



Electricity 101

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Introduction

Traditional forms of power include muscle (human and animal) wind, water and steam. However, our modern world is based on the availability of electricity to power our machines, heat and cool our homes, and preserve and cook our food. A basic knowledge of electricity is critical to understanding how heating, ventilating, air conditioning and refrigeration (HVACR) operates.

Goals

By the end of this discussion you will understand what electricity is, why it flows, and the two basic types used in HVACR.

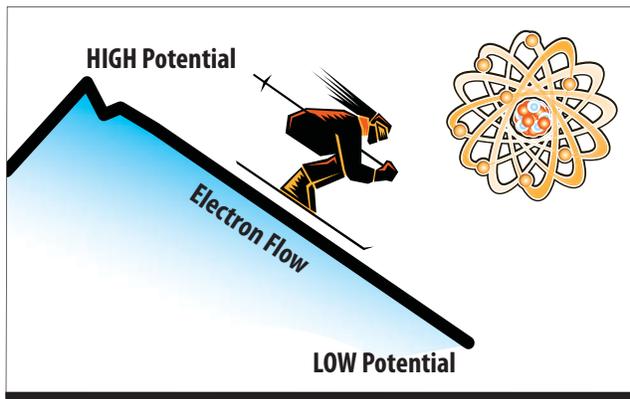
Definitions

- Electricity** the flow of electrons.
- Potential** the latent ability to do electrical work, measured in volts.
- Volts/voltage** the measure of potential charges. Sometimes called electrical pressure.
- Electrons** particles of the atom that have an electrical charge of -1, that is, a negative charge.
- Ampere/ amp** the measure of the number of electrons flowing past a particular location in a particular amount of time. One ampere is the movement of 6.3×10^{18} (6,300,000,000,000,000,000) electrons per second.
- Current** flow of electricity measured in amperes, sometimes shortened to amps.

How does electricity flow?

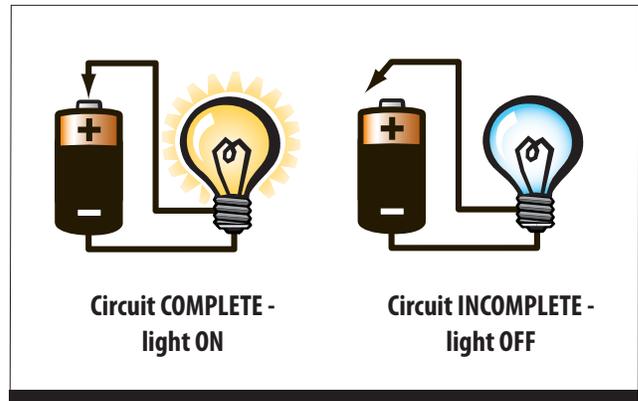
Electricity is defined as the flow of electrons. Electrons are the negatively charged particles in atoms. **Figure 1** is a stylized illustration of an atom where the electrons are shown orbiting around the nucleus of the atom. The electrons are loosely bound to the nucleus but can be induced to "jump" from one atom to another by inputting energy or creating a voltage potential difference. This jumping of electrons from one atom to another in a particular direction is the Flow of electricity. Flow is always from a higher potential, or voltage, to a lower potential, or voltage.

Figure 1 - Flow of Electricity - High Potential to Low Potential



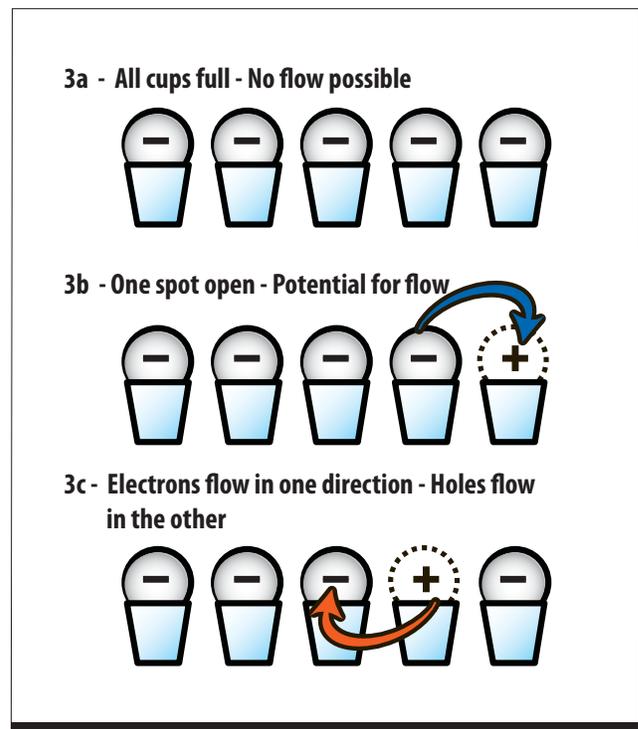
The flow of electrons is electricity, but that is only half the story. In order for electricity to do work, it must flow in a complete circuit. The circuit consists of the source of the potential, the pathway or conductor of the potential, and the consumer or work to be done. Refer to **Figure 2**.

Figure 2 - Complete and Incomplete Circuits



Another necessity for electricity to flow is the source of electrons, and places for them to go while flowing. These places to go during flow are called "electron holes", or just holes. An illustration of this flow is shown in **Figure 3 a, b & c**, with ping pong balls and paper cups. In **Figure 3a**, all cups are full and no flow

Figure 3 - Electron "Holes" and Electrical Flow



is possible. This is an electrical state where there is no potential or complete circuit. A potential with a complete circuit, **Figure 3b**, gives the ping pong ball (electron) a place to move to. The electron can move and create a hole for the next electron to fill. **Figure 3c** shows that as electrons flow in one direction, the holes flow in the other.

How potentials are created

As stated, electricity can only flow if there is a complete circuit and a potential to drive flow. Since the First Law of Thermodynamics states that energy cannot be created or destroyed, and the Second Law states that entropy always increases (see form 9.W.2 Basic Thermodynamics), electrical potentials and electrical flow must be created by conversion of another form of energy. **The potential, or pressure to flow, is called voltage and can be created chemically, thermally, mechanically and electromagnetically.**

Batteries are the simplest **chemical** creator of voltage. When two materials with different numbers of holes and loosely bound electrons are connected by conductors or electrolytes, the electrons will flow from the material with the greater number of loose electrons to the material with the greatest number of unfilled holes. If a galvanized nail and copper wire are inserted into a lemon, the zinc in the galvanic plating gives up 2 loose electrons and two hydrogen atoms in the citric acid in the lemon juice absorbs one electron each. This exchange of electrons is a flow of electricity that can easily be measured as a voltage potential.

Thermal voltage potentials are less obvious in everyday life but are common in HVACR and automotive applications. If wires of two special metallic compounds are connected and the joint heated, a small but measurable potential will be created and current will flow.

Mechanically created electrical potentials are very familiar to anyone who has walked across a carpet on a dry day and

received a shock from touching a door knob. Friction between two materials can rub electrons from one of the materials and “stick” them on to the other. Potentials or voltages resulting are in the thousands of volts.

By far the most common, and useful, means of creating potentials and current is **electromagnetic**. When a conductor or wire is moved through a magnetic field, a current will be induced to flow through the wire. This generation by induction is the basis of almost all the current used in our homes and businesses throughout the world. Magnets spun by wind, water, engines or steam are housed by cages of wire and the resultant power is measured in thousands of volts, millions of amps and billions of watts.

What types of currents are used?

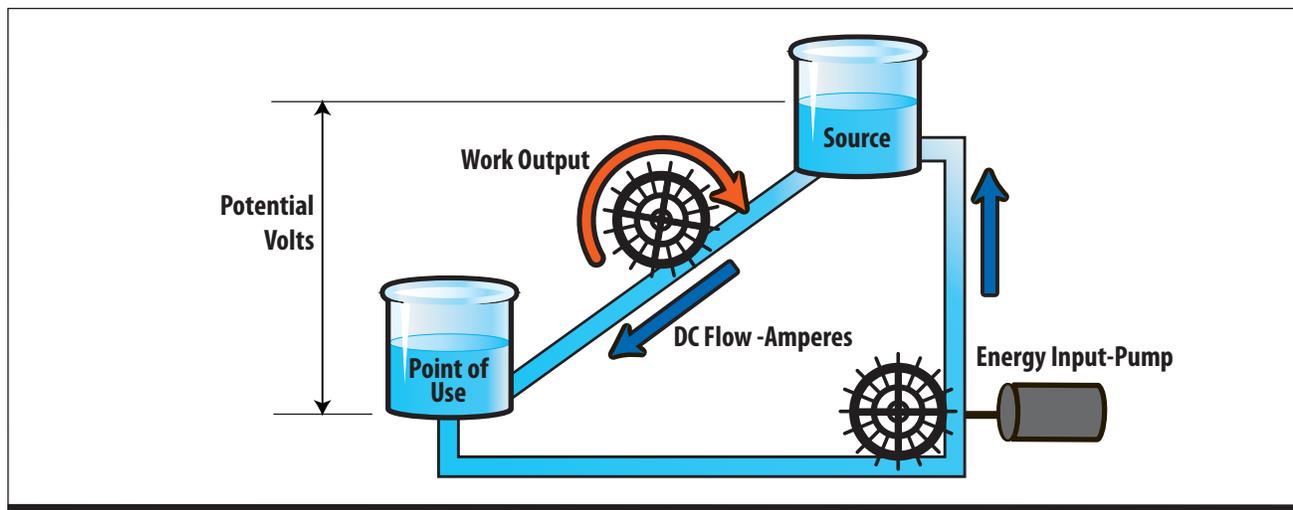
Electricity is divided into 2 main types: direct current (DC) and alternating current (AC). While both are used in HVACR, they are generally applied in different parts of the system.

Direct Current

DC is electricity that always flows in one direction, and is usually thought to flow from positive (+) to negative (-). This concept of electric flow is called Conventional Flow and was defined by Benjamin Franklin. Since electricity is the flow of the negatively charged electrons, technically, the flow is from the negative to the positive pole. This is known as Electron Flow.

Batteries are the most familiar source of DC, and the **—** and **+** signs are clearly shown on the poles of the battery. In electrical symbols, DC is often denoted with the **.....** graphic. This is accurate because in DC, one pole is always at a relatively constant positive voltage while the other pole is at 0 volts, or ground. In a flashlight, each cell is about 1.5 volts at the positive side and 0 volts at the negative pole. When a number of cells are physically connected, the combination is referred to as a battery and the voltage will be the sum of all the individual cell voltages.

Figure 4 - Direct Current (DC) Flow



Although espoused by Thomas Edison, and still used in some power applications, DC is primarily used in electronics. Direct current cannot be transmitted over long distances efficiently and requires larger relays and switches than alternating current. Motors for use on DC are more complex and expensive than AC type induction motors. A modern example is the Electronically Commutated Motor (ECM).

The inefficiency of DC is based on the fact that all the electrons must actually flow from the source to the machine using it and then back to the source, as represented in **Figure 4**. In the figure, water is used to represent the flow of electricity. DC flows from the high voltage to the point of use and back to the source. Note that all of the flow is in one direction, and all the current must flow to do work. The complete loop is subject to "friction" between the electrons and the wire material. This friction is called resistance and serves to reduce the voltage received at the machine using the current. Therefore, a higher voltage must be supplied at the source and the cost of generating it is higher. The further from the source, the higher the voltage must be. Edison, himself, was aware of these limitations and planned to have a generation station every mile or two, which would have been exorbitantly expensive. A way to reduce some of the losses in transmission would be to use a much higher voltage to begin with and reduce it at the place of consumption. Unfortunately, there is no convenient way of raising or dropping DC voltage.

Alternating Current

AC, as its name suggests, does not constantly flow in one direction. Instead, AC changes direction many times per second. The

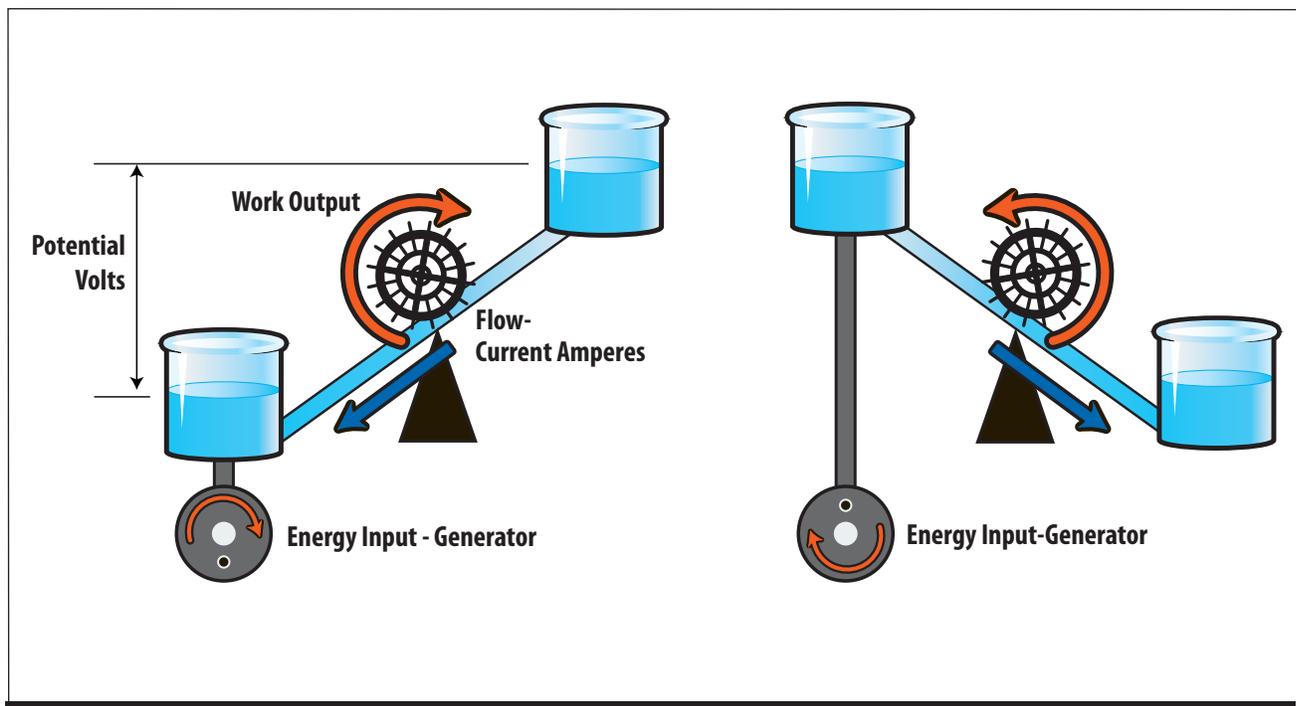
rate of this change is called the frequency or cycles per second, and is measured in hertz (Hz) after Heinrich Hertz, a pioneer in the study of electricity and electromagnetism. In the United States, AC is supplied at 60 Hz while in Europe, 50 Hz is the standard frequency. To change direction, the voltage drops to 0 and then to a negative voltage. This is represented by the sine wave symbol , and provides the push-pull of AC.

The real advantage and basis of the high efficiency of AC is the fact that the electrons do not flow the entire distance to the point of use.

Figure 5a & b represents this alternating current flow as a see-saw with buckets of water on each end. The difference in voltage potential or height of the buckets causes some of the water to flow to the lower side. However, a short time later, the see-saw flips and reverses the flow. Since the see-saw flips so quickly, very little of the water flows through the connecting pipe. Smaller amounts of flow decrease the effects of resistance and therefore efficiency remains high. In this example, the energy needed to create the electric flow is provided by a mechanism (generator) that flips the see saw back and forth.

In this mechanical example, the water wheel changes direction of rotation for each flip of the see-saw. In real applications of AC, the motors continue to rotate in the same direction even while the current flow is alternating.

Figure 5a & 5b- Alternating Current (AC) Flow





Questions

- 1) What is a simple definition of electricity?
- 2) Do electrons flow from the positive to the negative pole of a battery?
- 3) Why won't electricity flow in an "open" circuit?
- 4) Name 3 ways to generate an electrical potential.

Going Further

- 1) The frequency of AC is measured in Hz or Hertz and is named for Heinrich Hertz. Almost all other units used in electrical terminology are based on the names of pioneers in the science of electricity or power. Interested readers should investigate Watt, Volta, Galvani and Ampere for both the person and their namesake unit.

2 Electromagnetic generation of voltage is not limited to the cited means. So called Solar Cells or photovoltaic panels create voltage and power from light. Albert Einstein, best known for $E=MC^2$, received his Nobel Prize for describing this Photoelectric Effect, not from his Theory of Relativity.

3) Not all cells used in batteries have the same voltage. Car cells are lead/acid and develop 2 volts each. There are six connected together to get 12 volt batteries. Alkaline cells are 1.5 volts but nickel/cadmium cells only produce 1.2 volts. Lithium ion batteries win the race at 3.2 volts per cell. Other chemistries are also used, and can be investigated.

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