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Electricity Basics

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INTRODUCTION

This brochure explains the fundamentals of how electricity works, how it is generated, how it is provided to users and how it is used to power or provide signals to chemical dispensing equipment.

ATOMS AND ELECTRON FLOW

The basic building blocks of matter are atoms. An atom is composed of two parts. The center, called the nucleus, consists of positively charged particles called protons and uncharged particles called neutrons. Orbiting the nucleus at high rates of speed are negatively charged particles called electrons. Every atom of a particular element in nature has the same number of protons and electrons, but the number varies from element to element. Oxygen has 8 of each while carbon has only 6. There are over 100 different elements. Because the number of protons (and electrons) differs from element to element, different elements have different properties. When electrons from certain elements are caused to move in certain paths, electrical energy (electricity) and magnetic fields are generated. This creates a form of energy that can be harnessed to power devices.

To understand how electrical energy is measured, consider water flowing through a pipe. The force (energy) generated by the water is a function of both the diameter of the pipe and the rate of flow of the water within the pipe. The more water flowing past a given point, the more energy it has. Also, the faster the water flows, the more energy it has. These two basic concepts can also be used to describe electricity moving within a wire. The rate of flow of the electrons (speed) is known as the amperage or current of the electrons. The number of electrons moving past a given point generates the force of pressure, which is called voltage or electromotive force. Voltage can also be thought of as the energy that each electron has. Higher voltages mean more energy is present. Higher voltages are more dangerous to people than lower voltages. Ultimately the amperage is what determines how dangerous electricity is to a person. It matters very little how much energy the electrons have (voltage). What is critical is how fast they are moving (amperage). At high enough voltages, a current of 0.01 amps causes a strong convulsive muscle action and considerable pain. A current of 0.02 amps can be so strong that a person cannot release a conductor, such as an inadvertently grabbed wire.

TYPES OF ELECTRICITY

Electricity comes in 3 basic forms: static electricity, direct current (DC) and alternating current (AC). When electrons are moved from one object to a second object, both objects become charged. One is charged because it now has too many negatively charged electrons (giving it a negative charge), and the other because it has too few electrons (giving it a positive charge). Static electricity occurs when electric charges build up on the surface of an object, but the electric charges cannot move around. If these electrons are given the ability to move to another object that can receive them (such as the earth), this is called grounding an object. If you have ever touched a doorknob in winter and gotten a shock, this is the process that causes it. As you walk through a room, static electricity builds up on your skin. When you touch the doorknob, the doorknob provides a path for the electrons to move to ground (the earth). As the current moves you get a shock.

Sometimes we want electricity to move in a particular path. Imagine a loop of piping that has a pump in it. The pump, like the electricity generating facility, creates the force to move the water. Sources of electrical energy include batteries, generators, photovoltaic cells and thermocouples. The closed loop path in the pipe that the water follows is similar to an electrical circuit. In an electrical circuit, there is a point of origin of the electrical energy and a closed path that it follows. The closed loop is essential for electricity to flow continuously. Devices that need electricity to operate, such as lights and motors, can be placed in the circuit. These devices are called loads or resistance and remove energy from the electrons and are measured in units called ohms.

Electricity that is constantly flowing is called current electricity. Current electricity must flow along a pathway, usually a metal wire, called a conductor. Conductors are usually made from copper or aluminum, but could be any material that readily supports the flow of electrons. These materials all have large numbers of electrons and the outermost electrons are easy to remove from an atom. Materials that prevent the flow of electrons are called insulators. Insulators include many fabrics, plastics, rubber and glass, but could be any material in which the electrons are not easy to remove from the atom. In a circuit, electrons are eventually returned to the source of power or to a ground. If an insulator (or even air) separates two materials, and one material has more free electrons than the other does, there is said to be a "potential difference" or voltage difference between the materials. A voltage difference causes electrons to flow through a circuit. High energy electrons are supplied on one end and low energy electrons are received on the other end. Passing through the load in the circuit removes energy from the electrons. A circuit with no load (negligible resistance) allows the high energy electrons to flow through the circuit back to the source. This highly dangerous situation is called "short circuit-ing" a circuit.

Current electricity is either direct current (DC) or alternating current (AC). Both AC and DC current are measured in volts. In DC voltage, the electrons always flow in the same direction in the circuit from the negative terminal to the positive terminal. DC voltage is preferred for electronic circuit boards. In AC voltage, the flow of electrons reverses at regular intervals. The interval in which it reverses, or cycles, is its frequency. Typically residential electricity cycles at 60 cycles per second or 60 hertz. Transmission of electricity over long distances is easier and cheaper with AC electricity than DC electricity.

While small, the resistance of the transmission wires is significant enough to lower DC voltage. If DC voltage was to be transmitted over long distances, electrical substations would need to be located at close intervals to make up for the voltage drop. To a lesser extent, this can happen with AC voltage as well, but the effect isn't as dramatic. Thus, for reasons of efficiency (and ultimately cost), it is desirable to transmit AC electrical power at high voltages.

ELECTRICITY GENERATION

Electricity is closely linked to magnetism. Rotating a coil of conductive wire in a magnetic field generates a current (electricity) in the coil of wire. In electricity generating plants, the coils remain stationary and the magnetic field rotates, which produces the same effect. A large magnet is attached to a turbine. As the turbine is rotated, electricity is generated in the coil.

Graphically, AC electricity is represented by curves that resemble water waves, called "sinusoidal waves" or "sine" waves. Halfway up the wave is the zero point. Thus waves can either be positive or negative, if they are above the zero point or below it. Two waves that are positive at the same time are said to be "in phase". If one wave is positive and one wave is negative, the waves are out of phase. Electricity generated by a single wave is called "single phase" electricity. Electricity generated by two or three waves is called "two phase" or "three phase" electricity. If a clock face was used to represent an end-on view of the turbine, the magnet could be represented by hands located at 12:00 and 6:00 that rotate at the same speed.

In electricity generating plants, if one stationary coil of wire is mounted at 12:00 and 6:00, single phase electricity is generated as each hand passes the coils. If an additional set of coils is mounted at 2:00 and 8:00 and another set of coils is mounted at 4:00 and 10:00, three phase electricity is generated. As the magnet "hands" rotate, the electrical wave is generated at different times. This causes the waves to be out of phase with each other. While it can be provided at the same voltage as single phase electricity, 3-phase electricity has a number of advantages in power averaging and promoting motor life that are beyond the scope of this brochure.

SERIES AND PARALLEL CIRCUITS

When more than one load is on a circuit, the circuit can either be wired in "series" or in "parallel". When the electricity has only one path to take through the circuit, the loads are wired in series. An example would be a river that passes through several towns. The only way to travel on the river is downstream. Travelling upstream is not permitted. There is also no way to skip a town. You must go through each town in turn as you travel down the river.

If the circuit is wired so that electricity can flow to several loads from the same point, it is wired in parallel. A parallel circuit has the advantage that if one load does not work, the other loads continue to get power. In series, if one load goes bad, it can prevent power from reaching any load further downstream. Circuits in homes are wired in parallel. If one wall outlet goes bad, generally the other outlets in the circuit will still operate.

MEASURING VOLTAGE

A device capable of measuring voltage, amperage and resistance is called a galvanometer. Commonly people call them volt-ohm meters or simply voltmeters. The device itself is simple. A pivoted coil of thin wire (with a spring attached) is placed in the magnetic field of a permanent magnet. When there is current in the coil, the magnetic field generated by the current causes the coil to bend and a needle moves across a scale. If the current is removed, the spring pulls the coil back to the starting position. The degree of bending can be read from a scale allowing us to determine the voltage or amperage causing the bending. Newer digital voltmeters work on the same principles, but use an electronic circuit board to duplicate the effect. A voltmeter typically has two probes to allow it to be inserted in a circuit carrying electricity. If the voltmeter is hooked in series, amperage is measured and if it is hooked in parallel, voltage is measured.

If the voltmeter is also capable of measuring resistance (ohms), it will have a small battery built into it. To measure resistance, the voltmeter is wired into a circuit. If the circuit is open, the needle will not deflect at all, because the electricity has no path to move and moving electricity is necessary to cause the voltmeter needle to deflect. If the circuit is completed and there are no loads (no resistance), the needle on the voltmeter will deflect near the high end of the scale because all of the electricity is returning to the source. This technique is often used for checking fuses. If the voltmeter shows a full scale deflection, the fuse is good because voltage is passing through it. If the voltmeter needle doesn't move, the fuse is bad.

CIRCUIT INTERRUPT SAFETY DEVICES

In building a factory or a house, the electrical system will have a main control panel. Power from the utility company will be run to this panel and then an electrician will make connections to the panel to run smaller circuits to carry power through the building. Any main electrical panel should have a master control, which would shut off all power flowing through the panel and a label to indicate the voltage in the panel and the maximum amperage that can flow through the panel at any given time. The master control may be located outside the panel, or inside a movable cover.

In the panel are switch controlled safety devices, called circuit breakers, which limit the amount of amperage that can flow through the circuit. Older buildings may have an older style of circuit interrupter called a fuse. In either case, a particular circuit power starts at the control panel, runs through a circuit breaker and then to somewhere else in the building. This circuit may have multiple hookup points, such as a group of outlets or a group of lights, connected to it. Especially in commercial buildings, wall mounted switches usually are used to control overhead lights. A switch is a device (pair of contact points) that can interrupt the electricity in a circuit or allow it to flow, but doesn't consume any power itself. Just about every electrical device has a switch circuit to safely turn it on or off.

Several electrical devices, such as TV's, radios, portable heaters and appliances may be drawing electricity from a given circuit. However, if the maximum amperage being used by all of the devices in the circuit exceeds the rated amperage of the circuit breaker, it trips, killing power to the circuit. The switch for the circuit breaker must manually be turned off and then on again to reset the breaker. The reason for having circuit breakers is to prevent electrical fires. If too much amperage is drawn through a circuit, the wire will overheat and can cause a fire. Circuit breakers prevent this from happening. Fuses had pieces of metal that would melt, breaking the circuit. They had to be replaced to restore electricity. Because they were not reusable, they have been replaced by circuit breakers in any new construction.

WIRE SIZE

Wire sizes are rated by using the AWAG rating system. The larger the wire number, the smaller the cross-sectional area of the wire. For example, a #12 wire is thicker than a #14 wire, which is thicker than a #16 wire. To prevent electrical fires, electrical codes specify that certain wire sizes must be used in a given amperage circuit. Houses that have 20 amp circuits are typically required to have #12 wire (or thicker/ heavier) and houses with 15 amp circuits are typically require to have #14 wire (or thicker/ heavier). In houses, 15 amp circuits typically power lights while 20 amp circuits typically power outlets. Larger amp circuits (with thicker/heavier wire) are needed to control devices such as stoves, ovens and central air conditioning systems.

Loads consume the energy carried by the electrons in the circuit. Voltage, current and resistance are related by Ohm's Law which states that "Voltage (V) = Current (I) x Resistance (R)". A 10 ohm load that is powered by 100 Volts will draw 1 amp of electricity (Current = 100 V / 10 ohms). To measure the power provided by a circuit, the formula "Power = Voltage x Current" is used. Power is measured in watts or volt-amps. The same load being powered by 1 amp and 100 V uses 100 watts of power. Electrical devices are usually rated by the watts that they require to operate or the amps they require at a given voltage.

TRANSFORMERS

The two principle consequences of electricity flowing through a material are the heating effect and the magnetic effect. When electricity passes through a material, the current causes the temperature of the material to rise. A portion of the electrical energy is converted to heat because of the resistance value of the material. This causes a drop in voltage and if enough heat is generated, can cause a fire. It can be as little as a fraction of a volt or as high as hundreds of volts depending on the material. Also (as stated previously), electricity passing through a material creates a magnetic field. If the field is strong enough it can disrupt the proper functioning of other devices or create an electrical flow in a device. The most widely used application of this is for transformers.

A transformer transfers electrical energy from one coil to another by means of an alternating magnetic field. The incoming voltage never directly passes to the outgoing wires. The transformer consists of two coils, which are electrically insulated from each other and wound on the same iron core. Thus, there are 3 parts to any transformer. The primary coil is the winding that carries AC voltage from the supply lines. The core is the magnetic circuit that produces an alternating magnetic field. The secondary coil is the winding that surrounds the core and generates a different voltage caused by its proximity to the alternating magnetic field of the core. The voltage from the secondary is used to power the load. The power output from a transformer is always less than the input power because of voltage drops caused by inefficiencies in the transformer. Despite these losses, transformer efficiencies are usually greater than 90% and may reach 99%.

Typically, the output voltage from the secondary coil is lower than the voltage to the primary. This type of transformer is called a "step down transformer" and has several advantages in homes and buildings. Since the secondary is usually 12V or 24V and is considered "low" voltage, electrical codes do not usually require sealtite or conduit. The low voltage also allows for smaller diameter wires to be used and decreases the risk of fire as well. Power lines running from an electricity generating plant carry a high voltage, which is stepped down by a transformer on the utility poles before the electricity reaches a house. If the voltage of the secondary is higher than the primary, this type of transformer is called a "step up transformer", but has few applications and thus is rarely used.

Windings in transformers can be configured in a variety of ways. The connection point in the transformer that draws power for the wires running out of the secondary can be connected in two ways. If the connection point is in the center, this type of transformer is called "center tapped" or "delta" configuration. The other main transformer configuration is called a "Y" transformer. The configuration of a transformer is not discernable from the outside, although a label may indicate it. If the connection point for the secondary (called the tap or tap point) changes, the secondary voltage changes as well. The more windings the secondary has, the higher the secondary voltage will be.

HOUSEHOLD ELECTRICITY

Power to residential customers is actually distributed as single phase 240V. The 240V is run into a center tapped transformer to provide 2 legs of 120V and a neutral wire to the house. These three wires come to the residence's power meter and then to the main electrical panel in the home. The 2 legs of 120V are out of phase. As a result, if the voltage to either leg is compared to the neutral or a ground, the voltmeter will read 120V. When the two legs of 120V are compared to each other, the voltmeter will read 240V. This happens because the waves are out of phase and the effect is to make the voltages add together. This is not the same and should never be confused with an industrial voltage of 208V or 230V. The power company is allowed a 10% range for its power generation, so the voltage received at the house may be anywhere between 110V and 120V. Thus, in most cases, 110V and 120V electricity refer to the same electricity. This is also true of 220V and 240V electricity (double the 110V and 120V).

The earth can be either a limitless supply of electrons or a bottomless "sink" to receive electrons without changing its potential, also called a "ground". For practical purposes, we consider the voltage of the earth to be 0 volts. Thus, all home electrical systems are connected directly to the earth and are thus "grounded". While a neutral wire in a home does not carry any voltage, it is not the same as a ground. The neutral wire in a home completes the loop for a circuit and is ultimately grounded at the electrical panel. An additional ground wire may be present in a circuit. A ground is not designed to be part of a circuit. In the event of an electrical emergency, the ground is designed to give electricity a path to the earth to avoid electrocution and fires.

INDUSTRIAL ELECTRICITY

Industrial electricity customers are supplied with electricity in a variety of ways. The power company typically provides 3 phase voltage that varies from 440V to 480V. If any leg is compared to ground, the voltmeter will read 255 - 280V, but the voltage difference between any two legs will be 440 – 480V. At the building, the incoming supply may be transformed down to either 3 phase 277V or 208V. If this is the case, the voltage difference between any two legs is 277V or 208V respectively; however, any leg compared to ground will be roughly 58% of the voltage between any two legs.

Alternatively, a building may have 3 phase 230V supplied to it. 230V 3 phase will have a leg that is referred to as a "wild" or "stinger" leg. That is a result of the phasing of 230V, which can cause the voltage in the wild leg to spike momentarily. Equipment designed to run on 3 phase 230 is equipped to deal with the momentary spikes.

DISPENSER CONNECTIONS

When installing chemical dispensers with peristaltic pumps, there are usually two electrical components to the installation. There are signals to tell the dispenser to perform a particular function and main power to drive the dispenser and its pumps. Most machine power is 3 phase 208V or 230V. Machine supply signals would be considered "source power" and should use at least 16 gauge wire for 208V/230V electricity. Depending on the machine, supply signals can vary from 24V to 230V. Older dispensing systems use the same power source to both drive the dispenser and provide the signals. This runs the risk of causing problems with the machine by drawing power from its circuits, which can draw enough power from the machine to cause it to malfunction. This is often called "drawing down" the power from the machine. It is always better to have separate electrical connections for signals and dispenser power to prevent this from happening.

This problem can be prevented by using separate signals, because when separate electrical connections are used to provide supply signals, they do not need to transfer any power from the machine to the dispenser. The signal will trigger a circuit on the dispenser, but the board's electronics are isolated from the machine so that one cannot damage the other. This also eliminates the need to fuse the signal power. If dispenser signals and dispenser power come from the same source, the wires need to be fused to prevent damage to the machine in the event of a malfunctioning dispenser, which could potentially damage the machine. A separate "clean" power source can then be used to power the dispenser through a power cord or plug-in transformer.

Some machines will be powered by 440V. This will usually require the installation of step down transformers to break down the signals to 110V, 208V or 230V before the chemical dispenser can use the signals. The higher the voltage, the stronger the magnetic field it generates. If 440V power is run to a chemical dispenser and the step down transformer is installed in the dispenser box, the field generated by the 440V can interfere with the circuit board's performance.

U S Chemical does not carry a 440V to 24V transformer and does not warranty its equipment if the installer mounts a 440V transformer in the dispenser control box. If an installer bypasses the dispenser transformers and runs the dispenser without proper fusing, this also voids the warranty on U S Chemical equipment.

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