Fundamentals of Electricity

With content from Dale Woodall

Terms and Definitions

***Alternating Current (AC)**: An electric current that reverses its direction of flow periodically as contrasted to Direct Current (**DC**) that constantly flows in one direction. In the **US** this direction change occurs 60 times a second (60 cycles or 60 **hertz**).*

***Amp (Ampere):** A unit that measures the strength/rate of flow of electrical current.*

***Breaker:** A switch-like device that connects/disconnects power to a circuit.*

***Circuit:** A continuous loop of current (i.e. incoming "hot" wire, through a device, and returned by "neutral" wire).*

***Circuit Breaker:** The most common type of "overcurrent protection." A breaker trips when a circuit becomes overloaded or shorts out.*

CIRCUIT BREAKER

The circuit breaker is designed to open and close a circuit by nonautomatic means. If an over-current, or power overload, travels through the circuit, it will trip, or shut off the power for that circuit. Fuses, which were in use before circuit breakers, also protect against over-current. “A fusible part is heated and severed if an over-current passes through it.

Terms and Definitions

Conduit: *A protective metal or PVC tube that wires run through.*

Direct Current (DC)*:* ***Electricity*** *that flows continuously in one direction as contrasted with Alternating Current that flows in one direction than reverses. A Battery produces* ***Direct Current****.*

Duplex Receptacle: *The commonly used receptacle (outlet). Called "duplex" because it has two plug-in sockets.*

Fuses: *Removable devices that link a circuit at the fuse box. Fuse connections blow apart and break the circuit if an overload or short occurs.*

Terms and Definitions

GFCI or GFI (Ground Fault Circuit Interrupter): *A specific type of circuit protection (commonly required in kitchens & bathrooms) that helps safeguard against shocks. GFCI protection can come from an outlet or a breaker.*

Ground Fault: *Current misdirected from the hot (or neutral) lead to a ground wire, box, or conductor.*

Hot, Neutral, Ground: *The three most common circuit wires. The hot brings the current flow in, the neutral returns it to the source, and the ground is a safety route for returning current. The ground and neutral are joined only at the main service panel.*

Junction (Electrical) Box: *A square, octagonal, or rectangular plastic or metal box that fastens to framing and houses wires, and/or receptacles and/or switches.*

GFCI

The ground fault circuit interrupter, or GFCI, is an electronic device that monitors the flow of electricity in a circuit. This helps protect against electric shock and electrocution. Most homeowners will recognize GFCI outlets–those outlets with “test” and “reset” buttons.

These are especially crucial in bathrooms, kitchens, garages, crawlspaces and **any other area that is exposed to water.**

Terms and Definitions

Knockout: *A removable piece of an electrical box or panel that's "knocked out" to allow cable to enter the box.*

Load*: The amount of electric power delivered (or required), at any specified point(s) on a circuit or a system.*

Line Loss*: Can refer to the amount of* ***voltage****, power, or energy lost when carrying-current over a "conductive path" due the Resistance of the "conductive path."*

Ohm*: The unit of measurement of electrical Resistance to the flow of current. It is that Resistance through which a difference of potential of one* ***volt*** *will produce a current of one* ***ampere****.*

Pigtail: *A short, added piece of wire connected by a wire connector. Commonly used to extend or connect wires in a box.*

Terms and Definitions

Service Entrance (SE): *The location where the incoming electrical line enters the home.*

Service/Supply Leads: *The incoming electrical lines that supply power to the service panel.* ***Service Panel:*** *The main circuit breaker panel (or fuse box) where all the circuits tie into the incoming electrical supply line.*

Short Circuit: *When current flows "short" of reaching a device. Caused by a hot conductor accidentally contacting a neutral or ground. A short circuit is an immediate fault to ground and should always cause the breaker to trip or the fuse to blow. (also see ground fault)*

Transformer: *An "electromagnetic" device for changing the voltage of Alternating- current electricity. A* ***Step-up Transformer*** *increases the voltage from primary-to-secondary, while a* ***Step-down Transformer*** *decreases it.*

Terms and Definitions

Volt: *A unit that measures the amount of electrical pressure.*

Watt: *A unit that measures the amount of electrical power.*

Measurement

Energy: *The amount of power consumed over a given time period. As commonly used in the electric utility industry, electric energy is measured in units of kilowatt-hours.*

Frequency: *The number of "cycles" through which an electric current passes per second. Frequency has been standardized in the North American electric industry at 60 cycles per second (60 hertz). Other areas around the world use either 60-or 50-cycles per second.*

Kilovolt (kV)*: A* ***kilovolt*** *is equal to 1,000* ***volts****. The common industry abbreviation is* ***kV****.*

Kilovolt-amperes (kVA)*: 1,000* ***volt-amperes****; the measure of the Apparent Power in an electrical system.*

Kilowatt (kW)*: One (1)* ***kilowatt*** *is equal to 1000* ***watts****; the measure of the Real Power in an electrical system.*

Kilowatt-hour (kWH)*: The unit of electric energy used by most Electrical Utilities and measured by most Electrical Billing Meters. One* ***kilowatt-hour*** *is equal to one* ***kilowatt*** *of power supplied to-or taken from-an Electric Circuit steadily for one hour.*

What is Electricity

It is much easier to describe *what it does* than *what it is*.

For example, ***electricity*** operates our Lights, runs our Refrigerators and powers our Electric Motors.

- ***Electricity*** is actually defined as: "the movement (or flow) of Electrons through a material."

- The word "electric" comes from the Greek word "amber" and has been used to describe a wide range of related phenomena. We cannot see ***electricity***, but we can see its effects (i.e. *light*).

Single-Phase AC

"Single-phase Alternating Current" is most often used in homes, small businesses and on farms. In large commercial buildings and industrial locations where larger Motors are used, *single-phase power* is not usually adequate.

Two Types of Electricity

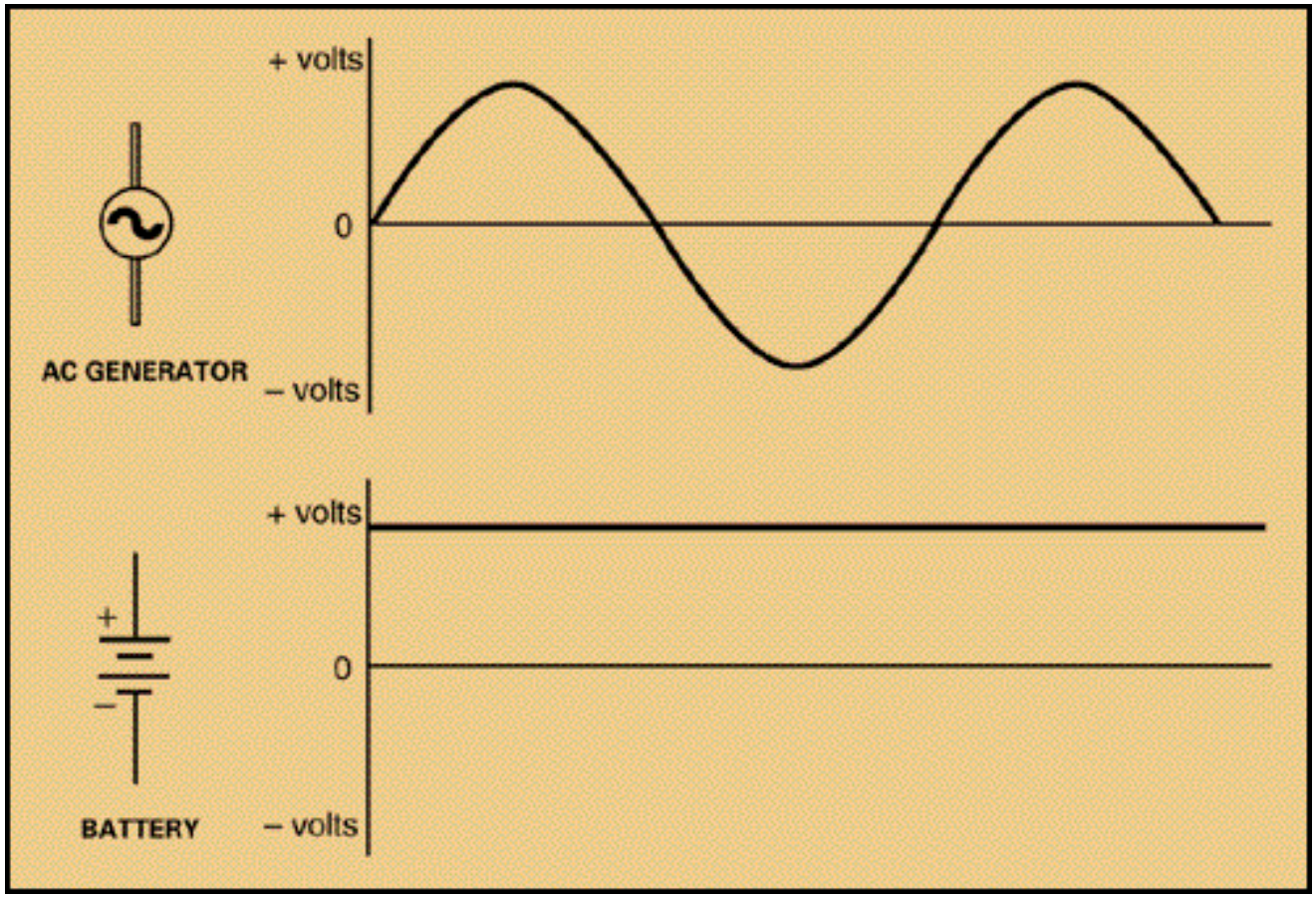
Electricity can exist in a number of forms; however, there are two types of commonly used ***electricity***:

- **Direct Current**: which is commonly provided by Batteries; and
- **Alternating Current**: provided by Electric Utilities or other Power Generators in the form of **Electrons** (called "current") flowing through a Wire called a "Conductor."

Two Types of Electricity

AC

DC



Current

When **Current** flows in a Conductor, *heat* is produced. This happens because every Conductor offers some Resistance to *current* flowing.

That is why the **Amperage** flow in a Circuit is important, since the more **Amps** flowing on a given Wire, the more *heat* is produced. Most people notice this heating effect when the Cord of any Appliance or electrical device heats up after the device has been running for an extended period of time.

Recognizing this *heat* production is important in specifying Wire sizes. When a Wire carries more **Amps** than it can handle without overheating, we say it is "overloaded." Overloaded Wires can melt the Insulation and create "shocks" or even Fires.

Do not overload an outlet!

Wire Size

Electrical Wire Sizes are indicated using two different systems: the ***American Wire Gauge System (AWG)*** and the ***Thousand Circular Mill system (KCMIL)***, which was known until recently as ***(MCM)***.

Both systems designate **Wire Size** based on their diameter or cross-sectional area. The ***American Wire Gauge System*** is used to refer to relatively small Wires (most commonly used in residential applications).

American Wire Gauge System

In the ***American Wire Gauge*** or "***AWG***" System, as the Wire gets smaller, the number of the Wire gets larger. The smallest ***AWG*** size is 40 and looks like a metal thread.

Common electrical Extension Cords on Lamps are typically "18-gauge" Wire. The smallest "gauge" allowed for Lighting and Receptacle Circuits in a house is "14-gauge" Wire. The "gauge" sizes get smaller with corresponding increases in the Wire's diameter all the way down to "0-gauge."

The higher number the gauge is, the less load (amps) it can carry.

Using the AWG System, higher AWG numbers mean skinnier wires and less capacity for heavy current.

Calculate your load and design your cord layout accordingly.

Overcompensation is a GOOD thing. Allow yourself a 25% "fudge" factor when calculating a load for extension cords. (*only use a cord up to 75% of its rated value)*

Compensate for Line Loss (determined by the length of your cord) vs. your desired load.

How Line Loss can affect your display

Wires carrying current always have inherent resistance, or impedance, to current flow. Voltage drop is defined as the amount of voltage loss that occurs through all or part of a circuit due to impedance.

Excessive voltage drop in a circuit can cause lights to flicker or burn dimly, heaters to heat poorly, and motors to run hotter than normal and burn out. This condition causes the load to work harder with less voltage pushing the current.

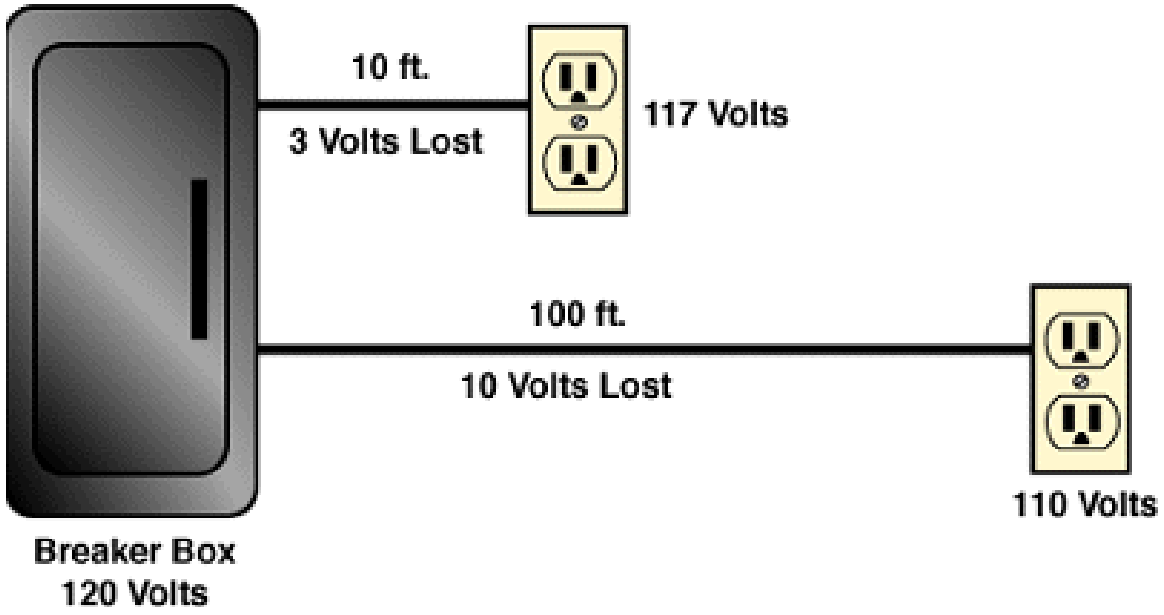
Overloaded wiring can overheat and create a potential for fire.

You do not want "spaghetti wiring" to burn up your light controller or outlets.

If in doubt, upsize.

How Line Loss can affect your display

Line loss will lower the voltage and current available at the outlet. You can compensate for line loss by increasing the size of the wiring.



Calculate the Line Loss (for extension cords or new auxiliary services)

http://www.gorhamschaffler.com/voltage_drop_calculator.html
(a great site that will calculate your line loss).

There are several other free calculators on the internet available.

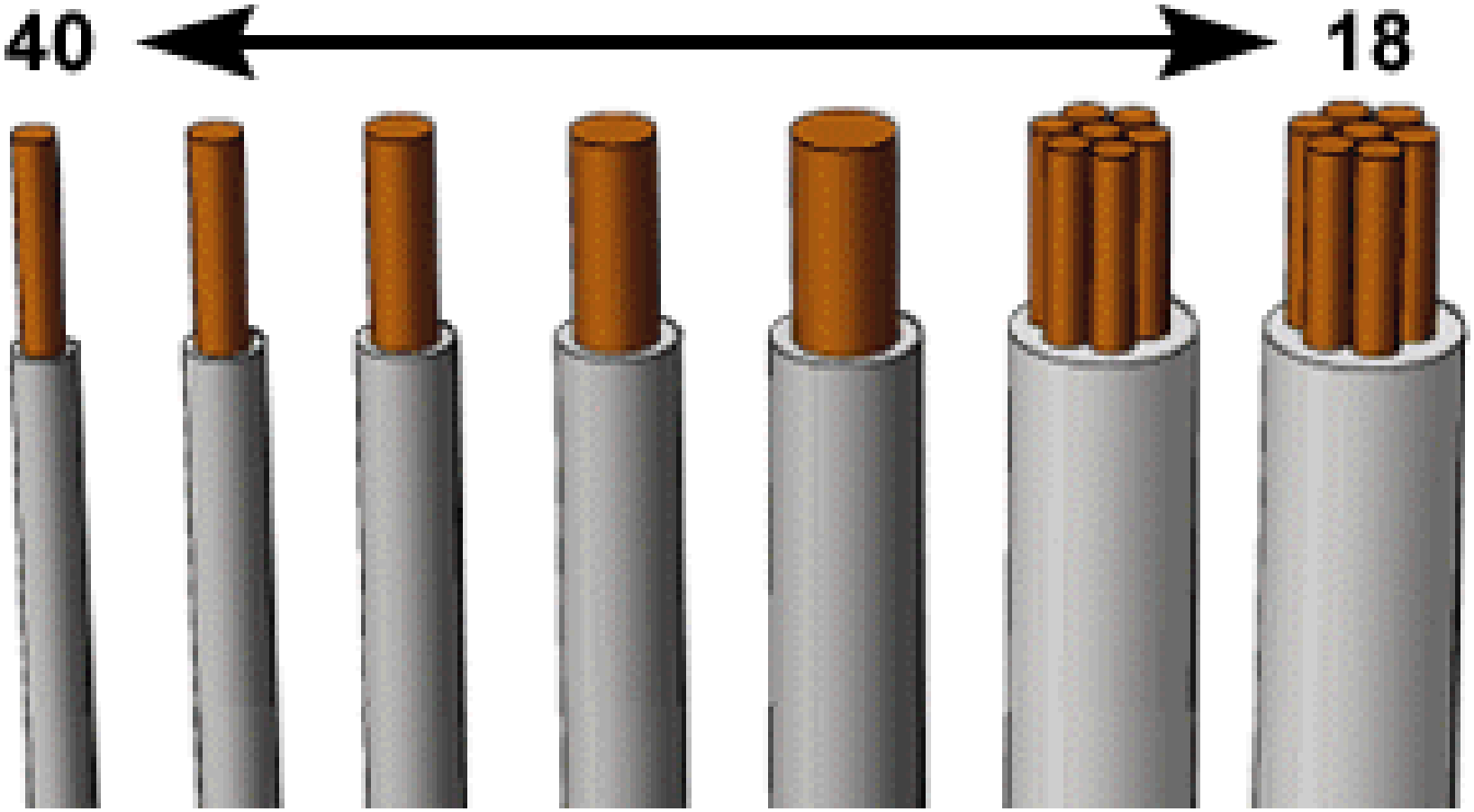
Circuits wired within a residential building usually are not long enough or heavily-loaded enough to make voltage drop a factor in selection of wiring.

In the case of very long circuits, for example, connecting a home to a separate circuit on the same property, it may be necessary to increase the size of conductors over the minimum requirement for the circuit current rating. Wiring codes or regulations may set an upper limit to the allowable voltage drop in a branch circuit[1].

[1] *http://en.wikipedia.org/wiki/Voltage_drop#Voltage_drop_in_household_wiring*

Line loss is something to consider in the planning of your display if you are going to have close current tolerances and/or a large load.

Wire Gauge



Calculate your light load!

We learned earlier that:

***Load is**:*

The amount of electric power delivered (or required), at any specified point(s) on a circuit or a system.

A properly balanced load will reduce potential for tripping circuit breakers, short circuits or fire.

So, lets calculate the load on our circuit

There are many ways to do this (we will only discuss two):

1. *Add up the amperage of the lights connected to the circuit;*

Or

2. *Use a Clamp meter to measure the Current of the circuit*

Adding up the light load

Find the ratings on the lights- there should be a tag denoting the amperage.

The typical (non-LED)100 count mini lights will operate at a load of approximately 0.34 amps

3 strands/circuit x 0.34 amps/strand = 1.02 amps/circuit

If your extension cord is rated for 16 amps, then you could place up to 35 strands (11.9 amps) on it (*using a 75% safety factor) – not compensating for line loss.*

Does it exceed your circuit breaker?

Know how to balance your load across your home.

If you are trying to operate 35 strands of lights (11.9 amps) on a 10 amp circuit breaker, then you will have problems with circuit breakers or fuses.

Sometimes, short circuits or fires can happen if a breaker overheats and melts before it trips.

If you have problems with tripping breakers, redistribute your load.

Adding up the light load

Look on the lights- a new carton of lights should have a tag that will denote the voltage, and current (amp) rating.

(Continued from other side) replacing fuses and
/or lamps. 5. To reduce the risk of overheating,
replace burned-out lamps promptly. Use 2.5 Volt
lamps only (provided with product) 6. This is a
series connected string. 7. Use only 125 V 3A fuse.
Model No.: KMO100 MADE IN CHINA
E241906 120V, 60Hz, 0.34A,

Current rated for 0.34 Amps

"Continued from other side"
do not attempt to replace lamps or
modify sting.This product employs series
connected lamps.3.Always unplug this product
Before installing or replacing fuses.
Model No.TL-70 120V,60Hz,0.040A
E241529 06/2006

Current rated for 0.04 amps

Or, you can measure the current load with a meter

A clamp meter can measure AC and/or DC voltage, ohms, current, continuity and much more (depending on the features of the meter itself).

For an accurate reading of you load, a clamp meter is essential for the hobbyist.

A meter can be obtained at nearly any hardware store at costs ranging from $25 to $400+ each, depending on desired functions.

Or you can measure with a meter

A clamp meter will "clamp" around the energized wiring and will denote current in amperage.

enter: "Digital Clamp Meter" into your search engine for more information

A multi meter will measure current across an open switch in a circuit

A clamp meter will "clamp" around the energized wiring and will denote current in amperage.

Current reading is 93.2 amps

Extension Cord Safety

The internet is filled with stories of fires started by either overloaded extension cords or those that were in a state of disrepair or misuse.

RULE #1

Always follow the manufacturer's instructions

EXTENSION CORD SAFETY-TAKE NO CHANCES!

We use extension cords almost every day both at work and at home. These are very useful devices, but they can present a fire or shock hazard when either worn out or used improperly.

Types of extension cords

- *Extension cords come in either two or three-wire types.*
- *Two-wire extension cords should only be used to operate one or two small appliances.*
- *Three-wire cords are used for outdoor appliances and electric power tools. The third wire on this cord is a ground and this type of cord should never be plugged into any ungrounded electrical outlet.*

EXTENSION CORD SAFETY-TAKE NO CHANCES!

Care and inspection of extension cords

- *Extension cords must be treated with care and checked regularly for damage or deterioration. The cord itself should never be pulled to disconnect it from an electrical source; remove it by the plug.*

- *They should not be placed under rugs or furniture and should never be strung through doorways, windows, walls, ceilings, or floors. Damaged cords present a potential fire or shock hazard and should be removed from service immediately.*

- *Extension Cords should not be fastened to a building or structure, even though staples are sold for this purpose at many hardware stores.*

- *Avoid plugging two cords together to make a longer one. It's best to use one cord in a continuous length from the receptacle to the appliance or tool. Extension cords which are either connected together or are too long will reduce operating voltage, reduce operating efficiency and may cause motor damage (where applicable).*

- *Use good housekeeping practices, to keep extension cords from being a tripping hazards or becoming damaged. Inspect them regularly for wear and replace defective units.*

EXTENSION CORD SAFETY-TAKE NO CHANCES!

1) Buy medium or heavy-duty extension cords, and avoid bargain brands.

2) Read all information and warnings on the package and safety label.

3) Always verify that the cord contains a certification label from an independent testing lab such as UL or ETL on the package and on the product.

EXTENSION CORD SAFETY-TAKE NO CHANCES!

4) Note the maximum amperage marked on the packaging, and don't connect loads that exceed 75% of this value. Do not assume a "standard rating" based on wire size. The manufacturer may de-rate heavy-duty cords, cords longer than 50 feet, or cords with integral switches. If you are unsure of a cord rating, assume that it is 10 amps if 50 feet or less, and 7 amps if over 50 feet long.

5) Be sure that the plug is polarized (one prong is wider than the other), or is a three-prong grounded type, and never defeat these features. Do not use two-prong adapters with a three-prong plug. Find an outlet that accepts the polarized or grounded plug.

6) Coiled cords can present a fire hazard. Always uncoil cords completely, and never double them up or cover them during use.

EXTENSION CORD SAFETY-TAKE NO CHANCES!

7) Damaged cords present both fire and electric shock hazard. Immediately discard any cord or outlet strip that shows signs of damage or feels hot to the touch during use.

8) Contact with live prongs can result in electrocution. Use care when inserting or removing plugs.

9) To prevent fire hazard, never install extension cords in a permanent fashion, or inside ceilings, floors, or walls. Use extension cords only for temporary purposes, and disconnect them when not in use.

10) Cords used outdoors or in damp areas must be designated for outdoor use, and should be connected to an outlet that is protected by a Ground Fault Circuit Interrupter (GFCI).

EXTENSION CORD SAFETY-TAKE NO CHANCES!

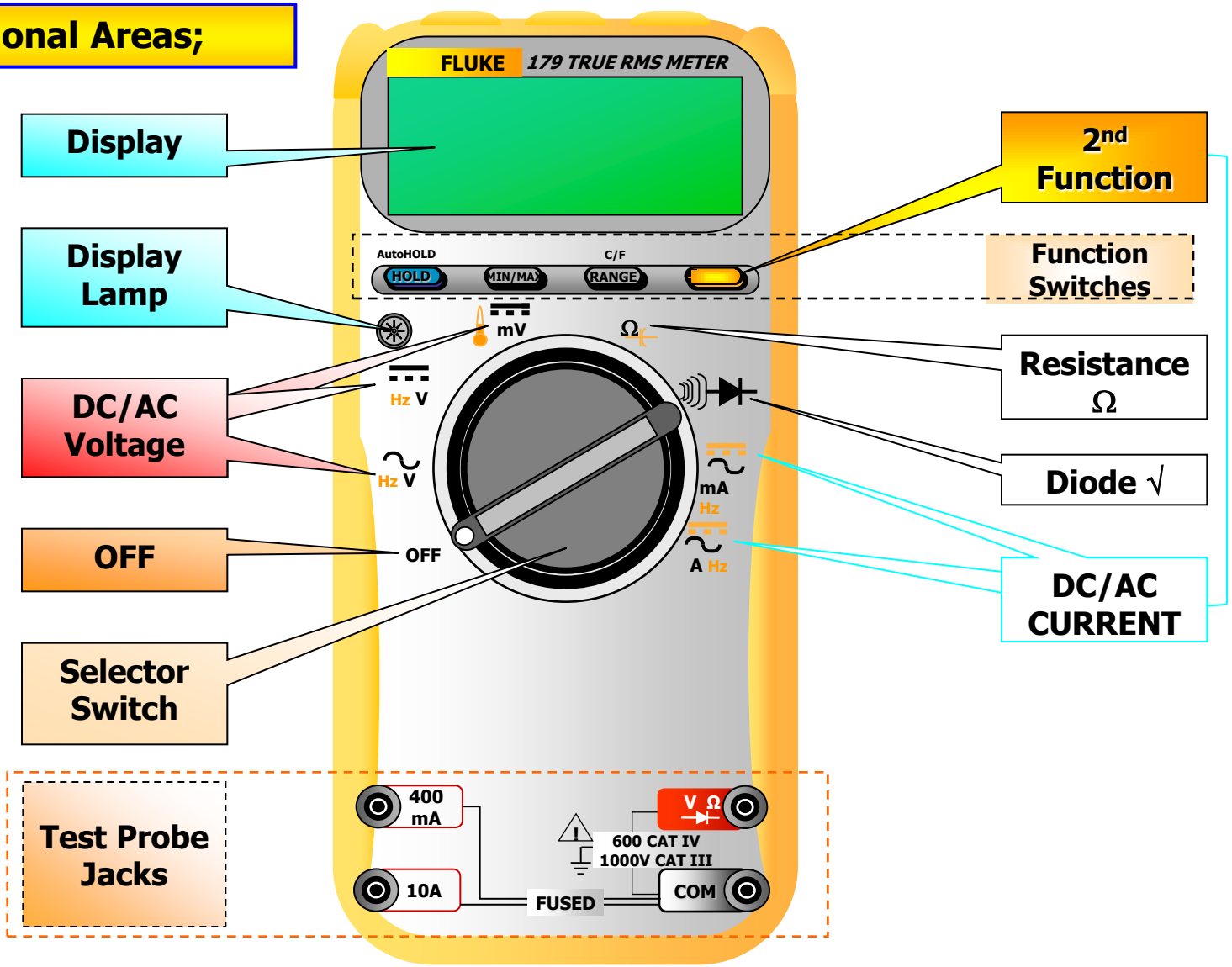
Do not coil extension cords, they can overheat and become a potential fire hazard!

Coiled cord after self-ignition from overheating

Multimeters

Using Multimeters

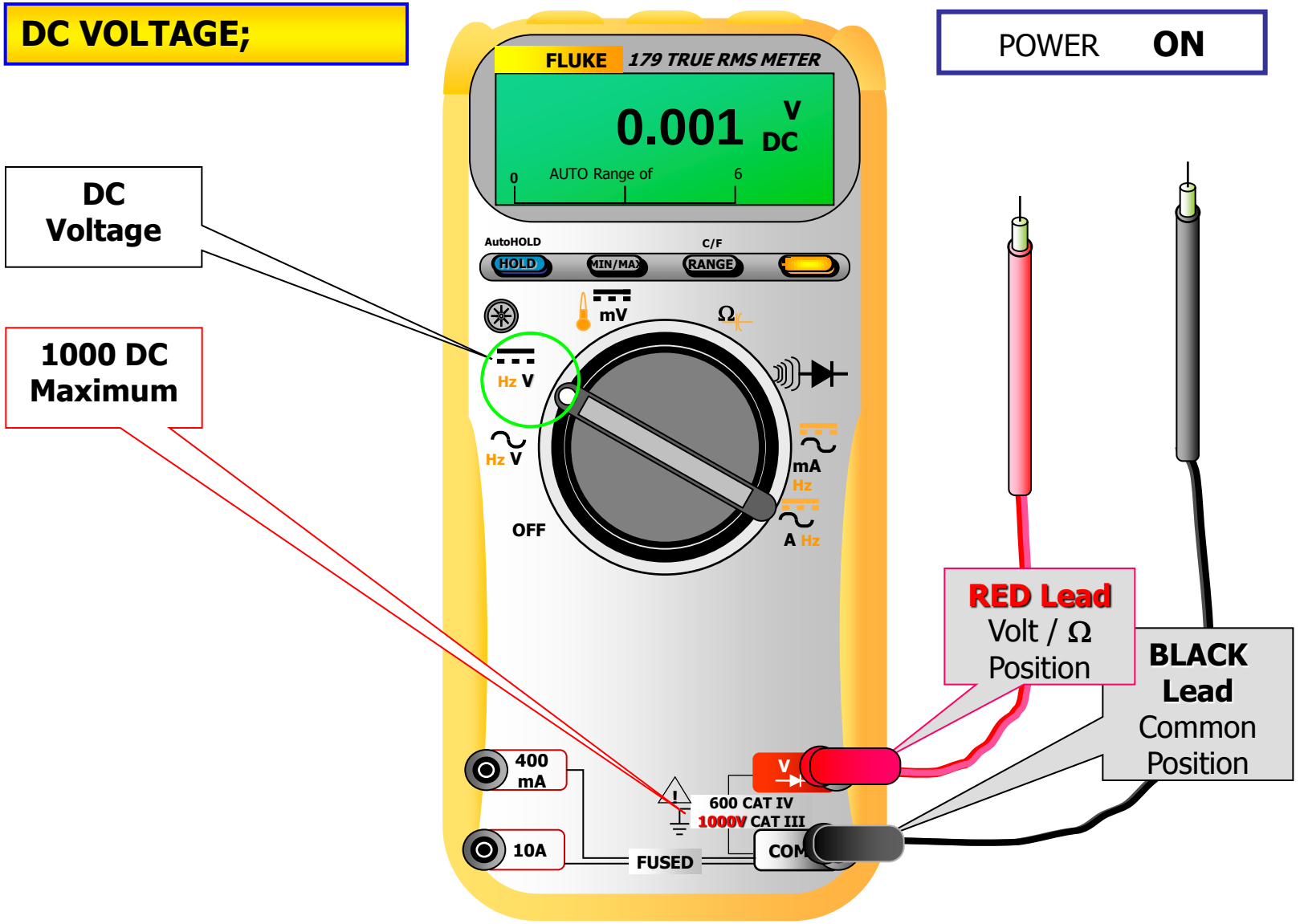
Functional Areas;



Using Multimeters

DC VOLTAGE;

POWER **ON**



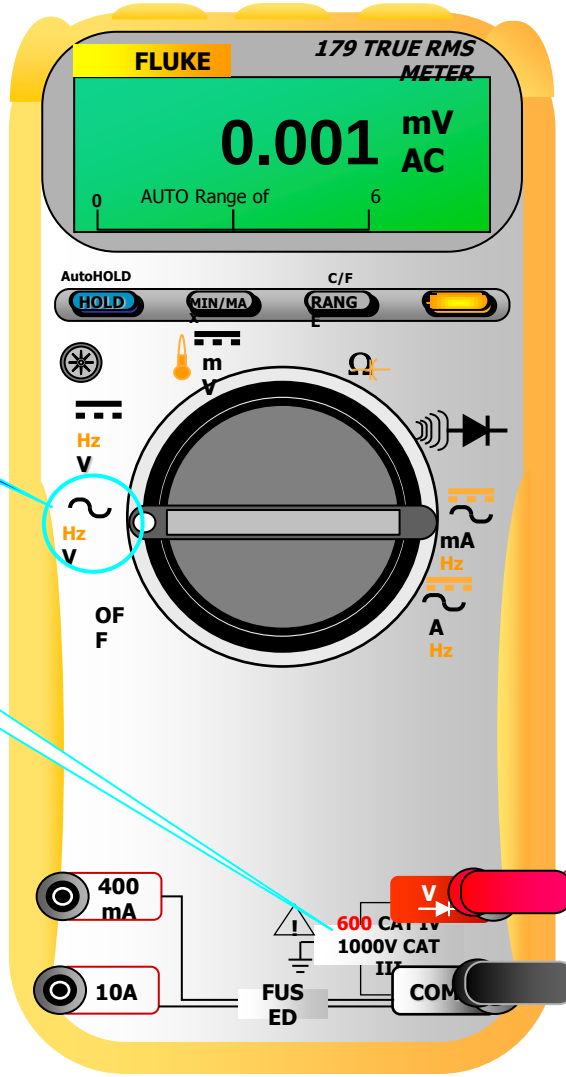
Using Multimeters

AC VOLTAGE;

POWER **ON**

AC Voltage

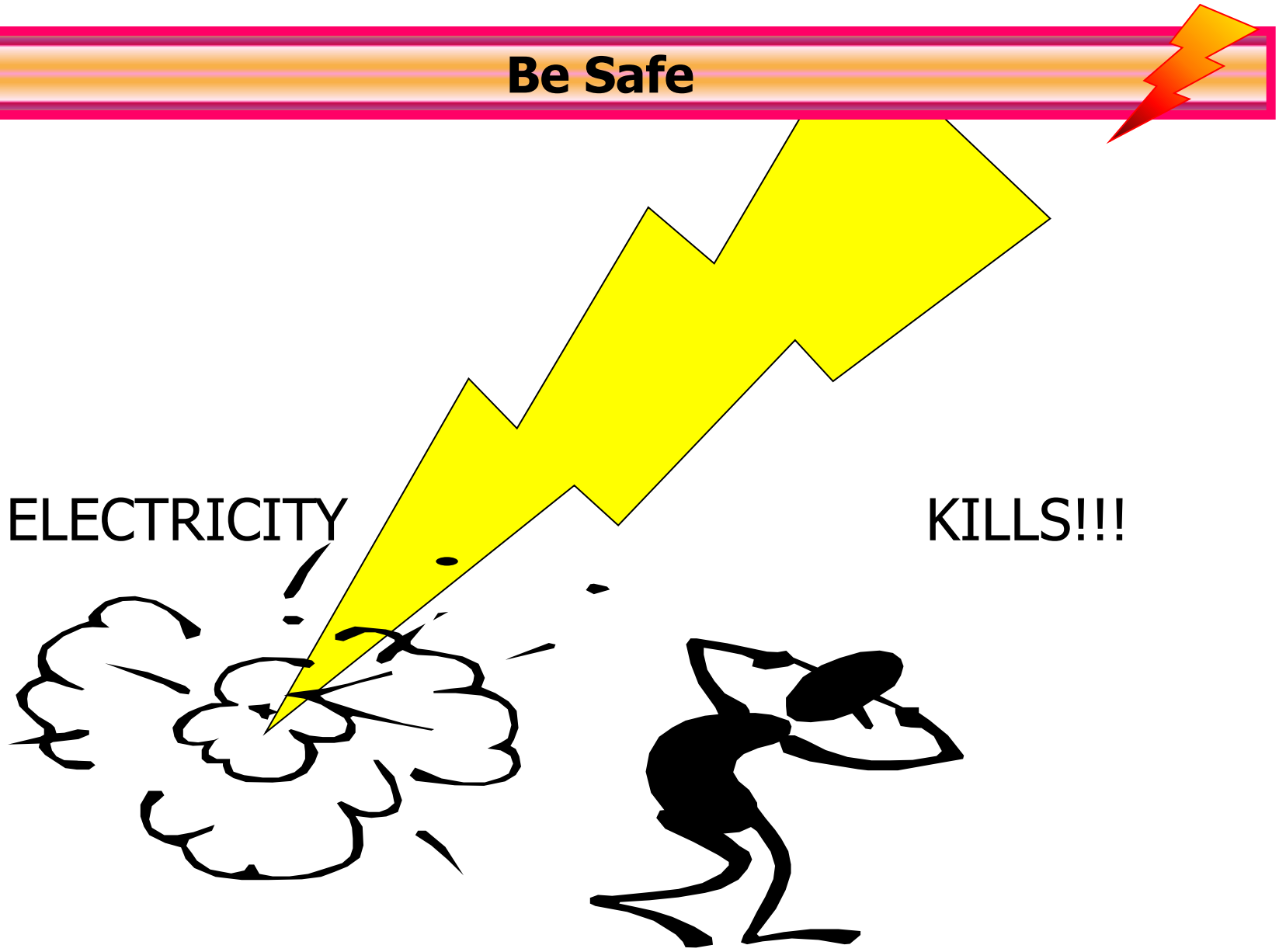
600 VAC Maximum



RED Lead
Volt / Ω
Position

BLACK Lead
Common
Position

Be Safe



Disconnect *the power to the circuit* **before** *replacing fuses, working on controllers, or any other activities that may expose you to* **live** *voltage!*

December is the most dangerous month for electrical fires!

Extension Cords

Avoid overloading extension cords. *Just because there are six receptacles doesn't mean you should plug something into every one.*

- *Extension cords are rated for a specific number of watts.*
- *Replace damaged or frayed cords*
- *Make sure the total load of all items plugged into the cord do not exceed the rating.*

Hints to keep breakers from tripping

- *Keep all plugs out of water or areas where water may accumulate. This will prevent GFCI from tripping and reduce potential for short circuit or injury.*

- *Do not operate display in heavy rains as this can cause breakers to trip and risk shorting out computerized controllers.*

- *Tighten all wires on Buss Bars in Controllers. A loose wire can potentially cause a short circuit.*

- *Balance your load across your home.*

- *Do not replace the fuses in light strands with nails or other objects meant to circumvent safety protocols.*

Warning Signs!

- *The following warning signs may indicate electrical problems that could cause a fire:*
- *Flickering or dimming lights.*
- *Switches or outlets that are hot to the touch or emit an acrid odor.*
- *Cords that are hot to the touch.*
- *Discolored cords, outlets and switchplates.*
- *Repeated blown fuses or tripped circuit breakers.*

Holiday Fire Safety

- *Maintain your holiday lights. Inspect them each year for frayed wires, bare spots, gaps in the insulation, broken or cracked sockets and excessive kinking or wear before putting them up.*
- *Use only lighting listed by an approved testing laboratory.*
- *Do not overload electrical outlets.*
- *Do not link more than three light strands, unless the directions indicate it is safe.*
- *Do not circumvent fuses in lights by replacing them with nails*

How much will it cost to run my display?

You can calculate your wattage based on your current load and voltage.

Watts = Volts x Current (amperage)

If your display is running at 40 amps x 120 volts; your wattage = 4,800 watts per hour or 4.8 Kilowatt-hours.

If you multiply by the number of hours per month, you can calculate your energy usage.

If you multiply your energy usage by your Utility supplier's adjusted energy rate, you can calculate your monthly cost.

How much will it cost to run my display?

"Electrical Energy" is the average amount of *power* used over a given time period and is commonly measured in "**kilowatt-hours**.“

Electric Utility Meters accurately measure the **kilowatt-hour energy use** by the customer and may also measure *peak power use* during a specified time interval.

Let's calculate the **energy use** for a Blow Dryer. Say the Blow Dryer is rated at 1,500 **watts** by the manufacturer. This is how much *electric power* it uses when it operates. If the Blow Dryer is operated for a total of 2 hours each month, the Blow Dryer consumes 1,500 **watts** x 2 hours = 3000 **watt-hours**.

Since "Utility Rates" are based on **kilowatt-hours**, divide by 1,000 to get 3 **kilowatt-hours**. This shows how power consumption and operating time are important in determining **energy use**

Multiply your utility rate per Kilowatt-hour and you can determine how much your power bill usage will cost you on a monthly basis.

NEMA Enclosures

Just a little bit of information about NEMA enclosures:

For more information, go to www.NEMA.org!

NEMA Enclosures

Non-Hazardous Locations

Type 1 : General Purpose - Indoor

- *Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment and to provide a degree of protection against falling dirt.*

Type 2 : Drip proof – Indoor

- *Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment, to provide a degree of protection against falling dirt, and to provide a degree of protection against dripping and light splashing of liquids.*

NEMA Enclosures

Non-Hazardous Locations

Type 3 : Dust tight, Rain tight, Sleet tight – Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, and windblown dust; and that will be undamaged by the external formation of ice on the enclosure.*

Type 3R : Rain tight, Sleet Resistant – Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, and snow; and that will be undamaged by the external formation of ice on the enclosure.*

NEMA Enclosures

Type 3S : Dust tight, Rain tight, Sleet tight - Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, and windblown dust; and in which the external mechanism(s) remain operable when ice laden.*

Type 4 : Watertight, Dust tight, Sleet Resistant - Indoor & Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, and hose-directed water; and that will be undamaged by the external formation of ice on the enclosure.*

NEMA Enclosures

Type 4X : Watertight, Dust tight, Corrosion-Resistant - Indoor & Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, hose-directed water, and corrosion; and that will be undamaged by the external formation of ice on the enclosure.*

Type 5 : Dust tight, Drip-Proof – Indoor

- *Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against settling airborne dust, lint, fibers, and flyings; and to provide a degree of protection against dripping and light splashing of liquids.*

NEMA Enclosures

Type 6 : Occasionally Submersible, Watertight, Sleet Resistant - Indoor & Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against hose-directed water and the entry of water during occasional temporary submersion at a limited depth; and that will be undamaged by the external formation of ice on the enclosure.*

Type 6P : Watertight, Sleet Resistant Prolonged Submersion - Indoor & Outdoor

- *Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against hose-directed water and the entry of water during prolonged submersion at a limited depth; and that will be undamaged by the external formation of ice on the enclosure.*

NEMA Enclosures

Type 12 : Dust tight and Drip tight – Indoor

- *Enclosures constructed (without knockouts) for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against circulating dust, lint, fibers, and flyings; and against dripping and light splashing of liquids.*

Type 12K : Dust tight and Drip tight, with Knockouts – Indoor

- *Enclosures constructed (with knockouts) for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against circulating dust, lint, fibers, and flyings; and against dripping and light splashing of liquids.*

Type 13 : Oil tight and Dust tight – Indoor

- *Enclosures constructed for indoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt; against circulating dust, lint, fibers, and flyings; and against the spraying, splashing, and seepage of water, oil, and noncorrosive coolants.*

NEMA Enclosures

For enclosures used in Hazardous Locations

Type 7 : Class I, Group A, B, C or D Hazardous Locations – Indoor

- *Enclosures constructed for indoor use in hazardous locations classified as Class I, Division 1, Groups A, B, C, or D as defined in NFPA 70.*

Type 8 : Class I, Group A, B, C or D Hazardous Location - Indoor & Outdoor

- *Enclosures constructed for either indoor or outdoor use in hazardous locations classified as Class I, Division 1, Groups A, B, C, and D as defined in NFPA 70.*

Type 9 : Class II, Group E, F or G Hazardous Locations – Indoor

- *Enclosures constructed for indoor use in hazardous locations classified as Class II, Division 1, Groups E, F, or G as defined in NFPA 70.*

Type 10 : Requirements of Mine Safety and Health Administration

Enclosures constructed to meet the requirements of the Mine Safety and Health Administration, 30 CFR, Part 18.

Additional Information

Sources:

http://science.howstuffworks.com/electricity5.htm
http://www.study-center.com/femp/content/demo/basics/bbp.htm
http://cipco.apogee.net/foe/frvt.asp
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