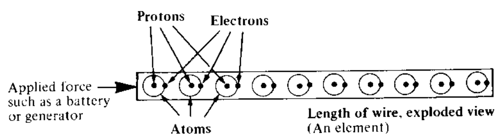
SKUTT CERAMIC PRODUCTS

# Electrical Theory

## ELECTRICITY

Simply stated, electricity is nothing more than the process of moving electrons from one atom to another. These moving electrons are able to do a fair amount of work, because we don't move one at time.

Various materials have different abilities to let go of their electrons and accept new ones. That is referred to as conductivity. Good conductivity means the electrons can easily move from one atom to another. Well get into later.




*Wire section with atoms*

## 4 ingredients of electricity:

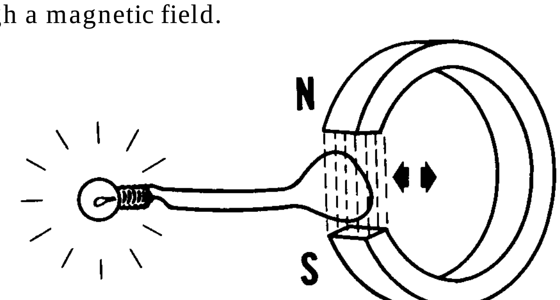
Before we look at the basic components in electricity it is helpful to think of electricity like water. In a water system we look at some form of **pressure**. When water is pumped up to a tower it has gravitational potential energy, which will release when the water is allowed to go downhill. The diameter and length of the pipe that carries the water to our home must be adequately sized so it doesn't introduce **resistance** for the flow of water we plan to move through the pipe. There is a certain **rate** at which the water will flow through this pipe and finally we have **gallons** of water as the product of the water flow.

Each of these elements to the water supply has a similar component in electricity.

## Voltage (V) = pressure

Voltage is a term we are all pretty familiar with but may not really understand it. Voltage is the pressure, or force, the electrons feel which persuades them onto the next atom. It is also called electromotive force and is often shown in equations as E. We will keep things simple here and denote voltage with a V.

There are two basic types of voltage AC, alternating current, and DC, direct current. Virtually all power supplied to houses, schools and industrial is AC voltage. All of our kilns operate on AC. However we take some of that AC voltage potential and convert it into much lower DC voltage that is used for the circuit board on KM type kilns. AC voltage is generated by passing a large coil of wire through a magnetic field.




The unit of measure for voltage is a volt.

(continued)

## Resistance (R or Ohms) = pipe diameter + distance

As electrons move through the wire it encounters resistance. The resistance is caused by 3 things:

1) The diameter of wire
2) The length of the wire
3) The material of the wire

1 and 2 will be discussed later in the section on wiring.

The electrons in some materials are very willing to move to another atom, while the electrons in other materials are extremely reluctant to allow an electron out of its grasp.

The materials that easily allow electron movement are said to have low resistance (or are good conductors of electrons).

The opposite of a good conductor is a material that allows no electron flow between the atoms. These materials are called insulators. The plastic wrapping on a piece of wire keeps the electron move contained to the metal inside the wire.

Somewhere in-between a good conductor and an insulator are materials that are specially designed to allow some electron movement. The benefit to this type of material is it will produce heat as the voltage moves the electrons through the material. Before the electrons move they encounter resistance. The force (V) must overcome resistance for electrons to move.

<u>Good Conductors</u>
Silver, copper, nickel & gold

<u>Insulators (poor conductors)</u>
Glass, wood, porcelain and rubber

Kanthal resistance wire is somewhere in between which is why it generates heat.

Resistance increases with temperature.

Resistance is measured in ohms (R) is it also abbreviated, R.

## Amperage (A) = rate

In our water analogy amperage would be the rate the water flows through the pipe. It would be measured in gallons per minute or hour. Amperage is the rate electrons are moving in the conductor.

One way to limit the flow of water through a pipe would be to reduce the diameter of the pipe (increasing the resistance) and we would have fewer gallons of water coming out of the pipe in one minute than for a larger pipe.

This assumes the water pressure stays the same for both pipes. If we were to elevate the water tower the pressure would increase and we would be able to force more water through a pipe. So gallons per minute only means something when it is expressed relative to the water pressure. The same is true with amperage. <u>Amperage only has meaning when it is expressed relative to the voltage</u>. For example we would say a kiln draws “48 amps at 240 volts”.

The unit of measure of amperage is the ampere (A), sometimes shown as “I” (intensity of current) in electrical equations.

# ELECTRICAL THEORY CONTINUED

## Wattage (W) = gallons

To complete the metaphor with flowing water, wattage would be like the number of gallons received while water was flowing.

In an electric kiln it is really the wattage (which is directly proportional to BTUs) that gets the heatwork done.

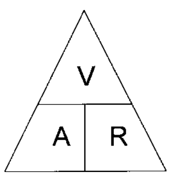
Just like with water flow an electric kiln needs a certain result (gallons or watts) in a given time. How frustrating is it to take a shower with just a trickle of water? All of these measures help us arrive at the wattage (also know as Power) the kiln is producing.

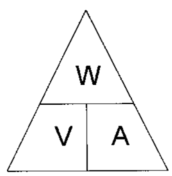
The Power Company will bill you on watts used for a given period of time, kilowatts (1000s of watts) used per hour. Example: a 11,500 watt load running for 1 hour would result in 11.5 kWh on your electric bill.

## Ohms Law

Now that you have an understanding of the elements of electricity you probably guessed there must be a relationship between them that is predictable, and there is. It is called Ohm's Law and can be expressed simply as:

**Amperage = Voltage / Resistance**




These 2 equation triangles are helpful in determining the proper formula to use. For example: by placing your finger over "R" in triangle 1 the remaining symbols express the formula for calculating "R", V / A.

Voltage is the biggest factor in determining how fast a kiln with fresh heating elements will fire. It is difficult to increase the voltage we get from the Power Company, but it isn't difficult at all to lower the voltage getting to the kiln. We will discuss this more in the section on Wiring an Voltage Drops.

Resistance of the heating elements is something we can control, initially at least. As the elements age they provide more resistance to electron flow and reduce the current. Which in turn reduces the wattage of the kiln.

Amperage and Wattage are results and can only be influenced by changing the voltage or the resistance in the circuit.

| Item | Water model | Electricity |
|---|---|---|
| Pressure or Force | Pounds per square inch (PSI) | Voltage (volts, V) |
| Resistance to flow | Pipe diameter & length of pipe | Resistance (ohms, R) |
| Rate of flow | Gallons per minute (GPM) | Amperage (amperes, A) |
| Work or result | Gallons | Wattage (watts, W) |

## Circuits

A circuit is simply an assembly of wires and components which allow current to flow (electrons to move). All circuits have these basic components:

1 voltage source

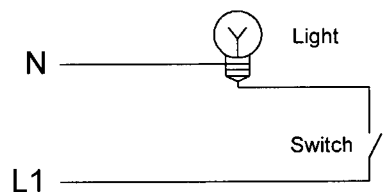
1 or more electrical loads (heaters, motors, something to consume power).

1 or more controls (switch, relay or actuator)

# ELECTRICAL THEORY CONTINUED

## Simple Circuit

A very common circuit which we all use everyday is a lightbulb and switch circuit. It looks like this when drawn as a schematic:




## Multiple Load Circuits

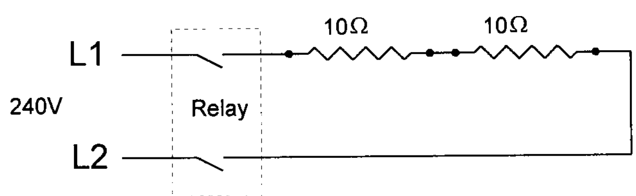
Now that we have a picture of a very simple circuit, there are 2 types of circuits that involve multiple loads. Simple circuits are easy to understand but most electrical circuits are some combination of components placed in series and parallel. The following will go into greater detail.

Series

A series circuit is one in which each load is lined up end to end. The current must flow through the first one then the next in a series to complete the circuit.

If a single component fails in a series circuit then power is lost to all components. And the entire circuit is de-energized. Remember those older style Christmas lights where 1 broken bulb would turn out all the lights?

An example of a series circuit in a Skutt kiln would be 2 818 elements going to 1 infinite switch or relay.

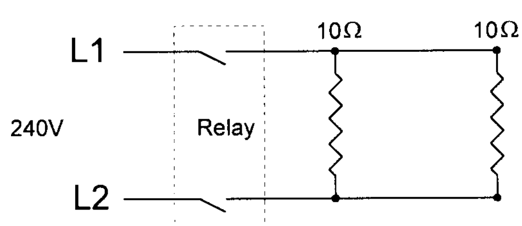



The working voltage is divided across each component in a series circuit. In the figure above if both resistors (heating elements) have the <u>same</u> resistance in ohms then the voltage would be consumed evenly between them. Specifically, if the applied voltage is 240 then each element would behave like a 120v element (240v / 2 elements = 120volts / element). Elements would be designed to operate on 120v instead of 240v when there are 2 elements in a series circuit.

If the 2 resistances are different, then the voltage drop across each would be proportional to the resistance.

Parallel

Unlike series circuits a parallel circuit applies the full line voltage to each load.



One of the main benefits of a parallel circuit is apparent when a component fails. The damaged component doesn't effect the other loads in the circuit. The remaining load(s) will still operate as designed. This is how Christmas lights are manufactured now and it is a simple task to find the one bulb that is burned out because all the others are still illuminated.

## Wiring & Voltage Drop

Every piece of wire has some resistance. The resistance is effected by 3 things:

1) The wire gauge or diameter.

2) The length of the run.

3) What the wire is made of. (A perfect conductor doesn't exist. Copper is a good conductor for the price thus explaining its popularity).

Let's take a closer look at each of these 3 factors individually before we look at the net effect.

## Wire gauge

Every wire has a theoretical maximum flow it can take in amperes before it overheats. A wire size that is too small will limit the flow of current and create an unnecessary hazard. Oversizing wire for a circuit does not present any hazard what so ever.

The following table will give a few pieces of important information for discussion later.

| American Wire Gauge AWG | Circular mils | Maximum amperage for copper 3 conductors in a cable at 86°F, 90°C wire National Electric Code. |
|---|---|---|
| 0 | 325 | 170 |
| 2 | 258 | 130 |
| 4 | 204 | 95 |
| 6 | 162 | 75 |
| 8 | 128 | 55 |
| 10 | 102 | 40 |
| 12 | 81 | 30 |
| 14 | 64 | 25 |

## Distance

Just as the diameter of the wire (pipe) can reduce or choke flow so can the length of the wire. As a general rule of thumb we recommend going to one size larger wire for each 50 feet of run from the circuit breaker panel to the wall outlet. These are calculations that electricians do all day long, but we have found this minimizes the effects of distance on kiln performance.

Wire type

| **Material** | **Resistivity (Ω-circ.mil/foot)** |
|---|---|
| Silver | 9.9 |
| **Copper** | **10.4** |
| Aluminum | 17.0 |
| Iron | 58.0 |
| Kanthal A1 | 872.0 |

## Bringing all 3 pieces together

There is an equation that will bring all 3 factors together into the resistance of a given length of wire of a certain distance and composition. The equation is:

**Resistance (W) = Resistivity * (length of wire / diameter of wire$^2$)**

Let's compare copper to aluminum in a 100 foot run with a diameter of 6 gauge.

$Rc = 10.4 * (100 / 162^2) = 3.96$ W

$Ra = 17.0 * (100 / 162^2) = 6.48$ W

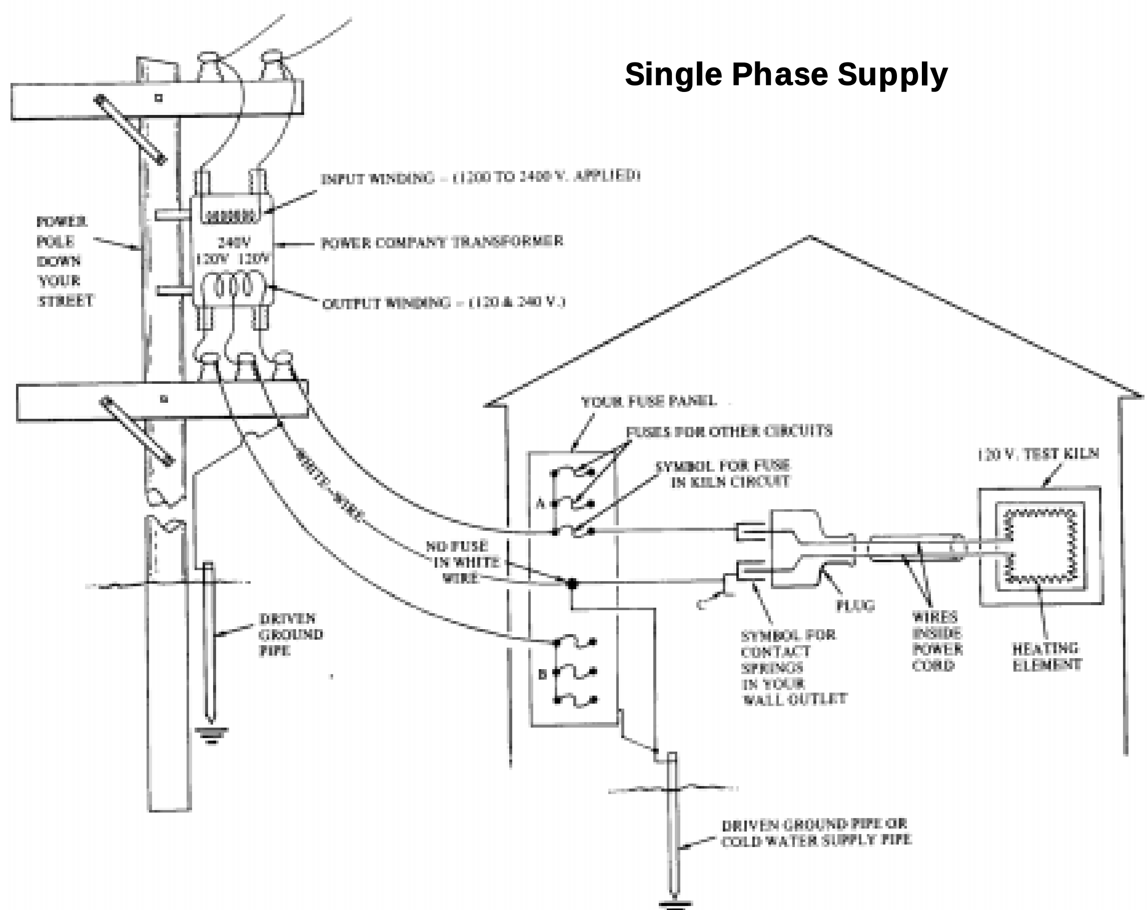
As you can see the Ra (aluminum) wire has much more resistance that the copper. This is why we recommend only working with copper wire when installing a kiln circuit.

## Single and 3 Phase supplies

Electricity is generated at large facilities that spin turbines holding large coils of wire through magnetic fields. Depending on the geometry of the magnets and coils, various frequency and phase configurations are generated.

That voltage travels down main distribution lines at very high voltage (pressure) and is transformed down to working voltages on the power pole outside your house.

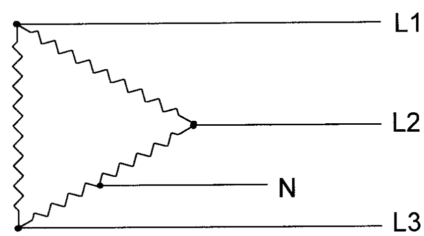
**Single Phase Supply**



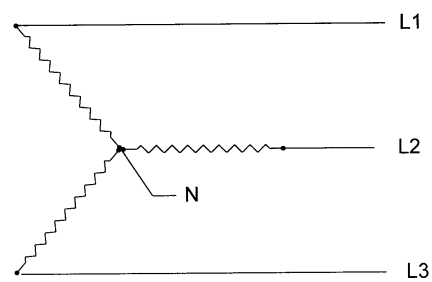
# ELECTRICAL THEORY CONTINUED

You have heard the term "Hot wire" referring to a wire that has voltage potential present. We may use this term interchangeably with Phase wire. In the following diagrams we will label the phase wires with the standard convention of L1, L2 and L3 for Lines 1, 2 or 3.

The two most common types of power distribution are "Delta" and "Y".

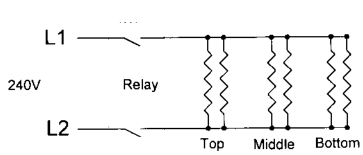



**120/240 = DELTA**

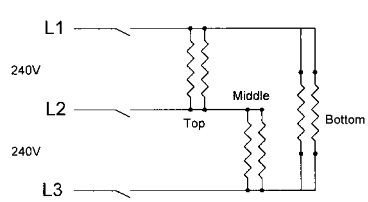



**120/208 = WYE OR "Y"**

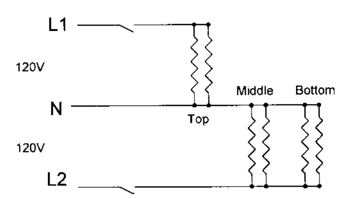
## Typical Kiln Circuits




*1 Phase 3 Section Kiln*




*3 Phase 3 Section Kiln*




*714 Kiln*

## CIRCUIT BREAKERS

Circuit breakers are over current protection devices. The purpose is to interrupt voltage to a circuit when the circuit has too much current flowing through it.

**Breaker Facts**

- The breaker will trip (open up) when it gets too hot.
- It is very normal for a circuit breaker to get warm when the kiln is operating, but not hot.
- Must be sized to 125% of the continuous load in Amperes.
- A 50A breaker will not run a 48A kiln.

### Phase (or "Hot") wires

As you open the front cover of a circuit breaker panel you will usually see 2 columns of switches or poles. Each pole will have a rating on stamped on it. This rating will be in amperes.

Each pole is a phase wire and must be protected from overcurrent.

To get 120v we combine 1 pole with a Neutral wire. Neutral wires are usually color-coded white.

### Breaker Interlocks

2 poles that are connected with small rods, make up a 208 or 240v circuit (depending on the power distribution). If we are working with a 2 pole circuit you don't add the values of each pole. The capacity of the circuit is still the stamped amperage, but it is now 208-240 instead of 120. Example: 30A bridged to another 30A is not 60A single phase, it is only 30 amps single phase.

3 phase circuits will have 3 poles all connected (i.e. 2,4 & 6 on panel)