

Physics

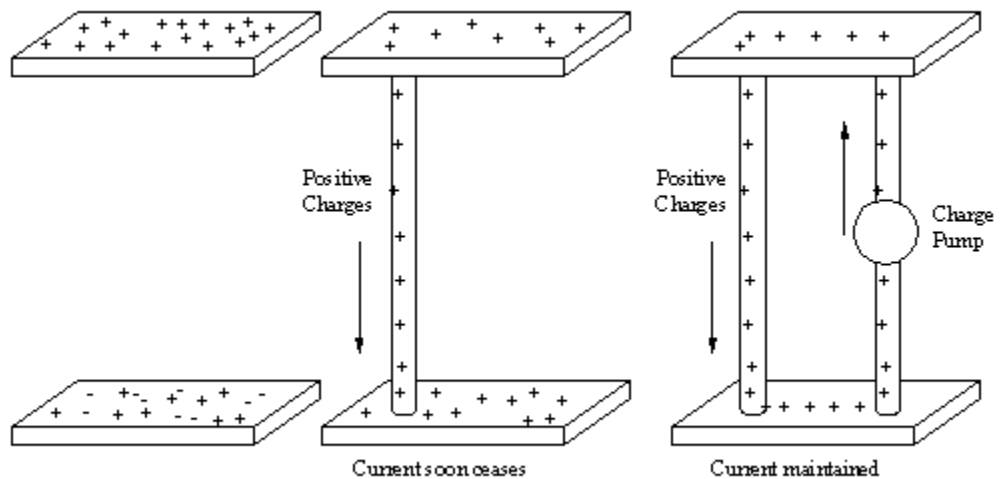
Lesson Plan #13
Current Electricity
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Current and Circuits

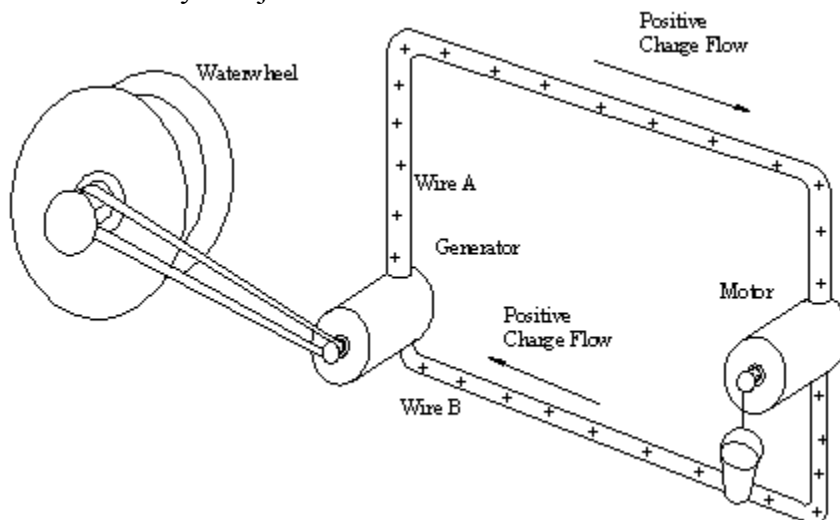
Objectives: Define an electric current and the ampere; Describe conditions that create current in an electric circuit; Draw circuits and recognize that they are closed loops; Define power in electric circuits; Define resistance and describe Ohm's law.

- Producing Electric Current

- In talking about static electricity, we found that a charged object would create electron flow to a neutral object. This flow will continue until the potential difference of both spheres are equal.
 - Electrical potential difference is measured in as the work required to move an charge. This difference is measured in joules/coulomb and is called a **volt**.
 - Review: $W=Fd = Nm = \text{Joule (J)}$, Coulomb = charge of 6.25×10^{18} electrons or protons
 - A continuous flow of charged particles is called an **electric current**.
 - If we have two object's, one with a higher potential difference and they are connected by a conductor, then charges flow from the higher potential difference object to the lower potential difference until they are equal. A positive flow of charges is called **conventional current**.
 - How could you keep the flow going? If you were to supply a second path for the flow of charged particles with a charge pump , then the flow would continue.



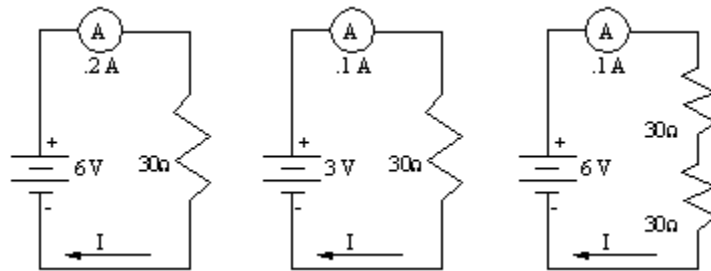
- How would you keep the flow going?
 - You would have to maintain a potential difference between the plates – this could be done by pumping charges from one plate to the other, forcing the charges back to the first plate. This would require external energy to run.
 - A battery – converts chemical energy to electrical energy
 - Photovoltaic cells (solar cells) that convert light into electrical energy
 - Generator – run by water, wind, or steam
- Electric Circuits
 - The example above shows how charges can move around a closed loop from the pump, through both plates and back to the pump again – Such a closed loop is called an **electric circuit**.
 - The circuit includes the charge pump which increased the potential energy, and it is connected to a device that reduces the potential energy (the pole between the top plate and the bottom plate..
 - The potential energy lost by the charges, qV , in moving through the device is usually converted into some other form of energy.
 - Such as an electric motor to create kinetic energy
 - A lamp to create light
 - A heater to create heat
 - By strict definition, electrical potential difference is abbreviated as ΔV – historically it is just written as V and such is the convention we will follow



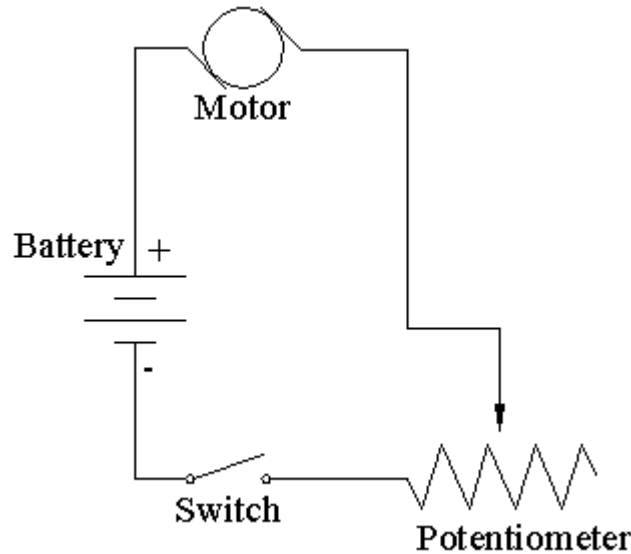
- The charge pump creates the flow of charged particles, or current.
 - If a waterwheel turns a generator, the kinetic energy of the water wheel is converted to electrical energy by the generator
 - The generator increased the electrical potential difference, V , on wires B & A as it removes charges from wire B and adds them to wire A.
 - Energy in the amount qV is needed to increase the difference of the charges, enough to produce the needed force (make the motor turn). The energy comes from the energy in the water.

- Since no generator is 100% perfect, some of the energy from the water is turned into heat in the generator.
 - As the wires from the generator are connected to a motor, the electrical energy is converted back to kinetic energy – but as with the generator, a motor is not 100% efficient, so some of the electrical energy is converted into heat in the motor.
 - We know that charges cannot be created or destroyed, only separated (electrons and positive ions) – thus the total amount of charge (electrons and positive ions) in the circuit does not change.
 - If one coulomb per second flows through the generator, the one coulomb per second also flows through the motor
 - The charge (q) is conserved.
 - The energy is conserved
 - The change in electrical energy, E , equals qV . Because q is conserved the net change in potential energy of the charges in the circuit must be 0.
 - The potential difference increase by the generator equals the potential difference decrease across the motor.
 - In real world terms, if the potential difference between the two wires is 120V, the generator must do 120J of work on each coulomb of positive charge that it transfers from the more negative wire to the more positive wire. Every coulomb of positive charge that moves from the more positive wire through the motor and back to the more negative wire delivers 120 J of energy to the motor.
- Rates of Charge Flow and Energy Transfer
- Remember that power is the rate at which energy is transferred. If a generator transfers 1J of kinetic energy to electric energy each second, it is transferring energy at the rate of 1J/sec or 1 watt.
 - The energy carried by an electric current depends on the charge transferred and the potential difference across which it moves – $E = qV$
 - The rate of flow of electric charge, or electric current, I , is called an **ampere** (or amp), A, and is 1C/sec
 - An ammeter measures current
 - If the current moving through a motor is measured at 3.0 C/s or 3.0 A, and the potential difference is 120V, then each coulomb of charge supplies the motor with 120J of energy.
 - With electricity, power is found by multiplying the potential difference (V), by the current (I)
 - $P = VI$
 - $P = (3.0C/s)(120J/C) = 360J/s = 360W$
- Resistance and Ohm's Law
- Suppose that you have two conductors with a potential difference between them.
 - If you connect them with a copper rod, you will create a large current.
 - If you connect them with an insulator, such as a glass rod, then there will be almost no current.

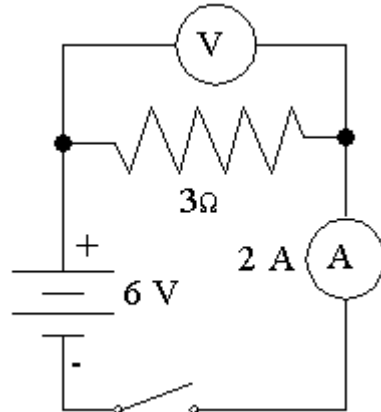
- The property that determines how much current will flow is called the **resistance (R)**.
- Resistance is measured by placing a potential difference across two points on a conductor and measuring the current.
- Resistance is defined to be the ratio of the potential difference to the current: $R = \frac{V}{I}$, where I is in amperes and potential difference (V) is volts.
- 1 Ω is the resistance that permits 1 A to flow when a potential difference of 1 V is applied across the resistance
- $R = \frac{V}{I}$ is called Ohm's Law in honor of Georg Ohm, who discovered that the ratio of potential difference to the current is always a constant for a given conductor – resistance does not vary according to the magnitude or direction of the potential applied.



- Most all metals obey Ohm's Law – at least over a limited range of voltages
 - Transistors and diodes do not obey Ohms' Law
 - Light bulbs have a resistance that varies according to the voltage, and thus does not follow Ohm's Law
- Wire that is used to connect electrical devices typically has a small resistance $\sim .004\Omega/\text{m}$. This adds up to a negligible amount and has almost no potential drop across them.
 - A **resistor** is a device that is designed to have a specific amount of resistance. Such items are constructed of long thin wires, carbon or semiconductors.
 - Superconductors have no resistance, and therefore are perfect transmitters of current – today's superconductors operate at near absolute zero.
 - As can be seen from Ohms Law, $R = \frac{V}{I}$, rearranging to solve for current, $I = \frac{V}{R}$ there are two ways to control the current in a circuit – change the voltage or resistance.
 - Resistors can be fixed or variable (often called a rheostat or **potentiometer**) – A circuit containing a potentiometer can continuously vary the amount of current in a circuit



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- Such a device is used in fan controls, mixer controls, light controls.
- The human body can conduct electricity, so it is not a total insulator
 - 1 mA – mild shock that can be felt
 - 5 mA – shock is painful
 - 15 ma – muscle control is lost
 - 100 mA – death can occur (heart flutters rather than beats)
- Diagramming Circuits
 - A proper circuit diagram is called a **schematic** and uses standard notation



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- In the example circuit above, there are several important features
 - The circuit makes a complete loop, starting with the positive terminal of the battery, through the voltmeter and resistance, then through the ammeter, through the switch and finally back to the negative terminal of the battery.
 - Where 3 wires come together, there is a heavy dot indicating a connection.
 - The resistor and the voltmeter form a **parallel connection**, because the resistor and voltmeter are aligned parallel to each other, and have the same connection points. The current is divided as it passes through both elements.

- The ammeter and the switch form a **series connection** – that one is connected to the next. The current must pass through one element before the next.

Using Electric Energy

Objectives: Explain how electric energy is converted into thermal energy; Determine why high voltage transmission lines are used to carry electric energy over long distances.

- Energy Transfer in Electric Circuits

- You use electric energy in numerous ways in your house – in all cases electric energy is converted into another form of energy – light, kinetic or heat are some of the most common
 - Heating a Resistor
 - A stove or hairdryer both are designed to convert electrical energy into heat energy. The device acts as a resistor in the circuit.
 - When a charge, q , moves through a resistor, its potential difference is reduced by an amount V .
 - As we have seen, energy change can be represented by qV . Or in other words, it is the rate at which energy is changed – that is the power. $P = \frac{E}{t}$.
 - Remember that $E = qV = q \frac{W}{q}$.
 - Also that current is C/s or $I = \frac{q}{t}$
 - And that the power dissipated in a resistor is $P = IV$
 - And using Ohm's law we get $V=IR$
 - So if we substitute $V=IR$ into $P = IV$ we get $P = I^2R$
 - The power dissipated by a resistor is proportional to the square of the resistance that passes through it and the resistance.
 - So the electrical energy is transformed into thermal energy, the resistor gets hot providing heat for drying your hair or cooking a meal.
 - If power continues to be dissipated at the same rate of a period of time, then the total amount of energy would be found as $E = I^2Rt$

Sample Problem

If an electric heater has a resistance of 10Ω , operates on $120V$, then

- a. What is the current passing through the resistance?

$$R = \frac{V}{I} \quad I = \frac{V}{R} = \frac{120V}{10.0\Omega} = 12.0A$$

- b. What thermal energy does the heater supply in $10.0s$?

$$E = I^2Rt = (12.0A)^2(10.0\Omega)(10.0s) = 14400A^2\Omega s \text{ or}$$

$$14400 \frac{C^2}{s^2} \frac{J/C}{C/s} s = 14400J \text{ or } 14.4kJ$$

- Transmission of Electric Energy
 - Power generating stations generate electricity that must be transmitted over great distances. Power companies are interested in doing this with as little loss as possible.
 - Most all losses would be due to the resistance of the wire converting some of the electrical energy into thermal energy.
 - We just saw that thermal energy is determined by the equation $P = I^2R$, so to reduce the amount of thermal energy we must reduce the current or the resistance.
 - All wire (except superconductors) have some resistance – the large wire used to connect your house to the power grid typically has a resistance of $0.20 \Omega/\text{km}$.
 - Let's see how this works out – if a farm house was only 3.5 km from power plant, then the resistance in the wires from the power plant to the house would be $3.5\text{km} \cdot 0.20 \Omega/\text{km}$ or $.7 \Omega$ per wire – remember that to have a complete electric circuit we must have a complete loop, so we have a wire from the plant to the house and another wire (of equal length) from the house to the plant, for a total resistance of 1.4Ω
 - If an electric stove were to draw 41A from the wires, the power dissipated by the wires would be

$$P = I^2R = (41A)^2(1.4\Omega) = 2400W$$
 - This is a lot of wasted power.
 - The lines could be made larger in diameter, which would decrease the resistance, but eventually they would become too heavy to support – and purchase.
 - The loss is proportional to the square of the current in the wire – so keeping the current low is desired.
 - Looking back at $P=IV$ we see that there is another way to keep the overall power the same by reducing the current – raise the voltage.
 - Some long distance lines use voltages as high as 500,000 V, this results in lower current and lower losses.
 - At electrical substations the voltage is reduced to 2400V.
 - Transformers located near homes reduce the voltage down to 240V and 120V for home usage.
- The Kilowatt-Hour
 - When you purchase electric energy from a power company, they monitor the amount of energy you consumed with a power meter located on the side of your house.
 - It measures the rate of consumption (joules/second) times the number of seconds used to give you $\frac{J \cdot s}{s}$, also known as a watt-second. This is a relatively small unit of measure, therefore power companies use the kilowatt-hour, which is the same as 1000w delivered for 1 hour
 - $1kWh = (1000J / s)(3600s) = 3.6 \times 10^6 J$
 - A kilowatt-hour is a large amount of electricity – equivalent to ten 100W light bulbs running for 1 hour.