A short Course in Energy Conversion
Session 6

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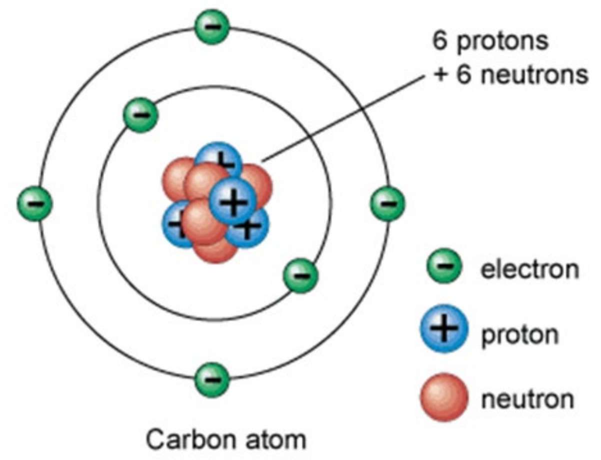
- Electrical Energy
    - Atoms
    - Electrons
    - Electric fields
    - Electric current
    - Magnetism
    - Generators
    - Motors
    - Photovoltaic effect
    - Batteries
    - Fuel cells
    - Thermoelectric effect

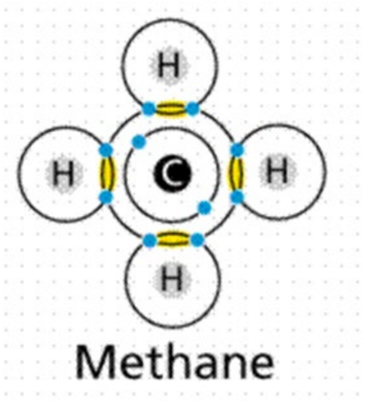
Atomic Theory

- The atom is composed of a **nucleus** at its center and **electrons** that “orbit” the nucleus
- Nucleus is composed of **protons** and **neutrons**
- Protons have a *positive* charge of $1.6021765 \times 10^{-19}$ coulombs
- Protons have a mass of 1.6726×10^{-27} kg (1,836 times that of the electron)
- Neutrons have *no* electrical charge
- Neutrons have a mass of 1.6929×10^{-27} kg (1,839 times that of the electron)
- Electrons have a *negative* charge equal to $1.6021765 \times 10^{-19}$ coulombs
- Electron has a mass of 9.11×10^{-31} kg
- Electron discovered by **Joseph John Thomson in 1897**

Atomic Theory

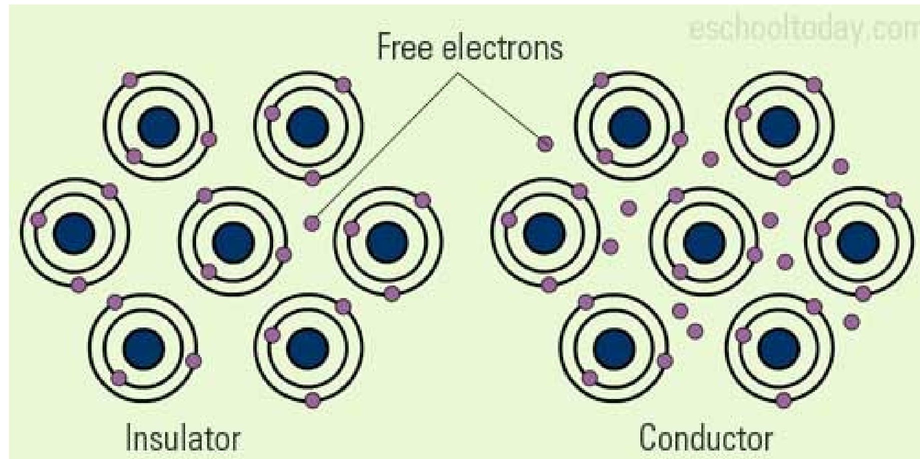
- Atoms are **small**
- The diameter of an atom ranges from about 0.1 to 0.5 nanometers or 1×10^{-10} m to 5×10^{-10} m
- Electrons "*orbit*" the nucleus
- Electron charge (-) balances proton charge(+) to make atoms neutral electrically
- "Sharing" of electrons between/among atoms is basis of chemistry





Atomic Theory

- *Electrical conductivity* in metals is a result of the movement of electrically charged particles
- The atoms of metal elements are characterized by the presence of *valence electrons*, which are electrons in the outer shell of an atom that are free to move about
- It is these '*free electrons*' that allow metals to conduct an electric current



- Insulators have few 'free electrons"

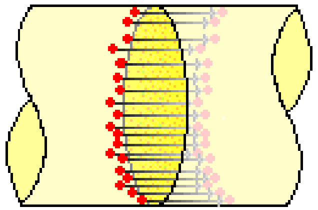
Electricity

- **Electricity** is the physical phenomena associated with the presence and flow of electric charges
- Electric charges produce electromagnetic fields which act on other charges
- **Electric current** is movement or flow of electrically charged particles
- Current is measured in **amperes**-
- Amount of charge passing a point in an electric circuit per unit time-

  1 **coulomb** per second

  or 6.241×10^{18} electrons/second
- **Conductor** is a material which contains movable electric charges , typically electrons as in metallic conductors

Typical Path of an Electron

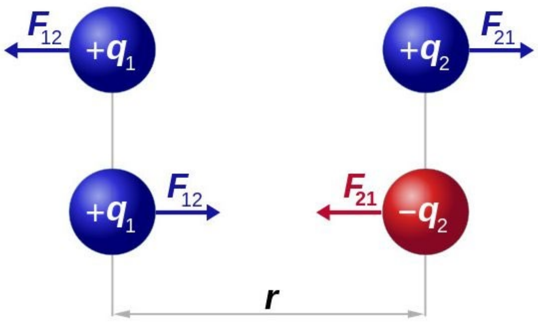


A high current results from many charge carriers passing through a given cross section of wire on a circuit.

- Current does not have to do with how far charges move in a second but rather with how many charges pass through a cross section of wire on a circuit

Electric Field

- **Electric field** is a simple type of *electromagnetic* field produced by an electric charge when it is not moving
- Electric fields produce a force on other charges in their vicinity



$$F_{12} = F_{21} = k\frac{q_1 q_2}{r^2}$$

$$F_g = \frac{Gm_1 m_2}{r^2}$$

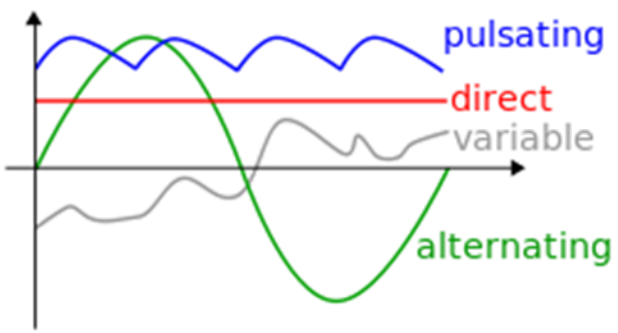
- Moving charges produce a **magnetic field**
- **Electric potential** is the capacity of an electric field to do work on an electric charge
- Potential is measured in **volts-**
- Defined as the *difference in electric potential* across a wire when a current of one ampere dissipates one watt of power

Volt=Watt/Amp=P/I

Electric Currents

- **Direct current** (**DC**) is the unidirectional flow of electric charge
- Direct current is produced by sources such as batteries, thermocouples, solar cells
- Direct current may flow in a conductor (wire) but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams
- The electric charge flows in a constant direction

- **Alternating current** (**AC) is** the movement of electric charge periodically reverses direction.
- Audio and radio signals carried on electrical wires are examples of alternating current
- The usual waveform of AC circuit is a sine wave

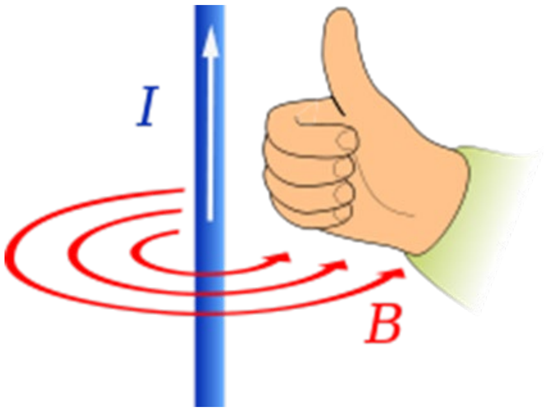


Electricity-Relationships

- Volts-electric potential
- Amps-electric current
- Watts-power
- Ohms-resistance

Magnetic Fields

- **Magnetic field** is a mathematical description of the magnetic influence of electric currents and magnetic materials
- The magnetic field at any given point is specified by both a *direction* and a *magnitude*
- Magnetic fields are produced by moving electric charges
- Rotating magnetic fields are utilized in both electric motors and generators

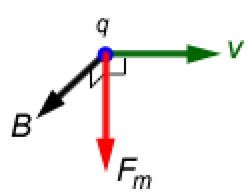


- Direction of magnetic field created by current in a wire

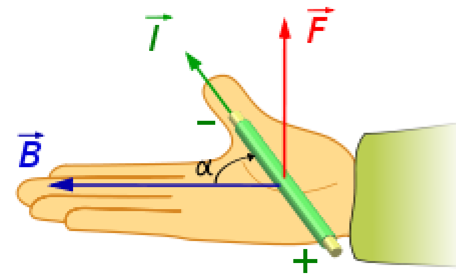
Direction of force in magnetic field created by current

- A charged particle (current) moving in a B-field experiences a *sideways* force that is proportional to the strength of the magnetic field, the component of the velocity that is perpendicular to the magnetic field and the charge of the particle (current)
- This force is known as the **Lorentz force**, and is given by

$$\vec{F}_m = q\vec{v}\ x\ \vec{B}$$



- The **Lorentz** force is always perpendicular to both the velocity of the particle (current) and the magnetic field that created it



Direction of force on wire in magnetic field

- This is basis for electrical generators and motors

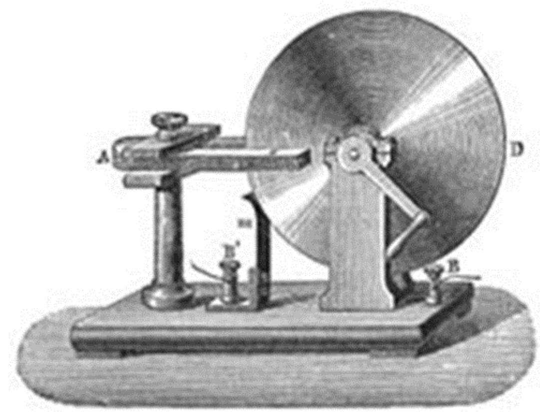
Electricity Generation

- **Electric generator** is a device that converts *mechanical energy* to *electrical energy*
- A generator forces electric charge (carried by electrons) to flow through an external electrical circuit
- The mechanical energy may be supplied by various sources:
  - Heat engines
    - Most common
      - Steam turbines
      - Gas turbines
      - IC engines
  - Water flowing thru a turbine
    - Hydroelectric
  - Wind turbine

- **Electric motor** is a device that converts *electrical energy into mechanical energy*
- Motors and generators have many similarities
  - Utilize Lorentz force
- Many motors can be mechanically driven to generate electricity, and frequently make acceptable generators

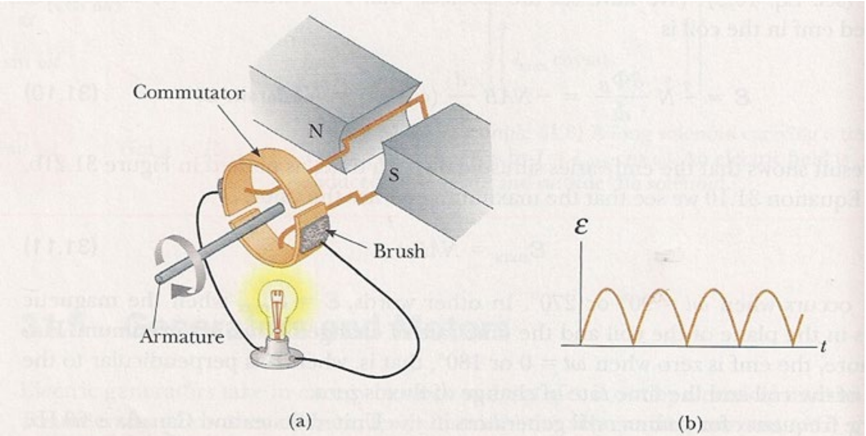
Electricity Generation

- In the years of 1831–1832, **Michael Faraday** discovered the operating principle of electromagnetic generators , Faraday's Law
- The principle is that an electromotive force is generated in an electrical conductor that encircles a varying magnetic flux
- He also built the first electromagnetic generator, called the Faraday disk, using a copper disk rotating between the poles of a horseshoe magnet
- It produced a small DC voltage- mechanical to electrical energy conversion



Electricity Generation

- The **dynamo** was the first electrical generator capable of delivering power for industry
- The dynamo uses electromagnetic principles to convert mechanical rotation into pulsed DC through the use of a commutator
- The first dynamo was built by **Hippolyte Pixxii** in 1832
- A dynamo machine consists of a stationary structure, which provides a constant magnetic field, and a set of rotating windings which turn within that field electromagnets, which are usually called field coils

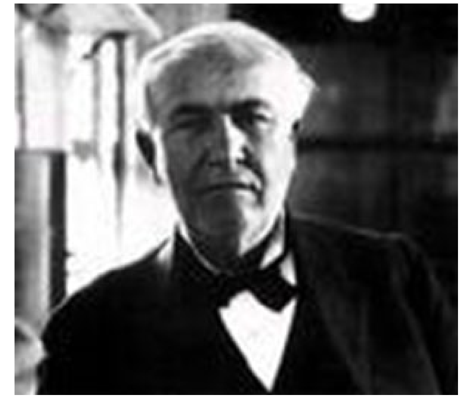


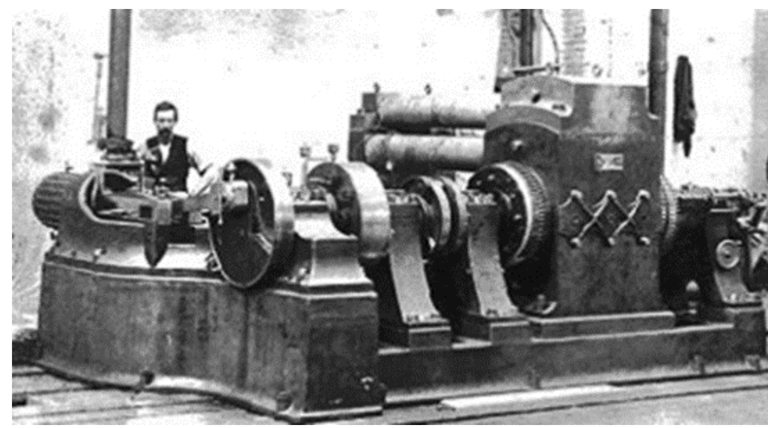
Active Figure 31.23 (a) Schematic diagram of a DC generator. (b) The magnitude of the emf varies in time but the polarity never changes.

- On small machines the constant magnetic field may be provided by one or more permanent magnets
- Larger machines have the constant magnetic field provided by one or more field coils

Electricity Generation

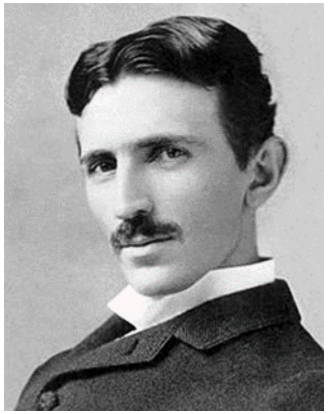
- **Thomas Edison's** Pearl Street station (1892) consisted of six huge dynamos—the largest ever built—" Jumbo"
- Each Jumbo weighed about 27 tons and had a 10-foot armature shaft and an output of 100 kilowatts
- Each dynamo was driven by a steam engine , which received steam from boilers located in another part of the plant
- The Pearl Street plant was designed to run up to 1,400 lamps (light bulbs inserted into fixtures) continuously, and served an area of about one square mile

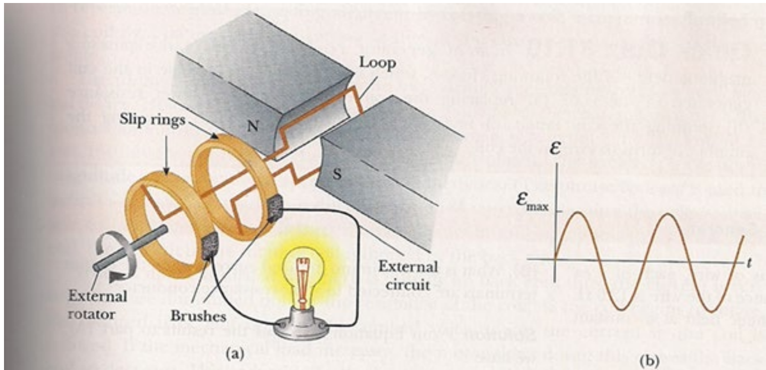




Electricity

- 1884 **Nikola Tesla** invented the electric alternator,
  an electric generator that produces alternating
  current (AC)
- Until this time electricity had been
  generated using direct current (DC)
- AC electrical systems are better for sending electricity over long distances
- The rotating magnetic field induces an AC voltage in the stator windings
- Often there are three sets of stator
  windings, physically offset so that
  the rotating magnetic field
  produces a three phase current

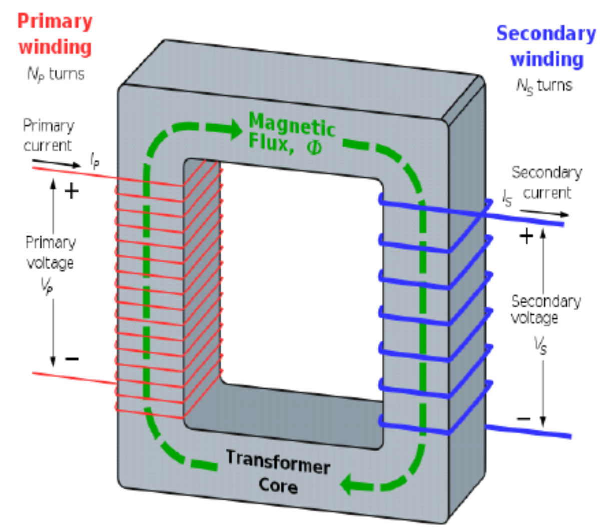


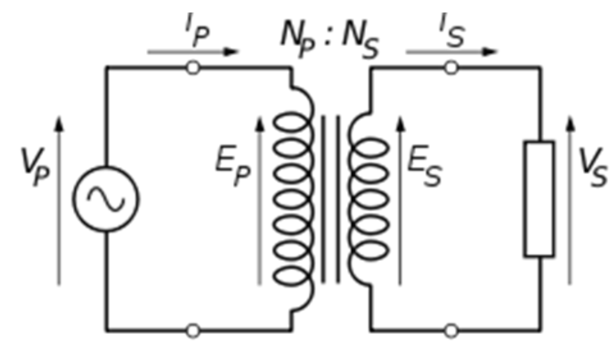


Active Figure 31.21 (a) Schematic diagram of an AC generator. An emf is induced in a loop that rotates in a magnetic field. (b) The alternating emf induced in the loop plotted as a function of time.

Electricity Generation

- A **transformer** is a device that transfers AC electrical energy from one circuit to another through inductance
- It is used to change *AC voltages*
- A varying current in the first or *primary* winding creates a varying magnetic field or flux in the transformer's core which creates a varying magnetic field through the *secondary* winding
- This varying magnetic field induces a varying EMF, or voltage, in the secondary winding
- Current will flow in the secondary winding to a load





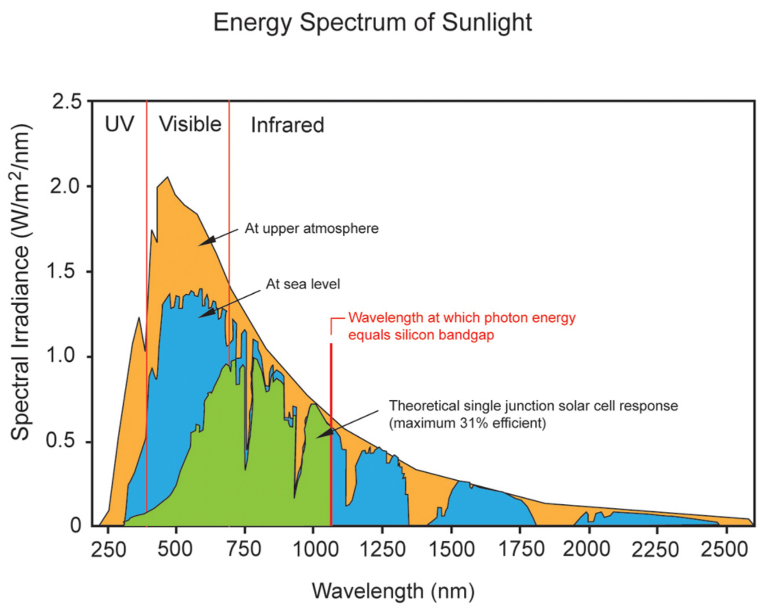
$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

Photovoltaic Effect

- The **photovoltaic effect** is the basic physical process through which a PV cell converts sunlight into electricity
- Sunlight is composed of photons--packets of solar energy
- These photons contain different amounts of energy that correspond to the different wavelengths of the solar spectrum
- When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through
- The absorbed photons generate electricity
- The energy of a photon is transferred to an electron in an atom of the semiconductor device
- With its newfound energy, the electron is able to escape from its normal position associated with a single atom in the semiconductor to become part of the current in an electrical circuit
- Special electrical properties of the PV cell a built-in electric field provide the voltage needed to drive the current through an external load

Photovoltaic Effect

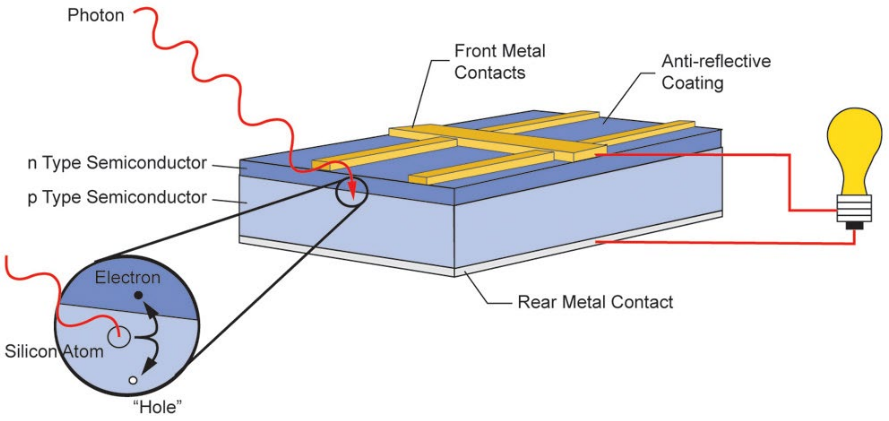
- The energy required to move an electron from the semiconductor atom to a conducting state is a discrete amount
- The energy of a photon of light is determined by its wavelength, with shorter wavelength photons having higher energy than those with longer wavelengths
- A photon with wavelength 1,100 nanometer (nm), corresponding to short wave infra-red light has just enough energy to promote an electron in a *silicon* atom
- Longer wavelength photons have insufficient energy to promote the electron
- They pass straight through the PV cell or are absorbed as heat



- Shorter wavelength photons have more energy than is required to promote the electron
- The excess energy is lost as heat
- The *efficiency upper limit* from a single junction of p-n semiconductor is around 31%
- A PV material made up of multiple layers, tuned to a different wavelength yield up to 44% efficiency in the lab

Photovoltaic Effect

- The heart of a PV cell is the interface between two different types of semiconductor (called p-type and n-type)
- When a light photon with **sufficient** energy hits an atom in this region, it throws out an electron
- The electron, now free to move, travels through the n-type semiconductor to metal contacts on the surface
- The hole left by the absence of the electron travels in the opposite direction, through the p-type semiconductor
- Once at the metal contact, the electron flows around an electrical circuit, doing work in the process, to meet up with a hole at the rear contact



Batteries

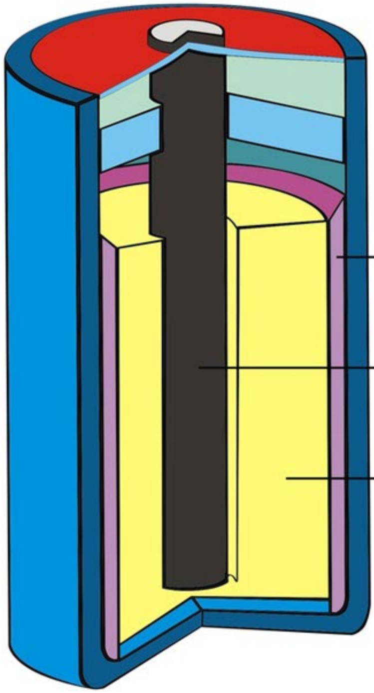
- A **battery** is a device that *converts* **chemical energy** directly to **electrical energy**
- When a load completes the circuit between the two terminals, the battery produces electricity through a series of electromagnetic reactions between the anode, cathode and electrolyte
- The anode experiences an **oxidation reaction** in which two or more **ions** (electrically charged atoms or molecules) from the electrolyte combine with the anode, producing a compound and releasing one or more electrons
- At the same time, the cathode goes through a **reduction reaction** in which the cathode substance, ions and free electrons also combine to form compounds
- The reaction in the anode creates electrons, and the reaction in the cathode absorbs them
- The net product is electricity
- The battery will continue to produce electricity until one or both of the electrodes run out of the substance necessary for the reactions to occur

Common Battery Chemistries

- The *zinc-carbon* chemistry is common in many inexpensive AAA, AA, C and D dry cell batteries
- The anode is zinc, the cathode is manganese dioxide, and the electrolyte is ammonium chloride or zinc chloride
- *Alkaline battery* is also common in AA, C and D dry cell batteries
- The cathode is composed of a manganese dioxide mixture, while the anode is a zinc powder
- It gets its name from the potassium hydroxide electrolyte, which is an alkaline substance
- *Lithium* chemistry is often used in rechargeable Lithium-ion batteries high-performance devices, such as cell phones, digital cameras and even electric cars
- *A* variety of substances are used in lithium batteries, but a common combination is a lithium cobalt oxide cathode and a carbon anode
- *Lead-acid battery* chemistry is used in a typical car battery
- The electrodes are usually made of lead dioxide and metallic lead, while the electrolyte is a sulfuric acid solution

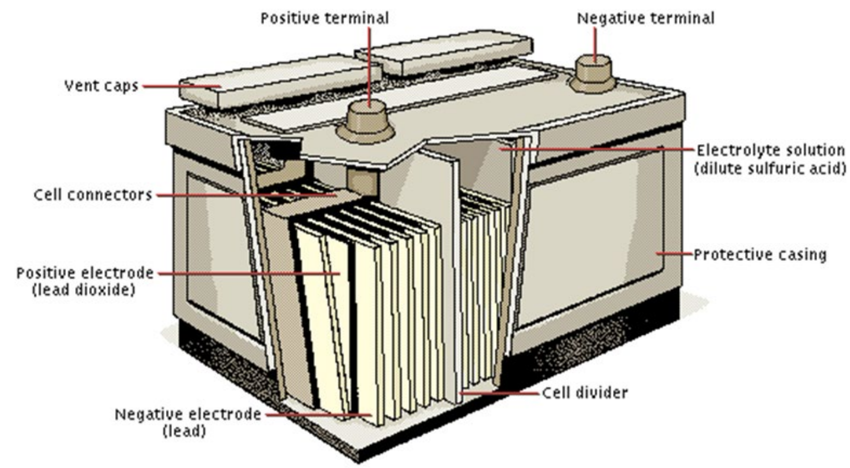
Batteries

- Dry cell batteries are the most widely used type of primary cell
- Every dry primary battery has two structures called *electrodes*
- Each electrode consists of a different kind of chemically active material
- An electrolyte between the electrodes causes one of them, called an ***anode***, to become negatively charged and the other, called a ***cathode***, to become positively charged
- The electrolyte helps promote the chemical reactions that occur at the electrodes



Batteries

- **Lead-Acid Storage Battery** consists of a plastic or hard-rubber container that holds three or six cells, each of which has two sets of latticelike electrodes or plates
- The frames of these structures, called *grids*, are made of a **lead-antimony** alloy
- The *meshes* (open spaces) of the negative electrode are filled with a mass of pure **lead** in spongy form



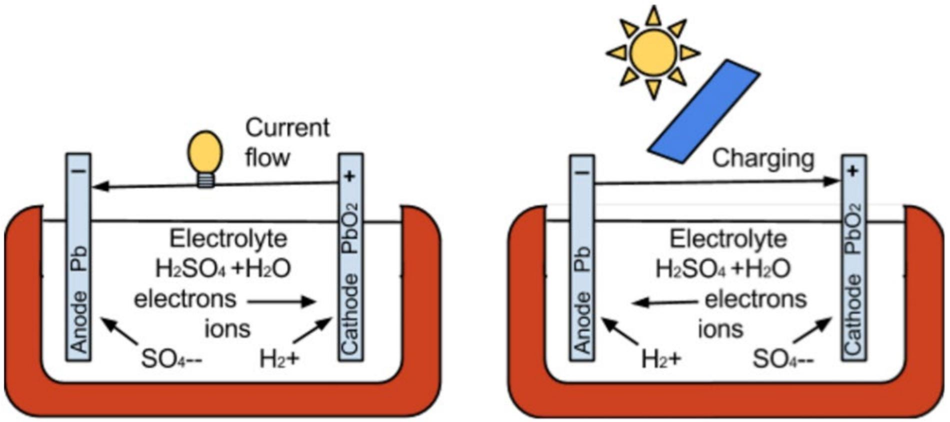
- The meshes of the positive electrode contain **lead dioxide**, a compound of lead and oxygen
- An electrolyte of **sulfuric acid and water** surrounds the electrodes
- Output is ~2 volts per cell

Batteries

- During the discharge process, chemical reactions take place between the electrode materials and the electrolyte
- At the negative electrode, atoms of pure lead react with negative sulfate ions of the electrolyte
- The negative sulfate ions, along with positive hydrogen ions, form when sulfuric acid dissolves in water
- As the lead atoms combine with the sulfate ions, each lead atom loses two electrons and becomes a molecule of lead sulfate
- The electrons lost by the lead atoms flow from the negative electrode to the positive electrode through a device using the electric current
- At the positive electrode, they are captured by molecules of lead dioxide, which in turn combine with the hydrogen and sulfate ions of the electrolyte
- This reaction produces lead sulfate and water
- The current-producing process decreases and dilutes the electrolyte of sulfuric acid by using up sulfate ions and by adding water molecules to the solution
- The battery becomes discharged when so little sulfuric acid remains that the necessary chemical reactions can no longer occur

Batteries

- A lead-acid battery can be recharged by forcing electrons through the battery in a direction opposite to that of the discharge process.
- This action reverses the chemical reactions that occur at the electrodes when a battery discharges
- The reversed reactions of the charging process restore the electrode materials to their original form
- They also increase the amount of sulfuric acid in the electrolyte to a satisfactory level



- Car batteries are recharged:
- Chemical energy converted to thermal energy-- IC engine
- Thermal energy converted to mechanical energy—IC engine
- Mechanical energy converted to electrical--alternator

Batteries

- The voltage developed across a cell's terminals depends on the energy release of the chemical reactions of its electrodes and electrolyte
- Alkaline and zinc carbon cells have different chemistries but approximately the same emf of 1.5 volts
- Ni Cd and NiMH cells have different chemistries, but approximately the same emf of 1.2 volts
- On the other hand the high electrochemical potential changes in the reactions of lithium compounds give lithium cells emfs of 3 volts or more

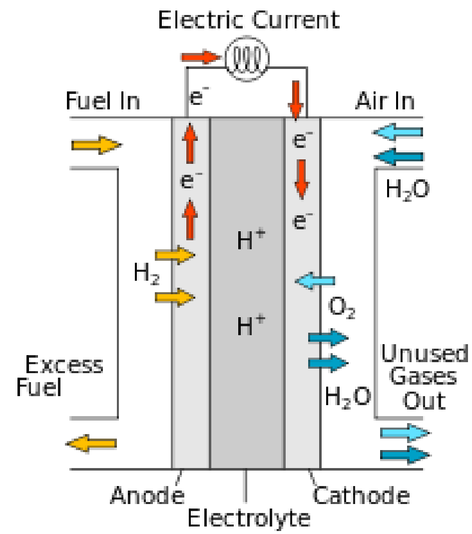
Type	Voltage	Mj/Kg
NiCd	1.2	0.14
Lead Acid	2.1	0.14
NiMH	1.2	0.36
NiZn	1.6	0.36
Li Ion	3.6	0.46

Gasoline `44 Mj/kg

Fuel Cells

- A **fuel cell** is a device that *converts* the chemical energy from a fuel into electricity through a *chemical reaction* with oxygen or another oxidizing agent
- Welsh Physicist **William Grove** developed the first crude fuel cells in 1839
- Hydrogen is the most common fuel, but hydrocarbons (natural gas and alcohols like methanol) are sometimes used
- Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run
- The first practical use of fuel cells was in NASA space programs to generate power for probes, satellites and space capsules
- There are many types of fuel cells, but they all consist of an *anode* (negative side), a *cathode* (positive side) and an *electrolyte* that allows charges to move between the two sides of the fuel cell
- Electrons are drawn from the anode to the cathode through an external circuit, producing DC electricity

Fuel Cells



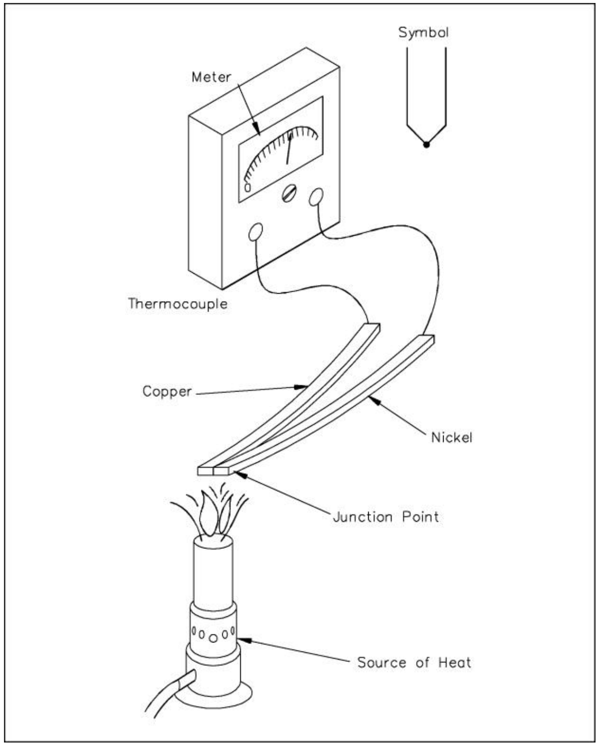
- Fuel cells are made up of three adjacent segments:
- The **anode**, the **electrolyte**, and the **cathode**
- Two chemical reactions occur at the interfaces of the three different segments
- The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created
- At the anode a *catalyst* oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron
- The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot
- The freed electrons travel through a wire creating the electric current
- The ions travel through the electrolyte to the cathode
- Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide

Fuel Cells

- Fuel cells can be thought of as batteries with a continuous supply of chemicals
- Fuel cells are classified by the type of electrolyte they use.
- Individual fuel cells produce very small amounts of electricity, about 0.7 volts, so cells are "*stacked*“ to increase the voltage and current output
- In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions.
- The energy efficiency of a fuel cell is generally between 40-60%

Thermoelectric Effect

- A **thermocouple** is a device used to *convert* heat energy into a voltage output
- It consists of two different types of metal joined at a junction
- As the junction is heated, the electrons in one of the metals gain enough energy to become free electrons
- The free electrons will then migrate across the junction and into the other metal
- The displacement of electrons produces a small voltage across the terminals of the thermocouple
- Materials used in thermocouples include: iron and constantan; copper and constantan; antimony and bismuth; and chromel and alumel



Thermocouples are normally used to measure temperature
The voltage produced causes a current to flow through a meter, which is calibrated to indicate temperature


BRIAN
TX PLANS
ARE YOU SURE IT'S
$E=\sqrt{\frac{P}{R}}$ NOT $E=P\times R$?

- Radiation
- Light
- Incandescent light
- Fluorescent light
- LED light
- Radioactivity
- Nuclear Fission
- Nuclear Fusion