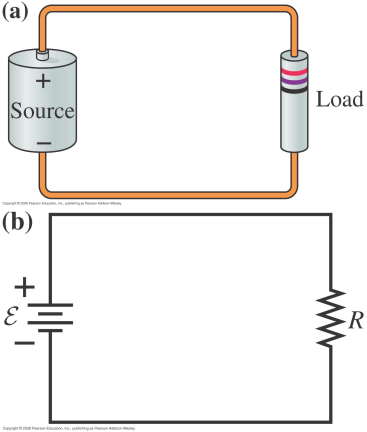
     Note that at least one ΔV must be negative. ΔV across a resistor in the direction of the current is negative (other direction is positive).

The Basic Circuit

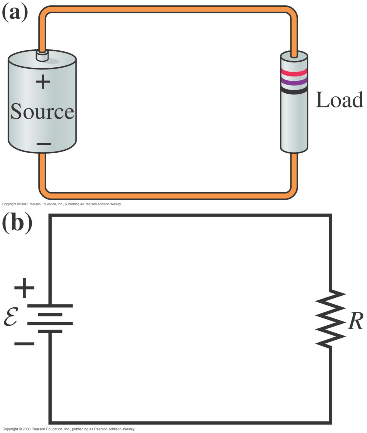


- The simplest complete circuit is shown on the left.

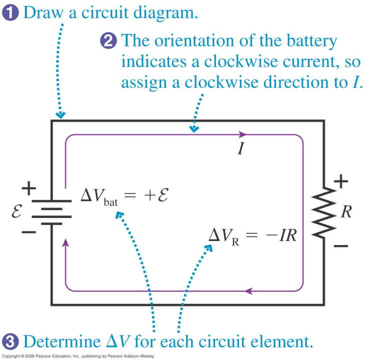
The Basic Circuit



- The simplest complete circuit is shown on the left.
- It consists of a battery (the source) and a generic resistor known as the load.

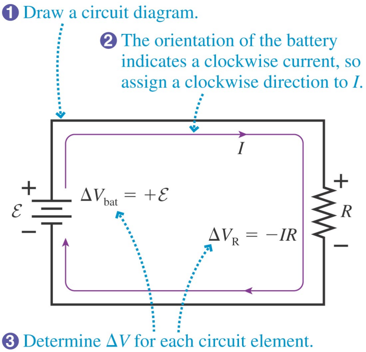


- The simplest complete circuit is shown on the left.
- It consists of a battery (the source) and a generic resistor known as the load.
- The second picture is the circuit diagram corresponding to the first.



- Assuming there is no resistance in the wires, we have a 2-element circuit and Kirchhoff's Loop Law gives

$$\Delta V_{loop} = \Delta V_{batt} + \Delta V_R = 0$$



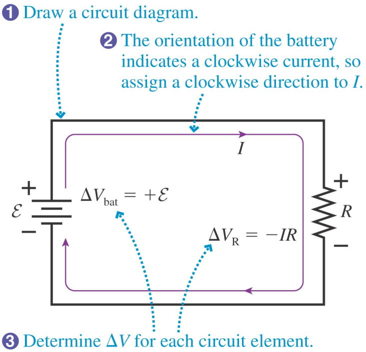
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- Assuming there is no resistance in the wires, we have a 2-element circuit and Kirchhoff's Loop Law gives

$$\Delta V_{loop} = \Delta V_{batt} + \Delta V_R = 0$$

- $\Delta V_{batt} = \mathcal{E}$ is the positive potential created by the battery.

The Basic Circuit



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- Assuming there is no resistance in the wires, we have a 2-element circuit and Kirchhoff's Loop Law gives

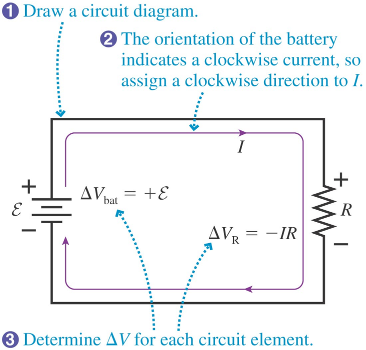
$$\Delta V_{loop} = \Delta V_{batt} + \Delta V_R = 0$$

- $\Delta V_{batt} = \mathcal{E}$ is the positive potential created by the battery.
- Ohm's law tells us by how much the potential drops across the resistor

$$\Delta V_R = -IR$$

(note that we include the minus sign because we assume a clockwise circuit direction)

The Basic Circuit

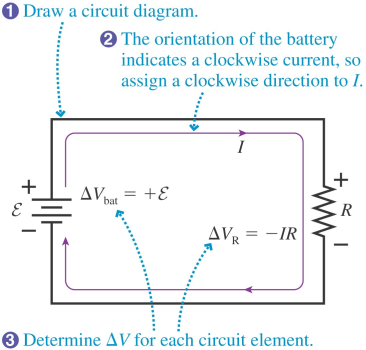


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- So, we have

$$\mathcal{E} - IR = 0 \rightarrow I = \frac{\mathcal{E}}{R}$$

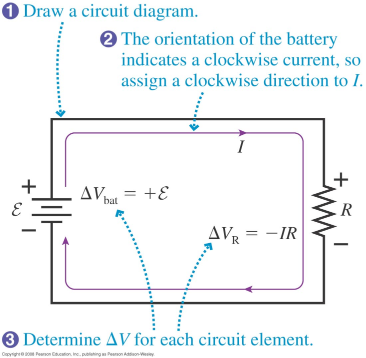
The Basic Circuit



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- So, we have

$$\mathcal{E} - IR = 0 \rightarrow I = \frac{\mathcal{E}}{R}$$



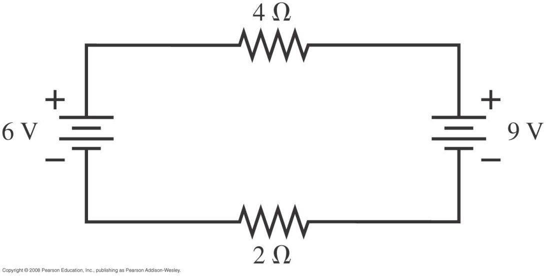
- So, we have

$$\mathcal{E} - IR = 0 \rightarrow I = \frac{\mathcal{E}}{R}$$

$$\Delta V_R = -IR = -\mathcal{E}$$

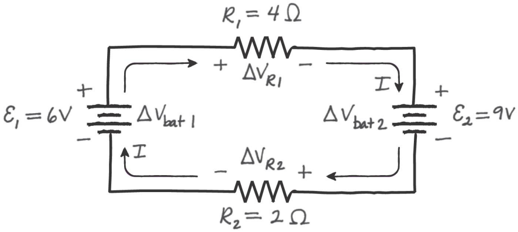
Example 32.2

Analyze this circuit:



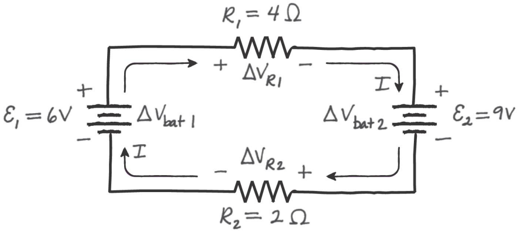
Find the current and potential across each resistor

Example 32.2



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.

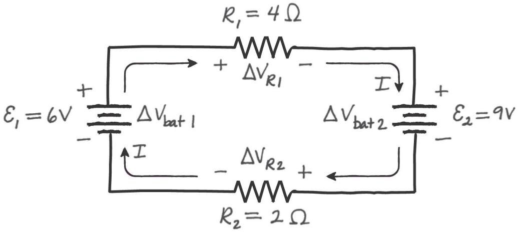


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.
- Kirchhoff's Loop Law:

$$\Delta V_{loop} = \Delta V_{batt1} + \Delta V_{R1} + \Delta V_{batt2} + \Delta V_{R2} = 0$$

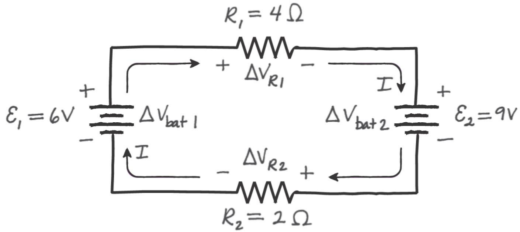
Example 32.2



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.
- Kirchhoff's Loop Law:

$$\Delta V_{loop} = \Delta V_{batt1} + \Delta V_{R1} + \Delta V_{batt2} + \Delta V_{R2} = 0$$

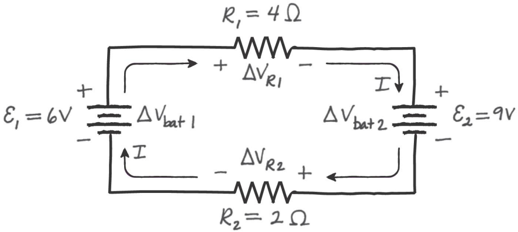


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.
- Kirchhoff's Loop Law:

$$
\begin{aligned}
\Delta V_{loop} &= \Delta V_{batt1} + \Delta V_{R1} + \Delta V_{batt2} + \Delta V_{R2} = 0 \\
&= \mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0
\end{aligned}
$$

Example 32.2

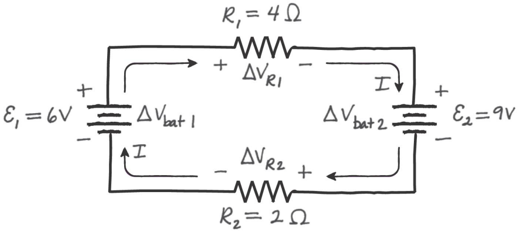


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.
- Kirchhoff's Loop Law:

$$\begin{aligned} \Delta V_{loop} &= \Delta V_{batt1} + \Delta V_{R1} + \Delta V_{batt2} + \Delta V_{R2} = 0 \\ &= \mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0 \\ &= \mathcal{E}_1 - \mathcal{E}_2 - I(R_1 + R_2) = 0 \end{aligned}$$

Example 32.2



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- We do not know if the current will flow cw or ccw around this circuit, just pick a direction and see how the sign comes out.
- Kirchhoff's Loop Law:

$$\begin{aligned}
\Delta V_{loop} &= \Delta V_{batt1} + \Delta V_{R1} + \Delta V_{batt2} + \Delta V_{R2} = 0 \\
&= \mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0 \\
&= \mathcal{E}_1 - \mathcal{E}_2 - I(R_1 + R_2) = 0 \\
I &= \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2} = -0.50A
\end{aligned}$$

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.
- However, energy does get dissipated as current flows through a circuit in the form of heat (and sometimes light).

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.
- However, energy does get dissipated as current flows through a circuit in the form of heat (and sometimes light).
- The power supplied by a battery is

$$P_{batt} = I\mathcal{E}$$

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.
- However, energy does get dissipated as current flows through a circuit in the form of heat (and sometimes light).
- The power supplied by a battery is

$$P_{batt} = I\mathcal{E}$$

- This energy comes from chemical reactions in the battery. Essentially, we change chemical energy to potential energy (with the escalator) which gets turned into kinetic energy of electrons, which collide with ions and make thermal energy.

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.
- However, energy does get dissipated as current flows through a circuit in the form of heat (and sometimes light).
- The power supplied by a battery is

$$P_{batt} = I\mathcal{E}$$

- This energy comes from chemical reactions in the battery. Essentially, we change chemical energy to potential energy (with the escalator) which gets turned into kinetic energy of electrons, which collide with ions and make thermal energy.
- Suppose the average distance between collision is d. The work done by the electric field is then

$$W = F\Delta s = qEd$$

Energy and Power (32.3)

- As we discussed earlier, current does not get "used up" as it moves around a circuit. Current in equals current out.
- However, energy does get dissipated as current flows through a circuit in the form of heat (and sometimes light).
- The power supplied by a battery is

$$P_{batt} = I\mathcal{E}$$

- This energy comes from chemical reactions in the battery. Essentially, we change chemical energy to potential energy (with the escalator) which gets turned into kinetic energy of electrons, which collide with ions and make thermal energy.
- Suppose the average distance between collision is d. The work done by the electric field is then

$$W = F\Delta s = qEd$$

- So, the energy per collision with the lattice is

$$\Delta E_{collision} = \Delta K = qEd$$

Energy and Power

- Collisions occur over and over. If L is the length of the resistor then the energy transferred by a charge is

$$\Delta E_{th} = qEL$$

Energy and Power

- Collisions occur over and over. If L is the length of the resistor then the energy transferred by a charge is

$$\Delta E_{th} = qEL$$

- But EL is the potential difference between the ends of the resistor so

$$\Delta E_{th} = q\Delta V_R$$

Energy and Power

- Collisions occur over and over. If L is the length of the resistor then the energy transferred by a charge is

$$\Delta E_{th} = qEL$$

- But EL is the potential difference between the ends of the resistor so

$$\Delta E_{th} = q\Delta V_R$$

- The rate of energy dissipation is then

$$P_R = \frac{dE_{th}}{dt} = \frac{dq}{dt}\Delta V_R = I\Delta V_R$$

Energy and Power

- Collisions occur over and over. If L is the length of the resistor then the energy transferred by a charge is

$$\Delta E_{th} = qEL$$

- But EL is the potential difference between the ends of the resistor so

$$\Delta E_{th} = q\Delta V_R$$

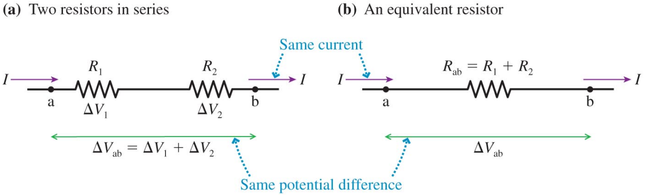
- The rate of energy dissipation is then

$$P_R = \frac{dE_{th}}{dt} = \frac{dq}{dt}\Delta V_R = I\Delta V_R$$

- Since the resistor obeys Ohm's Law

$$P_R = I\Delta V_R = I^2 R = \frac{(\Delta V_R)^2}{R}$$

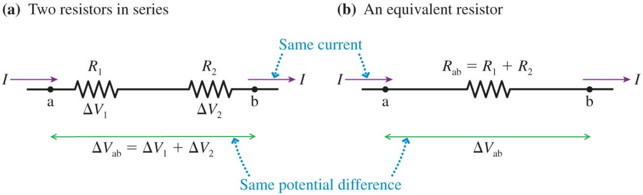
Series Resistors (32.4)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- When two resistors are placed end-to-end with no junctions between them we say the resistors are in series. The current is equal through the two resistors.

Series Resistors (32.4)

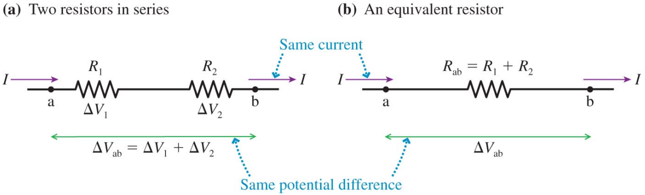


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- When two resistors are placed end-to-end with no junctions between them we say the resistors are in series. The current is equal through the two resistors.
- The total potential difference between *a* and *b* is

$$\Delta V_{ab} = IR_1 + IR_2 = I(R_1 + R_2)$$

Series Resistors (32.4)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

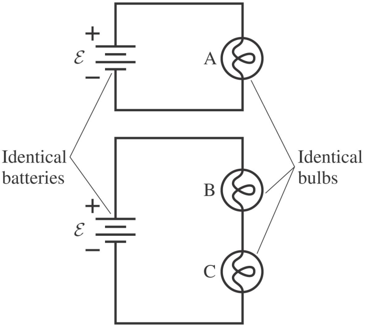
- When two resistors are placed end-to-end with no junctions between them we say the resistors are in series. The current is equal through the two resistors.
- The total potential difference between a and b is

$$\Delta V_{ab} = IR_1 + IR_2 = I(R_1 + R_2)$$

- We can replace the two resistors with an equivalent resistor having current I and potential difference ΔV_{ab}

$$R_{ab} = \frac{\Delta V_{ab}}{I} = \frac{I(R_1 + R_2)}{I} = R_1 + R_2$$

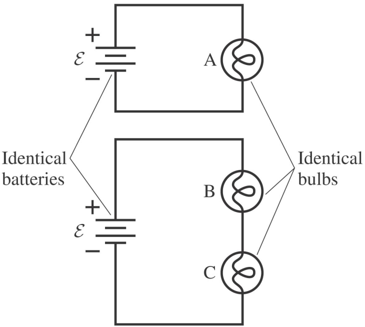
Series Resistors



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- How does the brightness of B compare to A?

Series Resistors

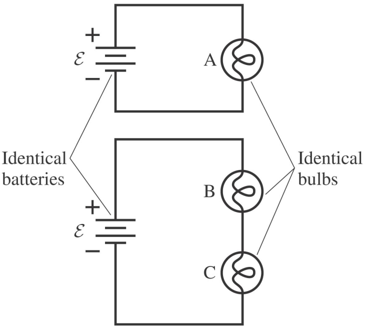


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- How does the brightness of B compare to A?
- If the resistance of each lightbulb is R then bulb A sees current

$$I_A = \frac{\mathcal{E}}{R}$$

Series Resistors



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- How does the brightness of B compare to A?
- If the resistance of each lightbulb is R then bulb A sees current

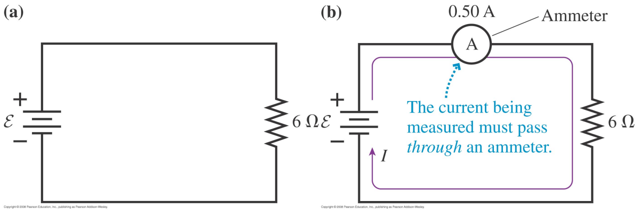
$$I_A = \frac{\mathcal{E}}{R}$$

- However, the equivalent resistance of the second circuit is $2R$, so

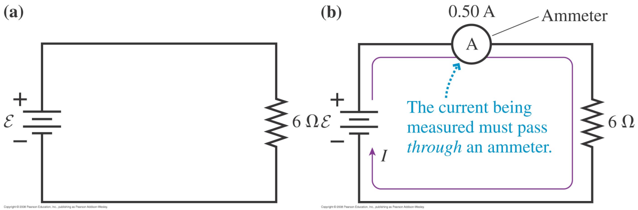
$$I_B = \frac{\mathcal{E}}{2R} = \frac{1}{2} I_A$$

B is dimmer!

Ammeters

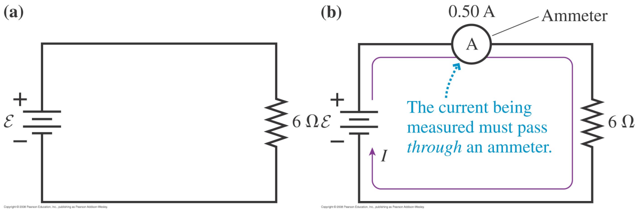


- A device which measures current is called an Ammeter



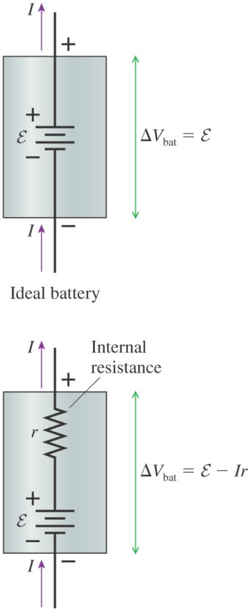
- A device which measures current is called an Ammeter
- An ammeter must be placed in the circuit in series with the element through which you want to measure current.

Ammeters



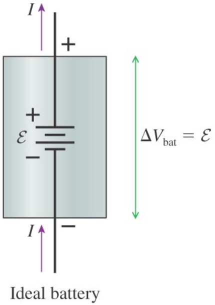
- A device which measures current is called an Ammeter
- An ammeter must be placed in the circuit in series with the element through which you want to measure current.
- Ideally, an ammeter would have $R = 0\Omega$ and thus have no effect on the current.

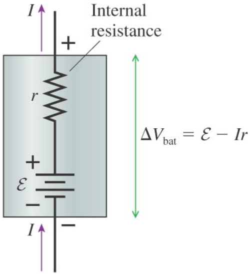
Real Batteries (32.5)



- The difference between an ideal battery and a real battery is internal resistance.

Real Batteries (32.5)

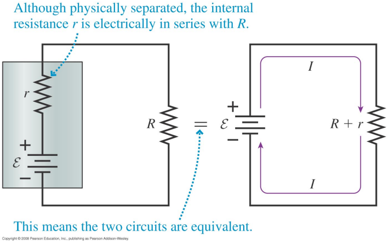




- The difference between an ideal battery and a real battery is internal resistance.
- For an ideal battery the terminal voltage is equal to $\mathcal{E}$. For a real battery

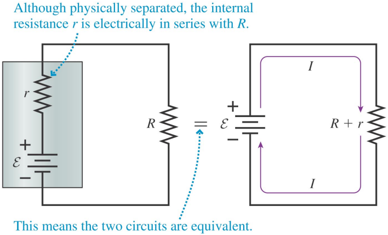
$$\Delta V_{bat} = \mathcal{E} - Ir \leq \mathcal{E}$$

Real Batteries (32.5)



- The internal resistance of a battery is part of the equivalent resistance of the circuit (ie. it is part of the load).

Real Batteries (32.5)

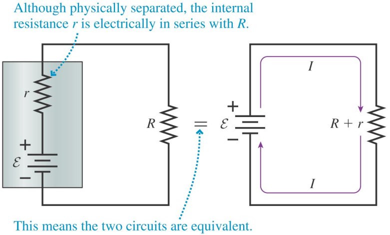


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- The internal resistance of a battery is part of the equivalent resistance of the circuit (ie. it is part of the load).
- The current in the circuit is then

$$I = \frac{\mathcal{E}}{R_{eq}} = \frac{\mathcal{E}}{R + r}$$

Real Batteries (32.5)



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

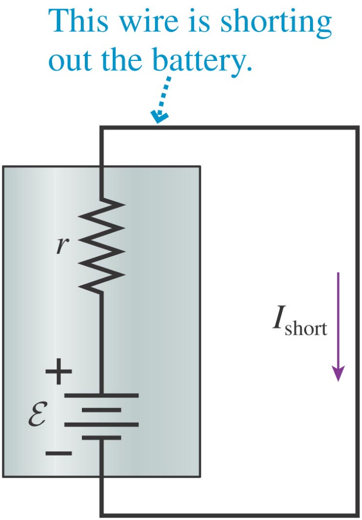
- The internal resistance of a battery is part of the equivalent resistance of the circuit (ie. it is part of the load).
- The current in the circuit is then

$$I = \frac{\mathcal{E}}{R_{eq}} = \frac{\mathcal{E}}{R + r}$$

- Using Ohm's Law

$$\Delta V_R = IR = \frac{R}{R + r}\mathcal{E} = \Delta V_{bat}$$

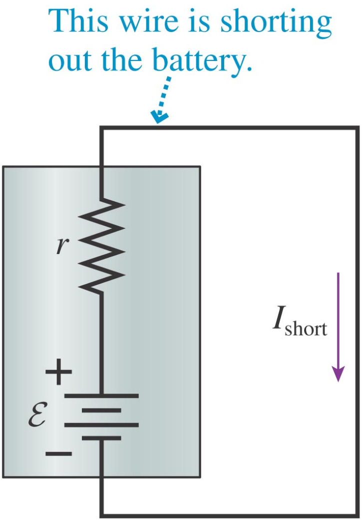
A Short Circuit



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- If the two terminals of a battery are connected via a zero-resistance wire we have a short circuit

A Short Circuit

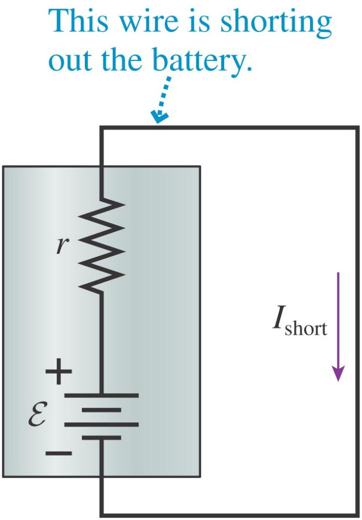


Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- If the two terminals of a battery are connected via a zero-resistance wire we have a short circuit
- If a battery were ideal a short circuit would lead to infinite current ($I = \mathcal{E}/0$). In practice we have

$$I_{short} = \frac{\mathcal{E}}{r}$$

A Short Circuit



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Addison-Wesley.

- If the two terminals of a battery are connected via a zero-resistance wire we have a short circuit
- If a battery were ideal a short circuit would lead to infinite current ($I = \mathcal{E}/0$). In practice we have

$$I_{short} = \frac{\mathcal{E}}{r}$$

- This formula gives the maximum possible current this battery can produce. Adding any resistance to the circuit will decrease the current.