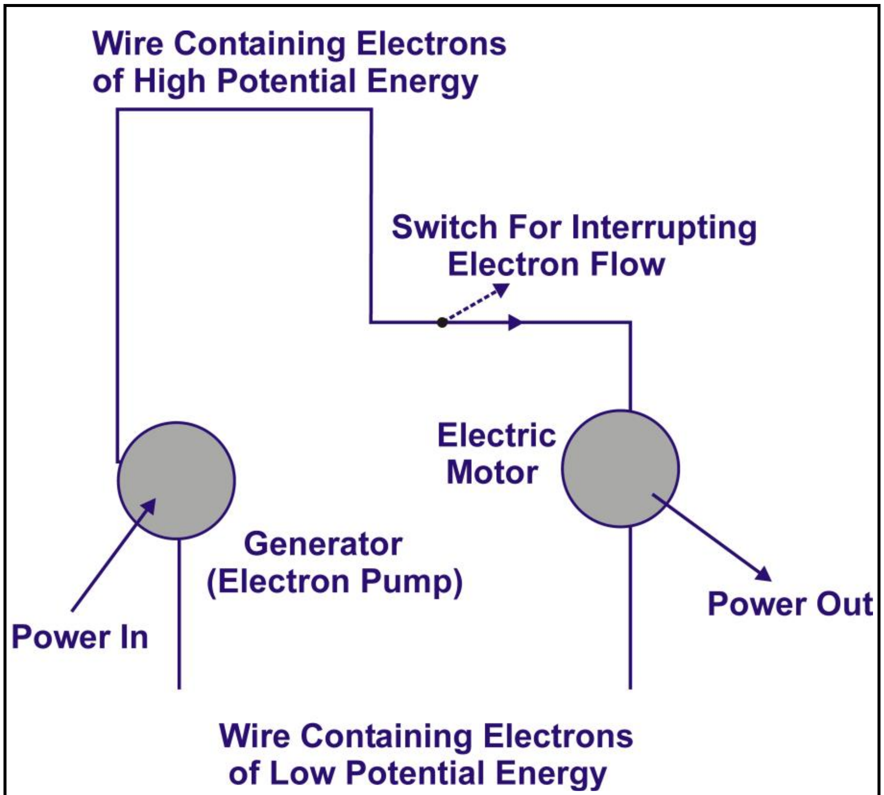
Electromotive Force

A. Electromotive Force (Voltage)

1. The electrical potential difference that causes free electrons to move in a conductor as an electric current is called an electromotive force (EMF). It is often referred to as voltage (E) or difference of potential. When difference of potential exists between two charged bodies connected by a conductor, electrons will flow along the conductor. This flow will be from the negatively charged body to the positively charged body until the charges equalize and the potential difference no longer exists.

2. Mechanical Analogy of EMF

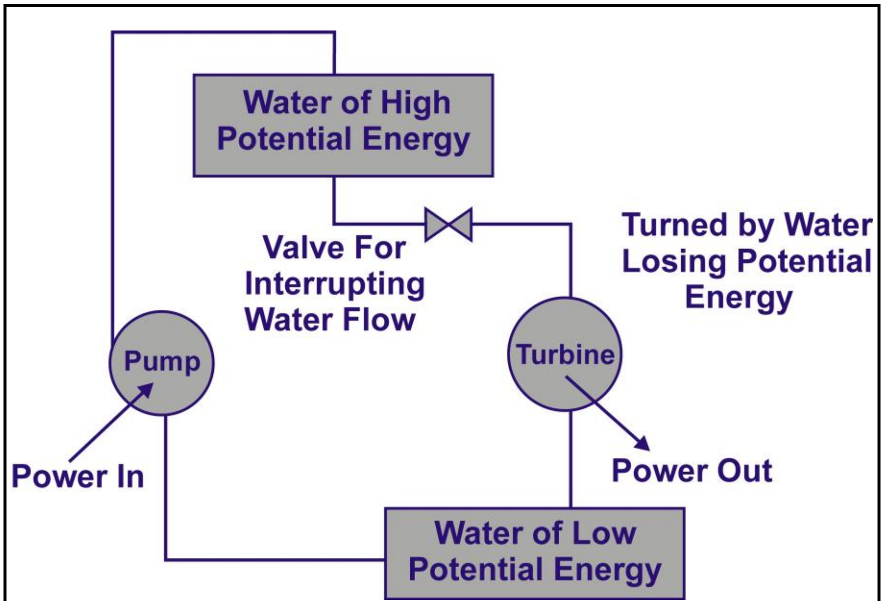
    a. The electron pump (following illustration) is a source of electromotive force or voltage. Any device which generates electrons of increased potential energy is a source of electromotive force.



Picture 1, Electrical Circuit

3. A volt is the unit of electrical potential difference between two points that pushes current through a circuit. One volt is defined as the EMF required to produce a current of one ampere through a resistance of one ohm. (Ampere and ohm will be defined later in this chapter.)

4. In the following illustration, the mechanical pump overcomes the potential difference between the tanks. By analogy, so must the electron pump overcome a potential difference which resists electron flow (resistance).



Picture 2, Mechanical Circuit

B. Electrical Null

1. If no difference of potential exists between two points, electrons will not be motivated to move between them. This does not mean that voltage cannot exist at each point. If two points have equal voltages with respect to some common point (such as the earth), then no difference (no voltage) exists between the two points. Therefore, no flow of electrons will occur even if the two points are connected together by a good conductor. This is called electrical null and is used by many electrical control circuits to match two different signals. This is commonly done prior to switching between (e.g.,

transferring a regulator from automatic to manual) or connecting two circuits (e.g., placing the main electrical generator on the grid).

2. The concept of electrical null is better seen using a mechanical analogy of two separate piping systems, each with a pump (equivalent to a voltage source). Each pump maintains its system at 100 pounds per square inch with respect to atmospheric pressure (equivalent to voltage potential). The pumps are connected by a closed valve. A pressure gauge placed across the valve (differential pressure gauge) will indicate no pressure (no "voltage potential" exist between the two systems). If the valve is opened, no water (equivalent to electrons) will flow between the two systems. With the systems at different pressures, output of one pump would be changed to match the system pressures, avoiding pressure surges when the valve was opened. This process is equivalent to nulling two electrical control signals.

C. Methods of Producing EMF

1. Some methods of producing voltage are much more widely used than others. The following are six common methods of producing a voltage:

   a. FRICTION (static electricity) - voltage produced by rubbing two materials together

   b. PRESSURE (piezoelectricity) - voltage produced by squeezing crystals of certain substances

   c. HEAT (thermoelectricity) - voltage produced by heating the joint (junction) which connects two dissimilar metals

   d. LIGHT (photoelectricity) - voltage produced by light striking photosensitive (light-sensitive) substances

   e. CHEMICAL ACTION - voltage produced by chemical reaction in a battery cell

f. MAGNETISM - voltage produced in a conductor when it moves through a magnetic field or when a magnetic field moves through the conductor, cutting magnetic field lines.

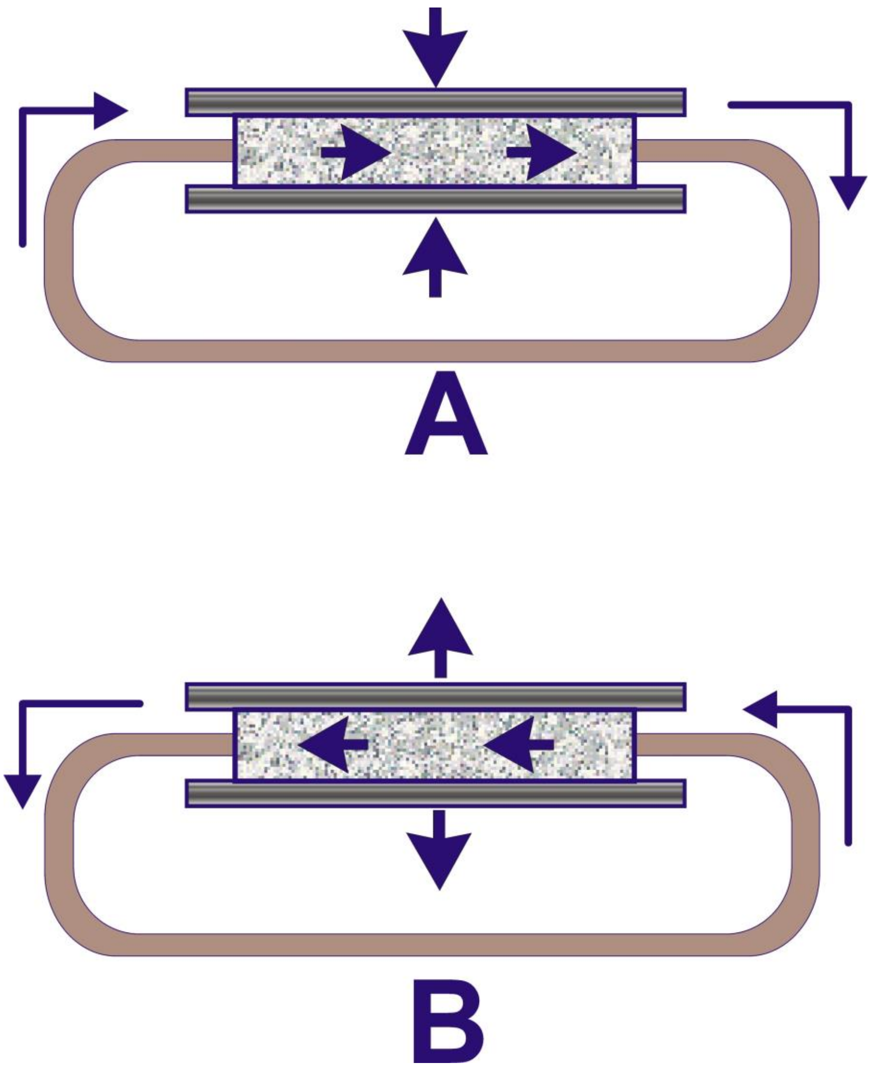
D. Voltage Produced by Friction

1. This is the least used method. Its main application is in Van de Graaff generators, used by some laboratories to produce high voltages. As a rule, friction electricity (static electricity) is a nuisance. An example is the unpleasant shock received from static electricity when walking across a dry carpet and coming into contact with some other objects, such as a doorknob.

E. Voltage Produced by Pressure

1. This action is referred to as piezoelectricity. It is produced by compressing or decompressing crystals of certain substances. In the non-crystallized state, molecules are arranged irregularly. In the crystallized state, the molecules are arranged in a regular and uniform manner. Natural crystalline matter is rare (for example, a diamond, which is crystalline carbon). Most crystals are manufactured.
2. Crystals of substances such as Rochelle salt, or quartz, exhibit peculiar electrical characteristics. These characteristics are referred to as piezoelectric effects. For instance, when a crystal of quartz in compressed (Figure 1-7A), electrons move through the crystal as shown. This creates an electrical potential difference between the two opposite faces of the crystal. If an external wire is connected while the pressure and consequent EMF are present, electrons will flow. If pressure is held constant, the electron flow continues until the charges are equalized.
3. When the force is removed (the crystal is decompressed) an electric force is immediately caused in the opposite direction, (Figure 1-7B). Thus, the

crystal is able to convert mechanical force (either pressure or tension) to electrical force.

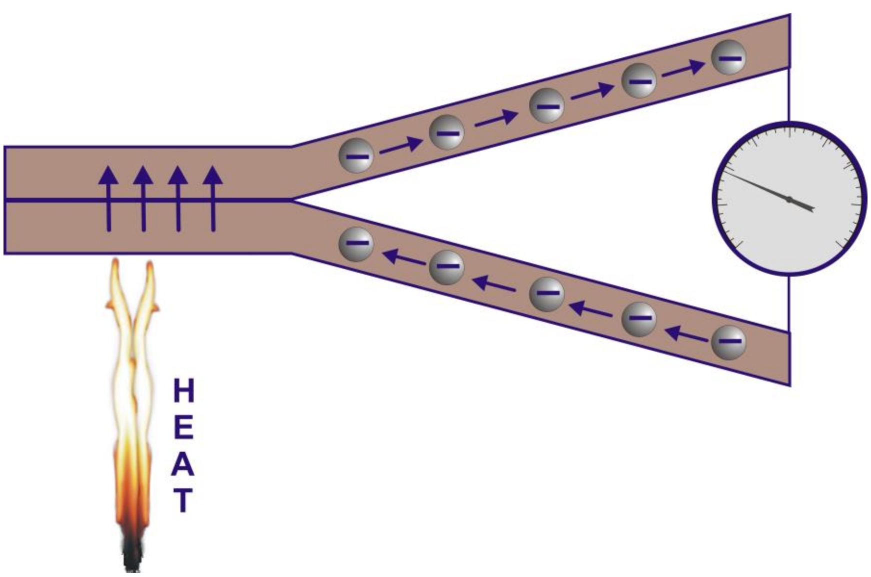


Picture 3, Voltage Produced by Pressure

4. The power capacity of a crystal is extremely small. However, crystals are useful because of extreme sensitivity to changes in mechanical force or temperature. Due to other characteristics not mentioned here, crystals are most widely used in radio communication equipment and vibration monitoring instruments, such as the acoustic monitors on tail pieces of steam relief valves and vibration monitors on recirculation and feedwater pump motors.

F. Voltage Produced by Heat

1. When a length of most metals, (such as copper), is heated at one end, electrons move from the hot end to the cooler end. However, in some metals (such as iron), the opposite takes place. These characteristics are illustrated in Figure 1-8. Negative charges (electrons) are moving through the copper away from heat, and through the iron toward heat. They cross from iron to copper at the hot junction and from copper through the current meter to iron at the cold junction. A device which uses this method is a thermocouple.



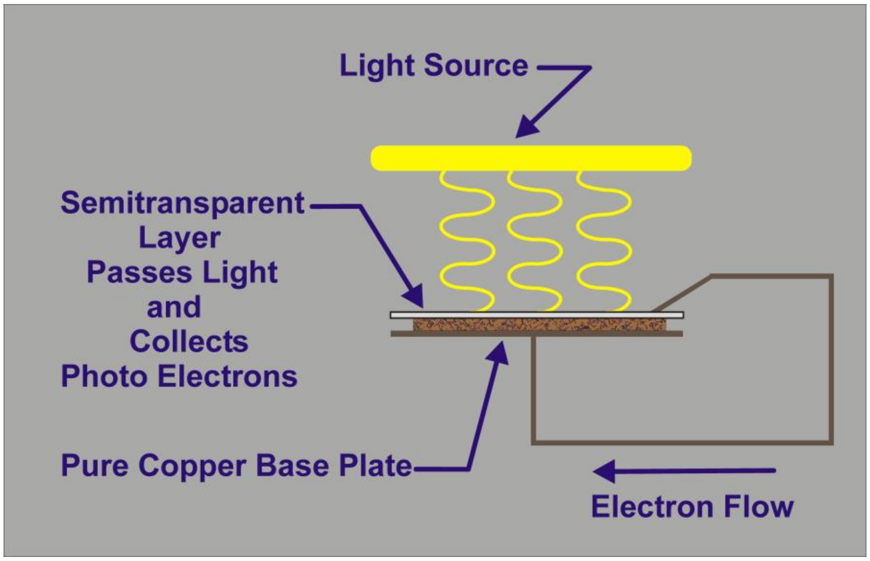
Picture 4, Voltage Produced by Heat

2. Thermocouples have somewhat greater power capacities than crystals, but still very small compared to some other sources. Thermoelectric voltage in a thermocouple depends mainly on the temperature difference between hot and cold junctions. Consequently, they are widely used to measure temperature or as heat-sensing devices in automatic temperature control equipment in the BWR plant. Thermocouples are generally subjected to much greater temperatures than ordinary mercury or alcohol thermometers.

G. Voltage Produced by Light

1. When light of sufficiently high frequency (energy) strikes the surface of a substance, it dislodges electrons from their orbits around the surface atoms. Some substances, mostly metallic ones, are far more sensitive to light than others. That is, with a given amount of light, more electrons are dislodged and emitted from the surface of a highly sensitive metal than from a less sensitive substance. Upon losing electrons, the photosensitive (light sensitive) metal becomes positively charged and an electric field is created. Voltage produced in this manner is referred to as photoelectric voltage.

2. Photosensitive materials most commonly used to produce photoelectric voltage are various compounds of silver oxide or copper oxide. A complete device which operates on the photoelectric principle is a photoelectric cell. There are many sizes and types of photoelectric cells in use, each serving a special purpose. Nearly all, however, have some basic features of the photoelectric cell shown in the illustration below.



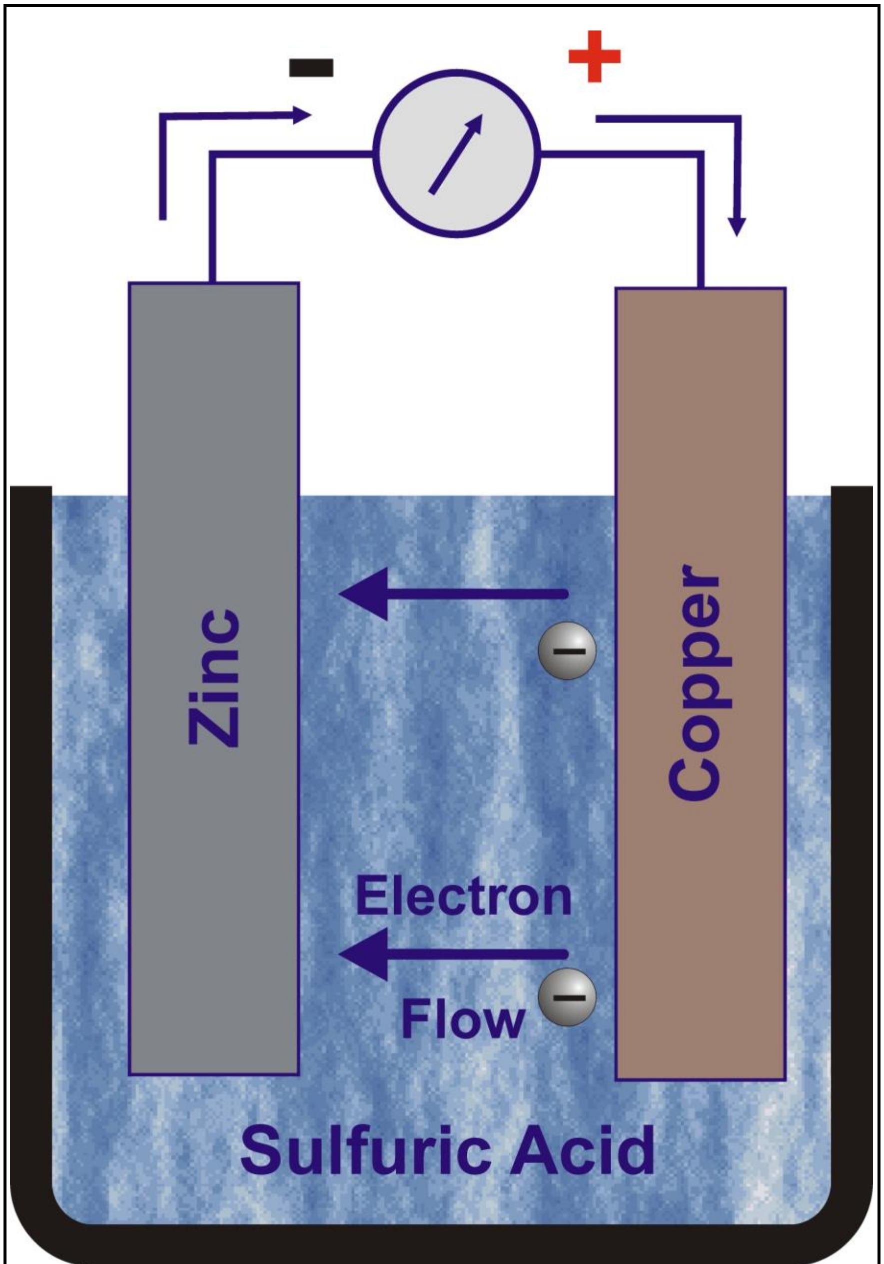
Picture 5, Voltage Produced by Light

3. The cell shown in the illustration above is constructed in layers. A base plate of pure copper is coated with light-sensitive copper oxide. An additional layer of metal is placed over the copper oxide. This additional layer serves two purposes. It is extremely thin to permit the penetration of light to the copper oxide and it accumulates the electrons emitted by the copper oxide.
4. An externally connected wire completes the electron path. The photocell's voltage is utilized by connecting external wires to some other device, which amplifies (enlarges) it to a usable level.
5. A photocell's power capacity is very small. However, it reacts to light-sensitive variations in an extremely short time. This characteristic makes the photocell very useful in detecting (or accurately controlling) a great number of processes or operations. The photoelectric cell, or some form of the photoelectric principle, is used in television cameras, automatic manufacturing process controls, door openers, burglar alarms, and scintillation detectors (which detect and measure radiation).

H. Voltage Produced by Chemical Action

1. Up to this point, it has been shown that electrons were removed from their parent atoms and set in motion by energy derived from friction, pressure, heat, or light. In general, these forms of energy do not alter molecules of substances acted upon. That is, molecules are not usually added, taken away, or split up when subjected to these four forms of energy. Only electrons are involved. A voltage produced by chemical action is the result of two or more different substances combining and/or transferring whole atoms between them with a resulting transfer of electrons. When strips of zinc and copper are immersed in a solution of sulfuric acid to form a simple electric cell (illustration below) a resultant chemical change causes the zinc and copper strips to take on electrical charges. This process of producing a

voltage by chemical action in batteries is explained in detail later in this volume.



Picture 6, Voltage Produced by Chemical Action

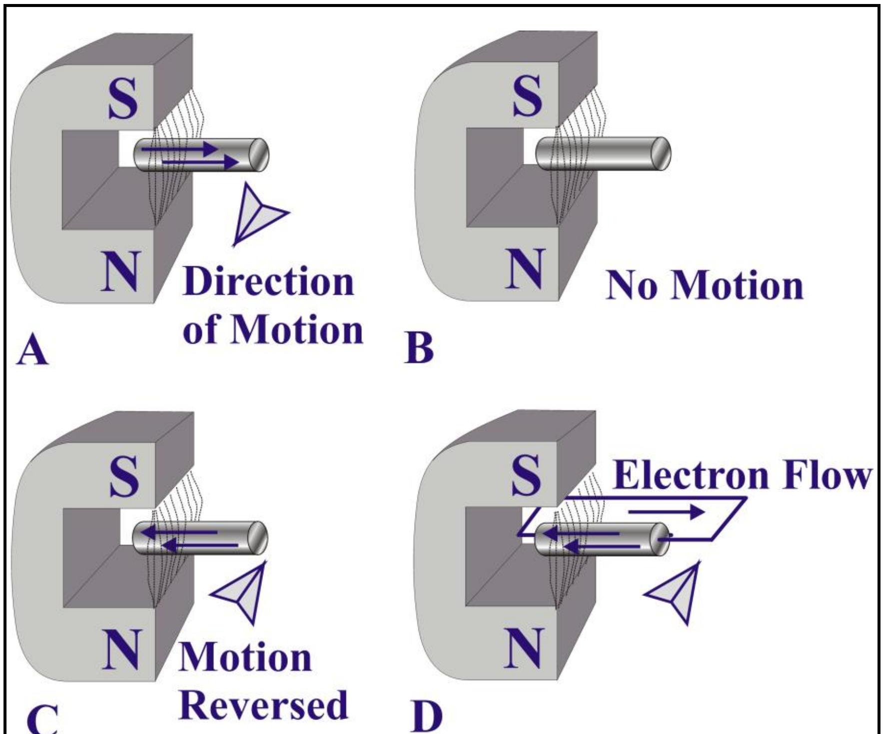
I. Voltage Produced by Magnetism

1. Magnets or magnetic devices are used for thousands of different jobs. One of the most useful and widely employed applications of magnets is in the

production of vast quantities of electric power from mechanical sources. Mechanical power is provided by a number of different sources, such as gasoline or diesel engines, and water or steam turbines. However, the final conversion of the power from these engines to electricity is done by generators employing the principle of electromagnetic induction. These generators (of many types and sizes) are discussed later. The important subject discussed here is the fundamental operating principle of electromagnetic induction generators.

2. Three fundamental conditions must exist before voltage can be produced by magnetism. There must be:
   a. a conductor, in which a voltage can be induced,
   b. a magnetic field in the conductor's vicinity, and
   c. relative motion between the field and the conductor.
3. When a conductor moves across a magnetic field to cut lines of magnetic force, electrons within the conductor are driven in one direction or another. Thus a potential difference (voltage) is created.
4. In Figure 1-11, the three conditions needed for creating an induced voltage are:
   a. a magnetic field existing between the poles of C-shaped magnet
   b. a conductor
   c. relative motion between the conductor and the magnetic field.
5. In the illustration below (A), the conductor is moving out of the page. The magnetic field acts upon the conductor's electrons so that they become free electrons and move from left to right. The right-hand end becomes negative, and the left-hand end positive. the illustration below (B), the conductor is stopped, eliminating motion. Since relative motion is one of the

three required conditions, there is no longer induced EMF. Consequently, there is no longer difference in potential between the two ends of wire. In the illustration below (C), the conductor is moving into the page. An induced EMF is again created. However, reversal of motion has caused a reversal in the direction of the induced EMF.



Picture 7, Voltage Produced by Magnetism

6. If a path for electron flow is provided between the ends of the conductor, electrons leave the negative end and flow to the positive end. This condition is shown in the illustration above (D). Electron flow continues as long as EMF exists. This is the basis underlying the operation of a generator. In studying illustration above, note that the induced EMF could also have been created by holding the conductor stationary and moving the magnetic field back and forth.

Electromotive Force

PRACTICE:

1 What is the electrical potential difference that causes free electrons to move in a conductor as an electric current called?

2. To what mechanical device would a generator equate?