Chapter 9: Current Electricity

Flow of Charge

- Charge can move from one object to another through a conductor
- Electric current: when a charge moves, or 'flows' from one place to another
- In metals, moving charges have a negative charge:

$I = Q/t$ Q = total charge flowing past a point in a circuit

t = time over which charge flowed

I = current (units: Amperes)

1 A = the electric current flowing when 1 C of charge moves past a point in a conductor in 1 s.

Ex.1: Calculate the current in an electric toaster if it takes 9.0×10^2 C of charge to toast 2 slices of bread in 1.5 min.

$Q = 9.0 \times 10^2 C$

$t = 1.5 min \times \frac{60 s}{1 min} = 90 s$

$I = ?$

$I = \frac{Q}{t}$

$= \frac{900 C}{90 s}$

$= 10 A$ or $1.0 \times 10^1 C$

Ex. 2: A light bulb with a current of 0.80 A is left burning for 25 minutes. How much electric charge passes through the filament of the bulb?

$I = 0.80 A$

$t = 25 min \times \frac{60 s}{1 min} = 1500 s$

$Q = ?$

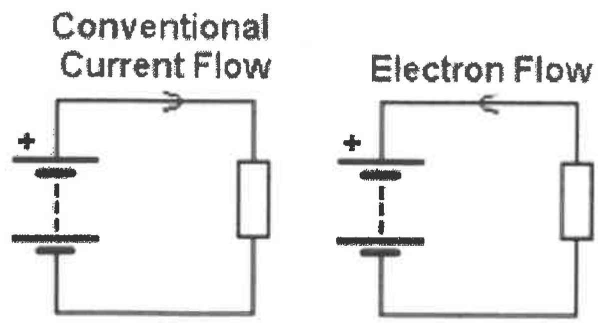
$I = \frac{Q}{t}$

$Q = I \cdot t$

$= (0.80 A)(1500 s)$

$= 1200 C$

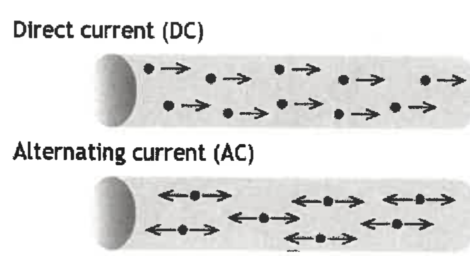
Conventional Current vs. Electron Flow



- Electric current is defined as the rate of flow of electrically charged particles past a point
- Benjamin Franklin, in the 19th century, assumed that a positive charge moved from an area where there was an excess of positive charges to an area where there was a deficit (a negative charge).
- Direction was therefore defined as moving from the positive terminal to the negative terminal of the source of potential energy. This is called conventional current
- After this concept was firmly entrenched, the electron was discovered and it became clear that an electric current is a flow of negatively-charged electrons from the negative terminal to the positive terminal - electron flow.
- Unless told otherwise, assume that all diagrams use conventional current

Sources of Electric Current

- Electric current supplied by a battery is significantly different from current supplied by a wall circuit
- Batteries supply direct current (DC) - flow is in a fixed single direction with a constant magnitude
- Wall sockets supply alternating current (AC) - flow periodically reverses direction in the circuit and the amount of current varies continuously.



Electric Charge and Current Worksheet

1. If there is a current of 10 amperes in a circuit for 10 minutes, what quantity of electric charge flows through the circuit?

$I = 10\ C/s$
$t = 10\ min = 600\ s$
$Q = ?$

$I = \frac{Q}{t}$
$Q = It$
$= (10\ C/s)(600\ s)$
$= 6000\ C$

2. How much current must there be in a circuit if 120 coulombs flow past a point in the circuit in 4.0 s?

$Q = 120\ C$
$t = 4.0\ s$
$I = ?$

$I = \frac{Q}{t}$
$= \frac{120\ C}{4.0\ s}$
$= 30\ A$

3. How much time is required for 10.0 C of charge to flow past a point if the current is 2A?

$Q = 10.0\ C$
$I = 2\ A$
$t = ?$

$I = \frac{Q}{t}$
$t = \frac{Q}{I} = \frac{10.0\ C}{2\ C/s} = 5\ s$

4. In a lightning flash, a typical amount of charge which reaches the Earth is 10 C. If the flash lasts for 0.50 ms, what is the average current?

$Q = 10\ C$
$t = 0.50 \times 10^{-3}\ s$
$I = ?$

$I = \frac{Q}{t}$
$= \frac{10\ C}{5.0 \times 10^{-4}\ s}$
$= 2 \times 10^{4}\ A$

* 5. The current in a small flashlight is 0.20 A.

a. What is the total electric charge which passes a point in the circuit in 12 min?

$I = 0.20A$ $\quad I = \frac{Q}{t}$

$t = 12 \times 60 = 720s$

$Q = ?$ $\quad Q = I \cdot t = (0.20A)(720s) = 144C$ or 140C

b. How many electrons pass this point in this time?

$Q = 144C$ $\quad N = \frac{Q}{e} = \frac{144C}{1.6 \times 10^{-19}C} = 9.0 \times 10^{20}$ electrons

$N = ?$

$e = 1.6 \times 10^{-19} C/e$

6. Calculate the number of electrons passing a point in a wire in one minute, when the current is:

a. 1.0 A $\quad Q = It$ + $Q = Ne$.

$Ne = It$

$N = \frac{It}{e}$

$I = 1.0A$

$t = 60s$

$e = 1.6 \times 10^{-19} C/e$

$N = \frac{(1.0A)(60s)}{1.6 \times 10^{-19} C/e} = 3.75 \times 10^{20}$ or 3.8×10^{20} electrons

b. 5.0 μA

$I = 5.0 \times 10^{-6} A$ $\quad N = \frac{It}{e}$

$t = 60s$

$e = 1.6 \times 10^{-19} C/e^-$ $\quad = \frac{(5.0 \times 10^{-6}A)(60s)}{1.6 \times 10^{-19} C/e^-} = 1.875 \times 10^{15} = 1.9 \times 10^{15}$ electrons

7. A certain type of rechargeable battery is capable of delivering a current of 0.2 A for 4000s, before its voltage drops and it needs to be recharged. Calculate:

a. The total charge the battery can deliver before it needs to be recharged.

$I = 0.2A$ $\quad I = \frac{Q}{t}$

$t = 4000s$

$Q = ?$ $\quad Q = It = (0.2A)(4000s) = 800C$

b. The maximum time it could be used without being recharged if the current through it was 0.5 A.

$I = 0.5A$ $\quad I = \frac{Q}{t}$

$Q = 800C$

$t = ?$ $\quad t = \frac{Q}{I} = \frac{800C}{0.5C/s} = 1600s = 2 \times 10^3 s$

ANSWERS: 1) 6000C 2) 3.0×10^1A 3) 5s 4) 2×10^4A 5a) 1.4×19^2C b) ~~8.8~~ 9.0 $\times 10^{20}$ e 6a) 3.8×10^{20} e b) $1,9 \times 10^{15}$ e 7a) 800C b) 2×10^3s *

Electric Potential Difference (Voltage)

- Electrical potential energy – stored energy as a result of electrical charges.
- Separating an electron from a proton requires Work, therefore increasing their stored energy (like stretching a spring).
- Charged particles move in the presence of an electric field and can Convert electrical potential energy into other forms of energy
- The loss of energy results in an electric potential difference between two points
- Potential difference is measured in volts (V), and is measured by a voltmeter:

1 volt = 1 joule/1 coulomb

ie., a 12 V car battery is a battery that does 12 J of work on each coulomb of charge that flows through it.

- The work done by a charge, Q, going through a potential difference, V, can be written as:

$$\Delta E = QV$$

Since $Q = I\Delta t$, then

$$\boxed{\Delta E = VI\Delta t}$$

Ex #1: A 12 V car battery supplies 1.0×10^3 C of charge to the starting motor. How much energy is used to start the car?

$V = 12V$
$I = 1000C$
$\Delta E = ?$

$\Delta E = IV$
$= (1000C)(12V)$
$= 12000 J$

Ex #2: If a current of 10.0 A takes 3.0×10^2s to boil a kettle of water requiring 3.6×10^5 J of energy, what is the potential difference across the kettle?

$I = 10.0A$
$t = 300s$
$\Delta E = 360\,000J$
$V = ?$

$\Delta E = VIt$

$V = \frac{\Delta E}{It}$

$= \frac{360\,000J}{(10.0A)(300s)}$

$= 120V$

Ex. #3: A 120 V electric sander operating for 5.0 min uses 1.0×10^5 J of energy. Find the current through the sander.

$V = 120V$
$t = 5.0min = 300s$
$\Delta E = 1.0 \times 10^5 J$
$I = ?$

$\Delta E = VIt$

$I = \frac{\Delta E}{Vt}$

$= \frac{1.0 \times 10^5 J}{(120V)(300s)}$

$= 2.8A$

Electric Potential Difference Worksheet

1 What amount of energy does a kettle use to boil water if it has 810 C of charge passing through it with a potential difference of 120 V?

$\Delta E = ?$
$Q = 810C$
$V = 120V$

$\Delta E = QV$
$= (810C)(120 J/C)$
$= 97200 J$
$= 9.7 \times 10^4 J$

2 What is the potential difference across a refrigerator if 75C of charge transfers 9.0×10^3J of energy to the compressor motor?

$V = ?$
$Q = 75C$
$\Delta E = 9000J$

$\Delta E = QV$
$V = \frac{\Delta E}{Q} = \frac{9000J}{75C}$
$= 120V$

3 An electric baseboard heater draws a current of 6.0 A and has a potential difference of 240V. For how long must it remain on to use 2.2×10^5 J of electrical energy?

$I = 6.0A$
$V = 240V$
$E = 2.2 \times 10^5 J$
$t = ?$

$\Delta E = VIt$
$t = \frac{\Delta E}{VI}$
$= \frac{2.2 \times 10^5 J}{(240V)(6.0A)} = 152.8s$
$= 150s$

4 A flash of lightning transfers 2.0×10^9 J of electrical energy through a potential difference of 7.0×10^7 V between a cloud and the ground. Calculate the quantity of charge transferred in the lightning bolt.

$\Delta E = 2.0 \times 10^9 J$
$V = 7.0 \times 10^7 V$
$Q = ?$

$\Delta E = QV$
$Q = \frac{\Delta E}{V}$
$= \frac{2.0 \times 10^9 J}{7.0 \times 10^7 V} = 28.57C$
$= 29C$

5 Calculate the energy stored in a 9.0 V battery that can deliver a continuous current of 4.0mA for 2.0×10^3s?

$\Delta E =$
$V = 9.0V$
$I = 4.0\times10^{-3}A$
$t = 2000s$

$\Delta E = VIt$
$= (9.0V)(4.0\times10^{-3}A)(2000s)$
$= 72J$

6 If a charge of 0.30 C moves from one point to another in a conductor and, in doing so, releases 54 J of electrical energy, what is the potential difference between the two points?

$Q = 0.30C$
$\Delta E = 54J$
$V = ?$

$\Delta E = QV$

$V = \frac{\Delta E}{Q} = \frac{54J}{0.30C} = 180V$

7 Describe the significance of two points in a conductor that are at the same electric potential. How much work must be done to move a charge between the two points?

No work is done if the two points have the same potential (no gain or loss of energy)

8 How are electric potential energy and gravitational potential energy different? How are they similar?

- both give the ability to do work.
- gravitational potential energy is due to grav. force due to separation of 2 objects;
- electric potential energy is due to the separation of charged particles

Answers: 1) 9.7×10^4J 2) 120V 3) 150s 4) 29C 5) 72J 6) 180V 7) no work

Resistance

- When charges pass through a material or device, they experience a resistance to their flow
- This results in a loss of electrical potential energy

Ohm's Law

- German scientist Georg Ohm (1787-1854) found that, for any conductor, the ratio of voltage to current is constant:

- The potential difference between any two points in a conductor varies directly as the current between the two points (if the temperature remains constant).

$R = V/I$

R = resistance (ohms - Ω)
V = potential difference (volts - V);
I = current (amperes - A)

Ex.1: What is the resistance in a toaster, connected to a 120V power supply, if the current through it is 8.7 A?

$V = 120V$
$I = 8.7A$
$R = ?$

$R = \frac{V}{I} = \frac{120V}{8.7A} = 13.79\Omega = 14\Omega$

Ex.2: Calculate the maximum rating (in volts) of a battery used to operate a toy electric motor that has a resistance of 2.4 Ω and runs at top speed with a current of 2.5 A.

$R = 2.4\Omega$
$I = 2.5A$
$V = ?$

$V = IR$
$= (2.5A)(2.4\Omega)$
$= 6.0V$

Ex.3: How much current is supplied by a 6 V battery if it is connected to a light bulb with a resistance of 20 Ω?

$V = 6V$
$R = 20\Omega$
$I = ?$

$V = IR$

$I = \frac{V}{R} = \frac{6V}{20\Omega} = 0.3A$

Ohm's Law

1. Find the current through a 12-ohm resistive circuit when 24 volts is applied.

$I = ?$
$R = 12\Omega$
$V = 24V$

$V = IR$

$I = \frac{V}{R} = \frac{24V}{12\Omega} = 2.0\,A$

2. Find the resistance of a circuit that draws 0.06 A with 12 V applied.

$R = ?$
$I = 0.06A$
$V = 12V$

$V = IR$

$R = \frac{V}{I} = \frac{12V}{0.06A} = 200\Omega$

3. Find the applied voltage of a circuit that draws 0.2 A through a 4800-ohm resistance.

$V = ?$
$I = 0.2A$
$R = 4800\Omega$

$V = IR$

$= (0.2A)(4800\Omega) = 960V$

4. Find the applied voltage in a telephone circuit that draws 0.017 A through a resistance of 15 000 ohms.

$V = ?$
$I = 0.017A$
$R = 15000\Omega$

$V = IR$

$= (0.017A)(15\,000\Omega)$

$= 255V$

$= 260V$

5. A 20 V relay has a resistance of 200 ohms. How much current does it draw?

$V = 20V$
$R = 200\Omega$
$I = ?$

$V = IR$

$I = \frac{V}{R} = \frac{20V}{200\Omega} = 0.1A$

6. A circuit consists of a 12 V battery connected across a single resistor. If the current in the circuit is 3 A, calculate the size of the resistor.

$V = 12V$
$I = 3A$
$R = ?$

$V = IR$

$R = \frac{V}{I} = \frac{12V}{3A} = 4\Omega$

ANSWERS: 1) 2.0A 2) 200Ω 3) 960V 4) ~~255V~~ 260V 5) 0.1A 6) 4Ω

*

Power in Electric Circuits (Joule's Law)

- To predict the amount of energy used by an electrical device, we first need to know the amount of time the device will be used.

$$\Delta E = VI\Delta t$$

$$P = \Delta E/\Delta t$$

Therefore, $P = VI\Delta t/\Delta t$ or $P = VI$

Since $P = VI$ and $V = IR$

Then $P = (IR)\,I$

$$P = I^2R$$

Since $P=VI$ and $I = V/R$

Then $P = V\,(V/R)$

$$P = V^2/R$$

Ex.1: Calculate the resistance of a 7.5 W light bulb plugged into a 120 V household outlet.

$R = ?$
$P = 7.5W$
$V = 120V$

$P = \frac{V^2}{R}$; $R = \frac{V^2}{P} = \frac{(120V)^2}{7.5W} = 1920\,\Omega = 1.9\times10^3\,\Omega$

Ex.2: What is the power rating on a light bulb with a resistance of 240 Ω if a 0.50A current runs through it?

$P = ?$
$R = 240\Omega$
$I = 0.50A$

$P = I^2R$
$= (0.50A)^2(240)$
$= 60W$ or $6.0\times10^1 W$

Ex.3: A 110 V household circuit contains a 1800 W microwave and an 800 W coffee maker, which are connected to a 20 A fuse. Will the fuse melt if both the microwave and coffeemaker are on?

$P = 1800W + 800W$
$= 2600W$
$V = 110V$
$I = ?$

$P = IV$

$I = \frac{P}{V} = \frac{2600W}{110V}$

$= 23.6 A$

$23.6 A > 20A$ ∴ Yes, it will melt.

Power Equation

1. If a small appliance is rated at a current of 10 A and a voltage of 120 V, what is its power rating?

   $I = 10A$ $P = IV$
   $V = 120V$ $= (10A)(120V)$
   $P = ?$ $= 1200W$ or $1000W$ (1 sf)

2. If a clock expends 2.0 W of power from a 1.5 V battery, what amount of current is supplying the clock? *

   $P = 2W$ $P = IV$
   $V = 1.5V$ $I = \frac{P}{V} = \frac{2W}{1.5V} = 1.3A$
   $I = ?$ or $1A$

3. Tommy runs his juicer every morning. The juicer uses 90 W of power and the current supplied is 4.5 A. How many volts are necessary to run the juicer?

   $P = 90W$ $V = \frac{P}{I} = \frac{90W}{4.5A} = 20V$
   $I = 4.5A$
   $V = ?$

4. A DC electric motor transforms 1.50 kW of electrical power into mechanical form. If the motor's operating voltage is 300 V, how much current does it "draw" when operating at full load (full power output)?

   $P = 1.50 \times 10^3 W$ $P = IV$
   $V = 300V$ $I = \frac{P}{V} = \frac{1500W}{300V} = 5A$
   $I = ?$

5. Calculate the amount of power dissipated by a heating element, if the generated output voltage is 110 V and the heater's resistance is 2.5 ohms?

$P = ?$

$V = 110V$

$R = 2.5\Omega$

$$P = \frac{V^2}{R} = \frac{(110V)^2}{2.5\Omega} = 4840W \text{ or } 4800W$$

6. What is the resistance in a lightbulb if it draws 1.5 W of power when it is connected to a 6 V battery?

$P = 1.5W$

$V = 6V$

$R = ?$

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(6V)^2}{1.5W} = 24\Omega = 20\Omega$$

7. A microwave has a power rating of 800 W. If it has a voltage of 120 V, what is the internal resistance of the microwave?

$P = 800W$

$V = 120V$

$R = ?$

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(120V)^2}{800W} = 18\Omega = 20\Omega$$

8. Calculate the resistance in a 3.6 W light bulb if a current of 0.6 A runs through it.

$R = ?$

$P = 3.6W$

$I = 0.6A$

$$P = I^2R$$

$$R = \frac{P}{I^2} = \frac{3.6W}{(0.6A)^2} = 10\Omega$$

ANSWERS: 1) 1000W 2) 1.3A 3) 20V 4) 5A 5) 4800W 6) 20Ω 7) 20Ω 8) 10Ω

Chapter 9 Review

1. What is conventional current, and how does it relate to electron flow?

Assumes a positive charge flows in a circuit from an area of excess positive charges to an area of a deficit of positive charges.
Electron flow is the flow of negative charges; opposite to conventional.

2. Differentiate between direct current and alternating current.

In direct current, the flow is in a single, fixed direction while in alternating current, the flow periodically reverses direction & varies constantly

3. What would happen to the current in a circuit if the voltage of the battery doubles?

$R = \frac{V^{\times 2}}{I_{\times 2}}$ If you double the voltage, you double the current (directly proportional) (doubles)

Numbering *

4. What would happen to the power in a circuit if both the current and the resistance double?

(increases by 8x)

$P = I^2R = (2I)^2(2R) = (4I^2)(2R) = 8I^2R$

*

~~6~~5. What quantity of electric charge would flow through a small motor in 2.5 minutes if the circuit has a 5~~.0~~ A current?

$Q = ?$
$t = 2.5\text{min} = 150\text{s}$
$I = 5\text{A}$

$I = \frac{Q}{t}$

$Q = It = (5\text{C/s})(150\text{s}) = 750\text{C}$ $= 800\text{C}$

750 C

~~7~~6. How many electrons flowed through the motor in Question ~~13~~ 5 in the 2.5 minutes? Fix

$Q = 750\text{C}$
$N = ?$
$e = 1.6\times10^{-19}\text{C/e}$

$Q = Ne$

$N = \frac{Q}{e} = \frac{750\text{C}}{1.6\times10^{-19}\text{C/e}} = 4.688\times10^{21}$ $= 4.7\times10^{21}$ electrons

4.7×10^{21} electrons

~~8~~7. Calculate the current if 1.0×10^{21} electrons flow through a circuit in 45 seconds.

$N = 1.0\times10^{21}\text{e}$
$e = 1.6\times10^{-19}\text{C/e}$
$t = 45\text{s}$
$I = ?$

$I = \frac{Q}{t}$ & $Q = Ne$

$I = \frac{Ne}{t} = \frac{(1.0\times10^{21}\text{e})(1.6\times10^{-19}\text{C/e})}{45\text{s}} = 3.5556\text{A}$ $= 3.6\text{A}$

3.6A

~~9~~8. What is the potential difference across a battery if 0.12 J of energy is given off when 2.0×10^{-2}C of charge flows through it.

$\Delta E = 0.12\text{J}$
$Q = 2.0\times10^{-2}\text{C}$
$V = ?$

$\Delta E = QV$

$V = \frac{\Delta E}{Q} = \frac{0.12\text{J}}{0.020\text{C}} = 6.0\text{V}$

FIX *

6V

9 10. Calculate the energy provided by 12 V battery if 0.20 A of current flows through it for 3.0 minutes.

$V = 12 V$ $\Delta E = VIt$
$I = 0.20 A$ $= (12 V)(0.20 A)(180 s)$
$t = 180 s$ $= 432 J$
$\Delta E = ?$ $= 430 J$

430 J

10 11. How many electrons flow through a 1.5 V battery in 1.0 minutes, if the current is 5.0 mA?

$V = 1.5 V$ $I = \frac{Q}{t}$ & $Q = Ne$
$t = 1.0 min = 60 s$ $Q = It$
$I = 5.0 \times 10^{-3} A$ $Ne = It$
$e = 1.6 \times 10^{-19} C/e$ $N = \frac{It}{e} = \frac{(5.0 \times 10^{-3} A)(60 s)}{1.6 \times 10^{-19} C} = 1.875 \times 10^{18} e$
$N = ?$ $= 1.9 \times 10^{18} e$

1.9x10^18 electrons

11 12. How much work can be done by a 12 V battery if 2.0×10^{21} electrons can flow out of it before it is discharged?

$\Delta E = ?$ $\Delta E = QV$ + $Q = Ne$
$V = 12 V$ $\therefore \Delta E = NeV$
$N = 2.0 \times 10^{21} e$ $= (2.0 \times 10^{21} e)(1.6 \times 10^{-19} C/e)(12 V)$
$e = 1.6 \times 10^{-19} C/e$ $= 3840 J$
$= 3.8 \times 10^{3} J$

3.8x10^3 J

* 12 15. What current flows through a light bulb with 144Ω of resistance, if it is attached to a 120 V power source?

$I = ?$ $V = IR$
$R = 144 \Omega$ $I = \frac{V}{R} = \frac{120 V}{144 \Omega} = 0.8333 A$
$V = 120 V$ $= 0.83 A$

(0.83 A)

13 16. If a 10 A current flows through a 3Ω resistor, what is the voltage drop across the resistor?

$I = 10 A$ $V = IR$
$R = 3 \Omega$ $= (10 A)(3 \Omega) = 30 V$
$V = ?$

(30V)

14. Your car's battery is a 12 V DC source. A fuse in the dashboard causes the circuit to break if there is a surge greater than 5.0 A. What resistance if that fuse protecting?

$V = 12V$

$I = 5.0A$

$R = ?$

(2.4Ω)

15. A flashlight runs 2 D-Cells of 1.5 V each in series. The bulb is rated at 0.7 A. What is its resistance?

$V = 1.5V + 1.5V = 3.0V$

$I = 0.7A$

$R = ?$

$R = \frac{V}{I} = \frac{3.0V}{0.7A} = 4.29\Omega = 4\Omega$

(4Ω)

16. A 900W electric stove is connected to a 220 V outlet. How much current will it draw?

$P = 900W$

$V = 220V$

$I = ?$

$P = VI$

$I = \frac{P}{V} = \frac{900W}{220V} = 4.09A = 4A$

(4A)

17. A 2.0W lightbulb has a resistance of 3.3Ω. What current is running through it?

$P = 2.0W$

$R = 3.3\Omega$

$I = ?$

$P = I^2R$

$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{2.0W}{3.3\Omega}} = 0.7785A = 0.78A$

(0.78A)

18. If a space heater produces 5400kJ of heat in 1.2 hours while plugged into a 110V outlet, how much current is flowing through the heater's element?

(11A)

$\Delta E = 5400 \times 10^3 J$

$t = 1.2h \times 3600 s/h = 4320s$

$V = 110V$

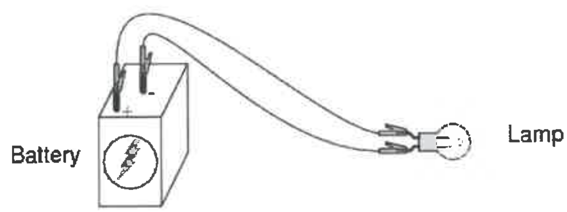
$I = ?$

$\Delta E = VIt$

$I = \frac{\Delta E}{Vt} = \frac{5{,}400{,}000J}{(110V)(4320s)} = 11.36A = 11A$

Chapter 10: Electric Circuits

- Electrons possess electric potential energy that can be transformed into heat, light, and motion.
- For such transformations to occur, a source of electric potential energy needs to connect to one or more components by means of an electric circuit (path for electric current)
- Any device in a circuit that converts electric potential energy into some other form of energy (causing an electric potential drop) is called a resistor. (or load)



- In the above circuit, the charges pass from the positive terminal of the battery, through the light bulb, and then back to the negative terminal of the battery.
- Electric potential energy acquired in the battery is carried by electric charges as they pass through the circuit.
- The electric potential energy is transferred to the light bulb and converted to light and heat.
- Electric current can only flow through a circuit if there is a continuous conducting path.
- Any break in the circuit will stop the flow.