

"To electrize plus or minus, no more needs to be known than this, that the parts of the tube or sphere that are rubbed, do, in the instant of the friction, attract the electrical fire, and therefore take it from the thing rubbing; the same parts immediately, as the friction upon them ceases, are disposed to give the fire they have received to any body."

Benjamin Franklin

Franklin's Discovery of the Positive and Negative States of Electricity, 1747

Introduction

Two basic codes concerned with residential wiring are important to the housing inspector. The first is the local electrical code. The purpose of this code is to safeguard persons as well as buildings and their contents from hazards arising from the use of electricity for light, heat, and power. The electrical code contains basic minimum provisions considered necessary for safety. Compliance with this code and proper maintenance will result in an installation essentially free from hazards, but not necessarily efficient, convenient, or adequate for good service or future expansion.

Most local electrical codes are modeled after the National Electrical Code, published by the National Fire Protection Association (NFPA). Reference to the "code" in the remainder of this chapter will be to the National Electrical Code, unless specified otherwise [1].

An electrical installation that was safe and adequate under the provisions of the electrical code at the time of

installation is not necessarily safe and adequate today. An example would be the grounding of a home electrical system. In the past, electrical systems could be grounded to the home's plumbing system. Today, many plumbing systems are no longer constructed of conductive material, but are made of plastic or polyvinyl chloride-based materials. Today, the recommendations for grounding a home electrical system are to use two 8-foot by $\frac{5}{8}$ -inch copper ground rods. These must be spaced 6 feet apart and be connected by a continuous (unbroken) piece of copper wire (the size of this wire corresponds to the size of the system main). It is also highly recommended that the system be grounded to the incoming water line if it is conductive or to the nearest conductive cold water supply line. Hazards often occur because of overloading wiring systems or usage not in conformity with the code. This occurs because initial wiring did not provide for increases in the use of electricity. For this reason, it is recommended that initial installations be adequate and that reasonable provisions for system changes be made for further increases in the use of electricity.

The other code that contains electrical provisions is the local housing code. It establishes minimum standards for artificial and natural lighting and ventilation, specifies the minimum number of electric outlets and lighting fixtures per room, and prohibits temporary wiring except under certain circumstances. In addition, the housing code usually requires that all components of an electrical system be installed and maintained in a safe condition to prevent fire or electric shock.

Definitions of Terms Related to Electricity

Ampere—The unit for measuring intensity of flow of electricity. Its symbol is "I."

Bonding—Applies inert material to metal surfaces to eliminate electrical potential between metal components and prevent components and piping systems from having an elevated voltage potential.

Circuit—The flow of electricity through two or more wires from the supply source to one or more outlets and back to the source.

Circuit breaker—A safety device used to break the flow of electricity by opening the circuit automatically in the event of overloading or used to open or close the circuit manually.

Conductor—Any substance capable of conveying an electric current. In the home, copper wire is usually used.

- A bare conductor is one with no insulation or covering.
- A covered conductor is one covered with one or more layers of insulation.

Flow of Electric Current

Electricity is usually created by a generator that converts mechanical energy into electrical energy. The electricity may be the result of water, steam, or wind powering or turning a generator. The electricity is then run through a transformer, where voltage is increased to several hundred thousand volts and, in some instances, to a million or more volts. This high voltage is necessary to increase the efficiency of power transmission over long distances.

This high-transmission voltage is stepped down (reduced) to normal 115/230-volt household current by a transformer located near the point of use (residence). The electricity is then transmitted to the house by a series of wires called a service drop. In areas where the electric wiring is underground, the wires leading to the building are buried in the ground.

For electric current to flow, it must travel from a higher to a lower potential voltage. In an electrical system, the

Definitions of Terms Related to Electricity

Conductor gauge—A numeric system used to label electric conductor sizes, given in American Wire Gauge (AWG). The larger the AWG number, the smaller the wire size.

Current—The flow of electricity through a circuit.

- Alternating current is an electric current that reverses its direction of flow at regular intervals. For example, it would alternate 60 times every second in a 60-cycle system. This type of power is commonly found in homes.
- Direct current is an electric current flowing in one direction. This type of current is not commonly found in today's homes.

Electricity—Energy that can be used to run household appliances; it can produce light and heat, shocks, and numerous other effects.

Fuse—A safety device that cuts off the flow of electricity when the current flowing through the fuse exceeds its rated capacity.

Ground—To connect with the earth, as to ground an electric wire directly to the earth or indirectly through a water pipe or some other conductor. Usually, a green-colored wire is used for grounding the whole electrical system to the earth. A copper wire is usually used to ground individual electrical components of the whole system. (The home inspector should never assume that insulation color wiring codes have been used appropriately.)

Ground fault circuit interrupter (GFCI)—A device intended to protect people from electric shock. It de-energizes a circuit or portion of a circuit within an established very brief period of time when a current to ground exceeds some predetermined value (less than that required to operate the over-current protected device of the supply circuit).

Hot wires—Those that carry the electric current or power to the load; they are usually black or red.

Insulator—A material that will not permit the passage of electricity.

Kilowatt-hour (KWH)—The amount of energy supplied by one kilowatt (1,000 watts) for 1 hour (3,600 seconds), equal to 3,600,000 joule. Electric bills are usually figured by the number of KWHs consumed.

Neutral wire—The third wire in a three-wire distribution circuit; it is usually white or light gray and is connected to the ground.

Resistance—A measure of the difficulty of electric current to pass through a given material; its unit is the ohm.

Service—The conductor and equipment for delivering energy from the electricity supply system to the wiring system of the premises.

Service drop—The overhead service connectors from the last pole or other aerial support to and including the splices, if any, connecting to the service entrance conductors at the building or other structure.

Service panel—Main panel or cabinet through which electricity is brought to the building and distributed. It contains the main disconnect switch and fuses or circuit breakers.

Short circuit—A break in the flow of electricity through a circuit due to the load caused by improper connection between hot and neutral wires.

Volt—The unit for measuring electrical pressure of force, which is known as electromotive force. Its symbol is “E.”

Voltage drop—A voltage loss when wires carry current. The longer the cord, the greater the voltage drop.

Watt—The unit of electric power. Volts times amperes = watts.

hot wires (black or red) are at a higher potential than are the neutral or ground wire (white or green).

Voltage is a measure of the force at which electricity is delivered. It is similar to pressure in a water supply system.

Current is measured in amperes and is the quantity of flow of electricity. It is similar to measuring water in gallons per second. A watt is equal to volts times amperes. It is a measure of how much power is flowing. Electricity is sold in quantities of kilowatt-hours.

The earth, by virtue of moisture contained within the soil, serves as a very effective conductor. Therefore, in power transmission, instead of having both the hot and neutral wires carried by the transmission poles, one lead of the generator is connected to the ground, which serves as a conductor (Figure 11.1). All electrical utility wires are carried by the transmission towers and are considered hot or charged. At the house, or point where the electricity is to be used, the circuit is completed by another connection to ground.

The electric power utility provides a ground somewhere in its local distribution system; therefore, there is a ground wire in addition to the hot wires within the service drop. In Figure 11.1 this ground can be seen at the power pole that contains the step-down transformer.

In addition to the ground connection provided by the electric utility, every building is required to have an independent ground called a system ground. The system ground is a connection to ground from one of the current-carrying conductors of the electrical system. System grounding, applied to limit overvoltages in the event of a fault, provides personnel safety, provides a positive means of detecting and isolating ground faults, and improves service reliability. Therefore, the system ground's main purpose is to protect the electrical system itself and offers limited protection to the user.

The system ground serves the same purpose as the power company's ground; however, it has a lower resistance

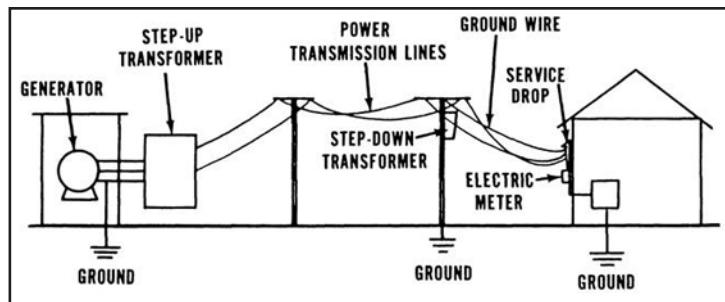


Figure 11.1. Utility Overview [2]

because it is closer to the building. The equipment ground protects people from potential harm during the use of certain electrical equipment. The system ground should be a continuous wire of low resistance and of sufficient size to conduct current safely from lightning and overloads.

Electric Service Entrance

Service Drop

To prevent accidental contact by people, the entrance head (Figure 11.2) should be attached to the building at least 10 feet above ground. The conductor should clear all roofs by at least 8 feet and residential driveways by 12 feet. For public streets, alleys, roads, and driveways on other than residential property, the clearance must be 18 feet.

The wires or conductor should be of sufficient size to carry the load and not smaller than No. 8 copper wire or equivalent.

For connecting wire from the entrance head to the service drop wires, the code requires that the service entrance conductors be installed either below the level of the service head or below the termination of the service entrance cable sheath. Drip loops must be formed on individual conductors. This will prevent water from entering the electric service system. The wires that form the entrance cable should extend 36 inches from the entrance head to provide a sufficient length to connect service drop wires to the building with insulators. The entrance cable may be a special type of armored outdoor cable, or it may be enclosed in a conduit. The electric power meter may be located either inside or outside the

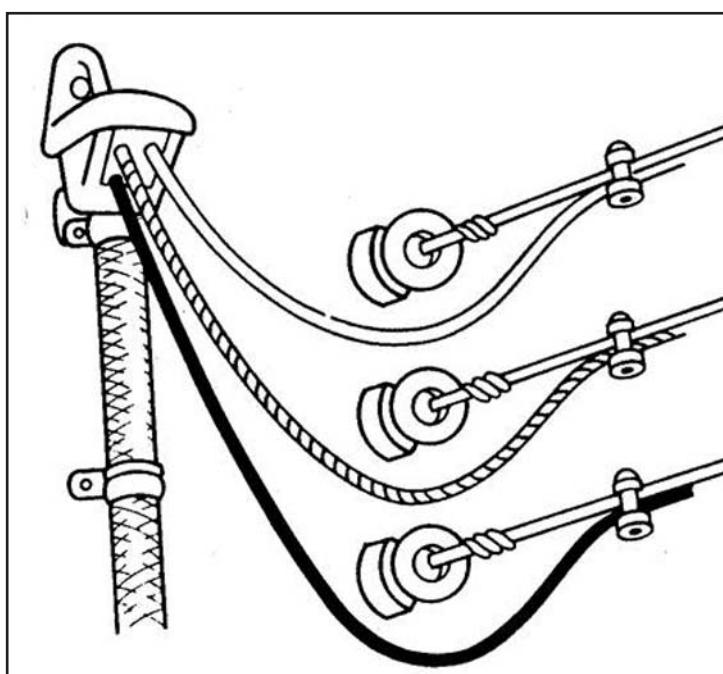


Figure 11.2. Entrance Head

building. In either instance, the meter must be located before the main power disconnect.

Figure 11.3 shows an armored cable service entrance with a fuse system. Newer construction will have circuit breakers, as shown in Figure 11.4. The armored cable is anchored to the building with metal straps spaced every 4 feet. The cable is run down the wall and through a hole drilled through the building. The cable is then connected to the service panel, which should be located within 1 foot of where the cable enters the building. The ground wire need not be insulated. This ground wire may be either solid or stranded copper, or a material with an equivalent resistance.

Figure 11.5 shows the use of thin-wall conduit in a service entrance.

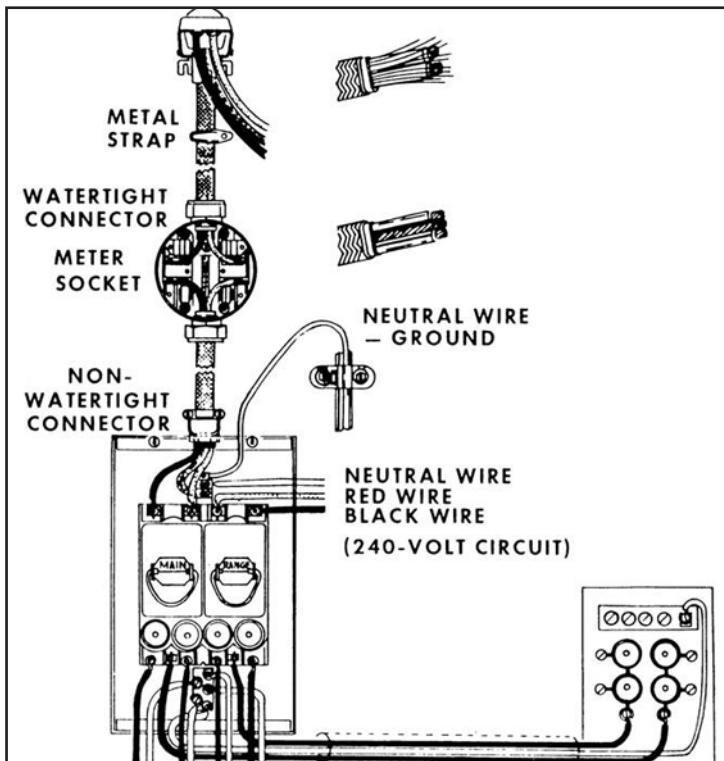


Figure 11.3. Armored Cable Service Entrance [2]

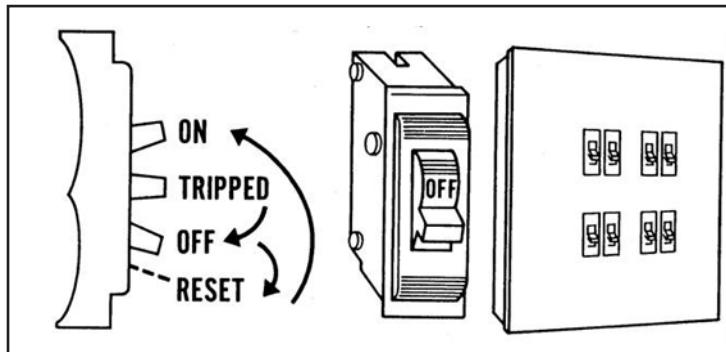


Figure 11.4. Breakers [2]

Underground Service

When wires are run underground, they must be protected from moisture and physical damage. The opening in the building foundation where the underground service enters the building must be moisture proof. Refer to local codes for information about allowable materials for this type of service entrance.

Electric Meter

The electric meter (Figure 11.6) may be located inside or outside the building. The meter itself is weatherproof and is plugged into a weatherproof socket. The electric power company furnishes the meter; the socket may or may not be furnished by the power company.

Grounding

The system ground consists of grounding the neutral incoming wire and the neutral wire of the branch circuits. The equipment ground consists of grounding the metal parts of the service entrance, such as the service switch, as well as the service entrance conduit, armor or cable.

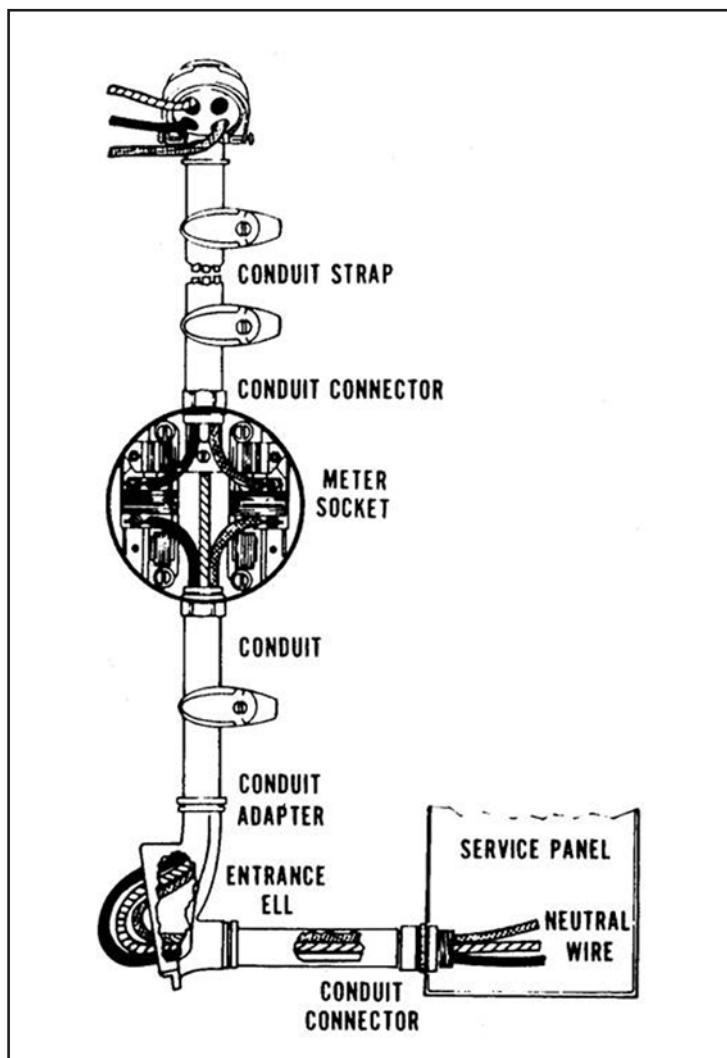


Figure 11.5. Thin-wall Conduit [2]

Poor grounding at any point can result in a person providing a more effective route to ground than the intended ground, resulting in electrocution. This can occur from damaged insulation allowing electricity to flow into the case or cabinet of the appliance.

The system must be grounded by two 8 foot by $\frac{5}{8}$ -inch copper ground rods of at least 8 feet in length driven into the ground and connected by a continuous (unbroken) piece of copper wire (the size of this wire corresponds to the size of the system main). It is highly recommended that the system also be grounded to the incoming water line or nearest cold water supply line if it is metal.

The usual ground connection is to a conductive water pipe of the city water system. The connection should be made to the street side of the water meter, as shown in Figure 11.7. If the water meter is located near the street curb, then the ground connection should be made to the cold water pipe as close as possible to where it enters the building. It is not unusual for a water meter to be removed from the building for service. If the ground connection is made at a point in the water piping system on the building side of the water meter, the ground circuit will be broken on removal of the meter. This broken ground circuit is a shock hazard if both sides of the water meter connections are touched simultaneously. Local or state codes should be checked to determine compliance with correct grounding protocols.

In increasing instances, the connections between the water meters and pipes are electrically very poor. In this case, if the ground connection is made on the building side of the water meter, there may not be an effective ground. To prevent the two aforementioned situations, the code requires effective bonding by a properly sized jumper-wire around any equipment that is likely to be disconnected for repairs or replacement.

Often, the house ground will be disconnected. Therefore, the housing inspector should always check the house ground to see if it is properly connected.

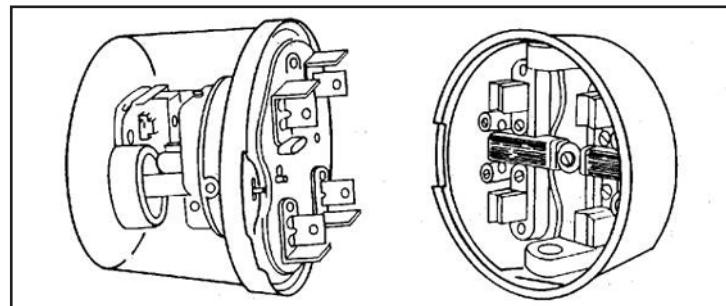


Figure 11.6. Electric Meter

Figure 11.8 shows a typical grounding scheme at the service box of a residence. In this figure, only the grounded neutral wires are shown. The neutral strap is a conductive bare metal strip that is riveted directly to the service box. This conductive strip forms a collective ground that joins the ground wires from the service entrance, branch circuits, and house ground.

Follow these key grounding points:

- Use two metal rods driven 8 feet into the ground.
- Bond around water heaters and filters to assure grounding.
- If water pipes are used, they must be supplemented with a second ground.
- Ground rod must be driven to full depth.
- If ground rod resistance exceeds 25 ohms, install two rods at a minimum of 6 feet apart.
- When properly grounded, the metal frame of a building can be used as a ground point.
- Do not use underground gas lines as a ground.
- Provide external grounds to other systems such as satellite, telephone, and other services to further protect the electrical system from surges.

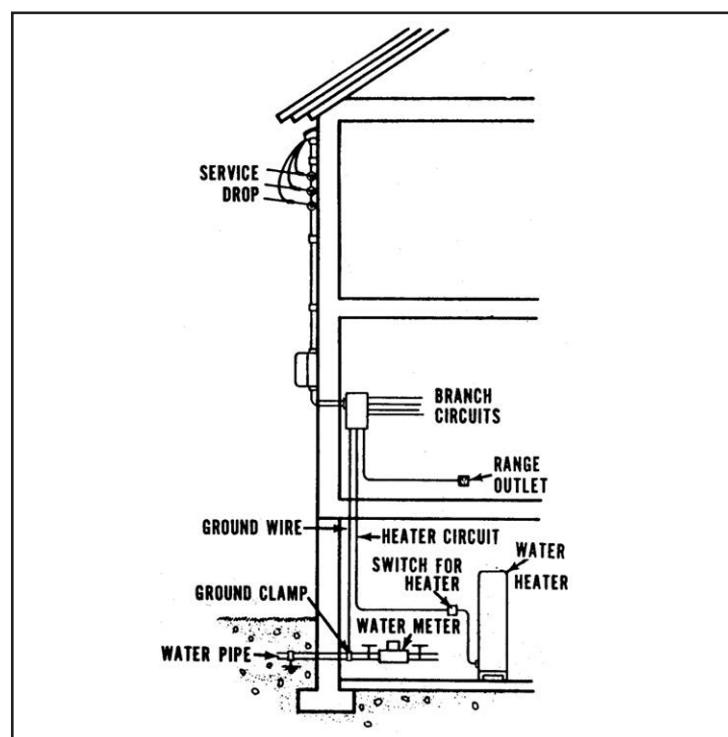


Figure 11.7. Typical Service Entrance [2]

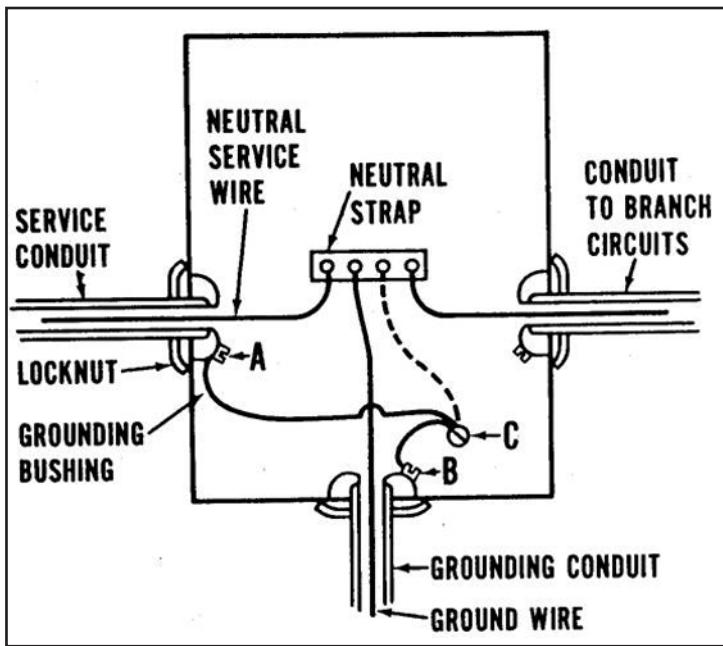


Figure 11.8. Grounding Scheme [2]

- If the water service pipes to the home are not metal or if all of the service components in the home are not metal, then the water system cannot play a role in grounding.

Bonding is necessary to provide a route for electricity to flow around isolated elements of a piping system to ensure electrical potential is minimized for both the protection of the system from corrosion and to protect individuals from electrical shock.

Two- or Three-wire Electric Services

One of the wires in every electrical service installation is supposed to be grounded. This neutral wire should always be white. The hot wires are usually black, red, or some other color, but never white.

The potential difference or voltage between the hot wires and the ground or neutral wire of a normal residential electrical system is 115 volts. Thus, where there is a two-wire installation (one hot and one neutral), only 115 volts are available.

When three wires are installed (two hot and one neutral), either 115 or 230 volts are available. In a three-wire system, the voltage between the neutral and either of the hot wires is 115 volts; between the two hot wires, it is 230 (Figure 11.9). The major advantage of a three-wire system is that it permits the operation of heavy electrical equipment such as clothes dryers, cooking ranges, and air conditioners, the majority of which require 230-volt circuits. In addition, the three-wire system is split at the service panel into two 115-volt systems to supply power

for small appliances and electric lights. The result is a doubling of the number of circuits, and, possibly, a corresponding increase in the number of branch circuits, with a reduction in the probability of fire caused by overloading electrical circuits if the electrical demands exceed the capacity.

Residential Wiring Adequacy

The use of electricity in the home has risen sharply since the 1930s. Many homeowners have failed to repair or improve their wiring to keep it safe and up to date. In the 1970s, the code recommended that the main distribution panel in a home be a minimum of 100 amps. Because the number of appliances that use electricity has continued to grow, so has the size of recommended panels. For a normal house (2,500 to 3,500 square feet), a 200-amp panel is recommended. The panel must be of the breaker type with a main breaker for the entire system (Figure 11.4). Fuse boxes are not recommended for new housing.

This type of service is sufficient in a one-family house or dwelling unit to provide safe and adequate electricity for the lighting, refrigerator, iron, and an 8,000-watt cooking range, plus other appliances requiring a total of up to 10,000 watts.

Some older homes have a 60-ampere, three-wire service (Figure 11.10). It is recommended that these homes be rewired for at least the minimum of 200-amperes recommended in the code. The 60-amp service is safely capable of supplying current for only lighting and portable appliances, such as a cooking range and regular dryer (4,500 watts), or an electric hot water heater (2,500 watts), and cannot handle additional major appliances. Other older homes today have only a 30-ampere, 115-volt, two-wire service (Figure 11.11). This system can safely handle only a limited amount of lighting, a few minor appliances, and no major appliances. Therefore, this size service is substandard in terms of the modern household's needs for electricity. Furthermore, it is a fire hazard and a threat to the safety of the home and the occupants.

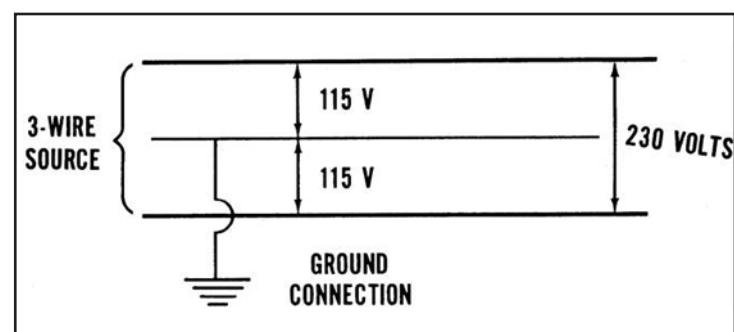


Figure 11.9. Grounding [2]

Wire Sizes and Types

Aluminum wiring, used in some homes from the mid 1960s to the early 1970s, is a potential fire hazard [3]. According to the U.S. Consumer Product Safety Commission (CPSC), fires and even deaths have been caused by this hazard. Problems due to expansion can cause overheating at connections between the wire and devices (switches and outlets) or at splices. CPSC research shows that homes wired with aluminum wire manufactured before 1972 are 55 times more likely to have one or more connections reach fire hazard conditions than are homes wired with copper. Post-1972 aluminum wire is also a concern. Introduction of aluminum wire alloys around 1972 did not solve most of the connection failure problems. Aluminum wiring is still permitted and used for certain applications, including residential service entrance wiring and single-purpose higher amperage circuits such as 240-volt air conditioning or electric range circuits.

Reducing Risk

Only two remedies for aluminum wiring have been recommended by the CPSC: discontinued use of the aluminum circuit or the less costly option of adding copper connecting "pigtail" wires between the aluminum wire and the wired device (receptacle, switch, or other device). The pigtail connection must be made using only a special connector and special crimping tool licensed by the AMP Corporation. Emergency temporary repairs necessary to keep an essential circuit in service might be possible following other procedures described by the CPSC, and in accordance with local electrical codes [4,5].

Wire Sizes

Electric power actually flows along the surface of the wire. It flows with relative ease (little resistance) in some materials, such as copper and aluminum, and with a substantial amount of resistance in iron. If iron wire were used, it would have to be 10 times as large as copper wire to be as effective in conducting electricity. In fine electronics, gold is the preferred conductor because of the resistance to corrosion and the very high conductivity.

Electricity is the movement of electrons from an area of higher potential to one of lower potential. An analogy to how electricity flows would be the flow of water along the path of least resistance or down a hill. All it takes to create the potential for electricity is the collection of

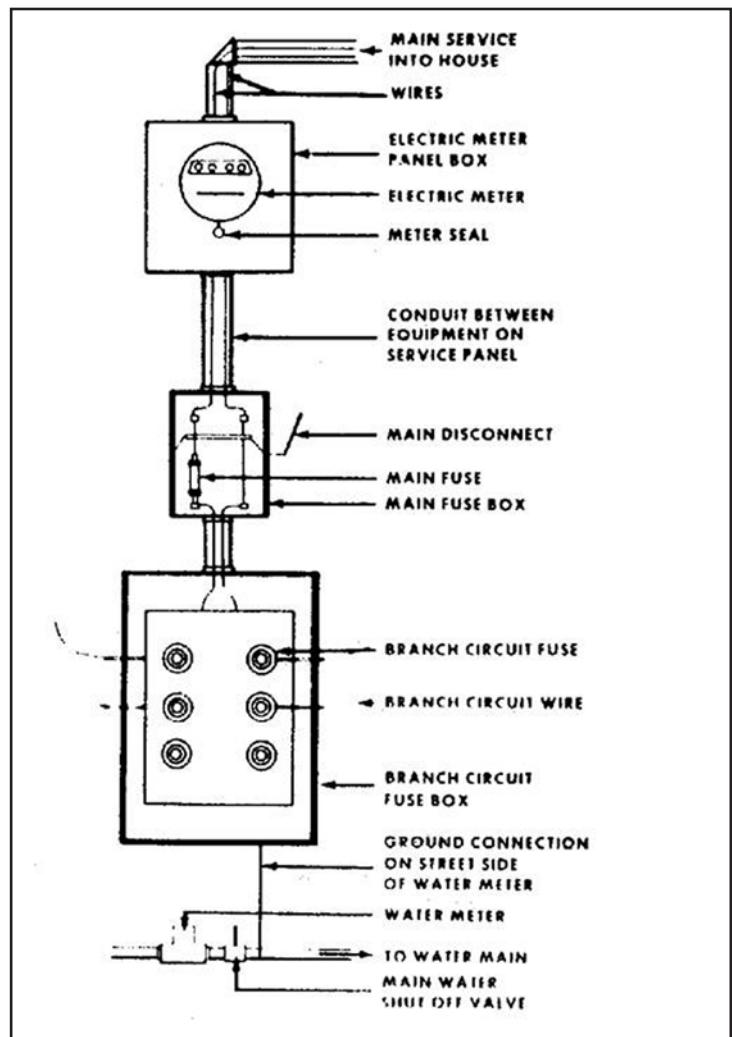


Figure 11.10. Three-wire Service [2]

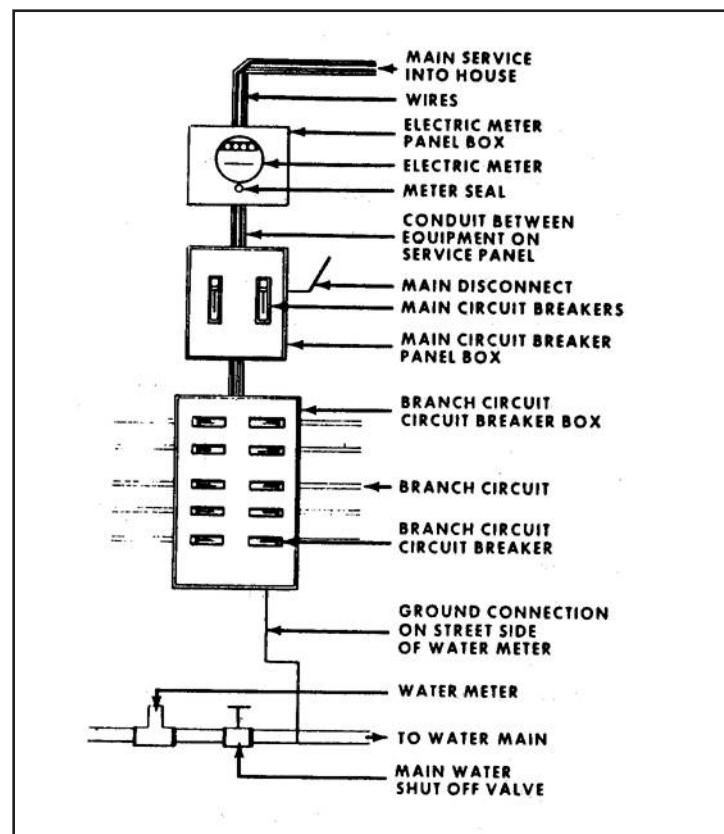


Figure 11.11. Two-wire Service [2]

Maximum Current Recommended for AWG Wire Size

Size wire (AWG) (larger wire, smaller number)	#14	#12	#10	#8
Maximum capacity in amperes	15	20	30	40

electrons and a pathway for them to flow to an area of lesser concentration along a conductor. When a person walks across a nylon carpet in times of low atmospheric humidity, his or her body will often collect electrons and serve as a capacitor (a storage container for electrons). When that person nears a grounding source, the electrons will often jump from a finger to the ground, creating a spark and small shock.

A number preceded by the letters AWG (American Wire Gauge) indicates copper wire sizes [6]. As the AWG number of the wire becomes smaller, the size and current capacity of the wire increases. AWG 14 is most commonly found in older residential branch circuits. AWG 14 wires should be used only in a branch circuit with a 15-ampere capacity or no more than a 1,500-watt demand. Wire sizes AWG 16, 18, and 20 are progressively smaller than AWG 14 and are used for extension wires or low-voltage systems. Wire of the correct size must be used for two reasons: current capacity and voltage drop or loss.

When current flows through a wire, it creates heat. The greater the amount of flow, the greater the amount of heat generated. (Doubling the amperes without changing the wire size increases the amount of heat by four times.) The heat is electric energy (electrons) that has been converted into heat energy by the resistance of the wire. The heat created by the coils in a toaster is an example of designed resistance to create heat. Most heat developed by an electrical conductor is wasted; therefore, the electric energy used to generate it is also wasted.

If the amount of heat generated by the flow of current through a wire becomes excessive, a fire may result. Therefore, the code sets the maximum permissible current that may flow through a certain type and size wire. The blue box provides examples of current capacities for copper wire of various sizes.

In addition to heat generation, there will be a reduction in voltage as a result of attempting to force more current through a wire than it is designed to carry. Certain appliances, such as induction-type electric motors, may be damaged if operated at too low a voltage.

Wire Types

All wires must be marked to indicate the maximum working voltage, the proper type letter or letters for the type wire specified in the code, the manufacturer's name or trademark, and the AWG size or circular-mil area (Figure 11.12). A variety of wire types can be used for a wide range of temperature and moisture conditions. The code should be consulted to determine the proper wire for specific conditions.

Types of Cable

Nonmetallic sheathed cable consists of wires wrapped in plastic and then a paper layer, followed by another spiral layer of paper, and enclosed in a fabric braid, which is treated with moisture- and fire-resistant compounds. Figure 11.12 shows this type of cable, which often is marketed under the name Romex. This type of cable can be used only indoors and in permanently dry locations. Romex-type wiring is normally used in residential construction. However, when cost permits, it is recommended that a conduit-based system be used.

Armored cable is commonly known as BX or Flexsteel trade names. Wires are wrapped in a tough paper and covered with a strong spiral flexible steel armor. This type of cable is shown in Figure 11.13 and may be used only in permanently dry indoor locations. Armored cable must be supported by a strap or staple every 6 feet and within 24 inches of every switch or junction box, except for concealed runs in old work where it is impossible to mount straps.

Cables are also available with other outer coatings of metals, such as copper, bronze, and aluminum for use in a variety of conditions.

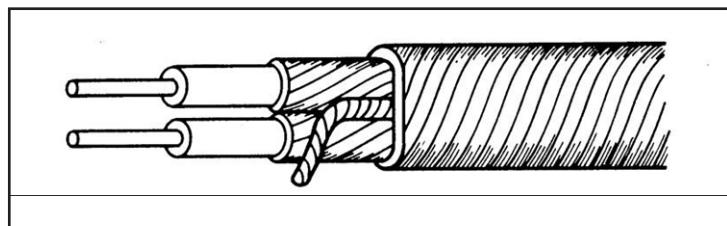


Figure 11.12. Wire Markings [2]



Figure 11.13. Armored Cable [2]

Flexible Cords

CPSC estimates that about 4,000 injuries associated with electric extension cords are treated in hospital emergency rooms each year. About half of the injuries involve fractures, lacerations, contusions, or sprains from people tripping over extension cords. Thirteen percent of the injuries involve children younger than 5 years of age; electrical burns to the mouth account for half the injuries to young children [7].

CPSC also estimates that about 3,300 residential fires originate in extension cords each year, killing 50 people and injuring about 270 others [7]. The most frequent causes of such fires are short circuits, overloading the system, and damage to or misuse of extension cords.

The Problem

Following are CPSC investigations of injuries that illustrate the major injury patterns associated with extension cords: children putting extension cords in their mouths, overloaded cords, worn or damaged cords, and tripping over cords:

- A 15-month-old girl put an extension cord in her mouth and suffered an electrical burn. She required surgery.
- Two young children were injured in a fire caused by an overloaded extension cord in their family's home. A lamp, TV set, and electric heater had been plugged into a single, light-duty extension cord.
- A 65-year-old woman was treated for a fractured ankle after tripping over an extension cord.

The Standards

The code says that many cord-connected appliances should be equipped with polarized grounding plugs. Polarized plugs can only be inserted one way into the outlet because one blade is slightly wider than the other. Polarization and grounding ensure that certain parts of appliances that could have a higher risk of electric shock when they become live are instead connected to the neutral, or grounded, side of the circuit. Such electrical products should only be used with polarized or grounded extension cords.

Voluntary industry safety standards, including those of Underwriter's Laboratory (UL), now require that general-use extension cords have safety closures, warning labels, rating information about the electrical current, and other features for the protection of children and other consumers.

In addition, UL-listed extension cords now must be constructed with 16-gauge or larger wire or be equipped with integral fuses. The 16-gauge wire is rated to carry 13 amperes (up to 1,560 watts), as compared with the formerly used 18-gauge cords that were rated for 10 amperes (up to 1,200 watts).

Safety Suggestions

The following are CPSC recommendations [7] for purchasing and safely using extension cords:

- Use extension cords only when necessary and only on a temporary basis.
- Use polarized extension cords with polarized appliances.
- Make sure cords do not dangle from the counter or tabletops where they can be pulled down or tripped over.
- Replace cracked or worn extension cords with new 16-gauge cords that have the listing of a nationally recognized testing laboratory, safety closures, and other safety features.
- With cords lacking safety closures, cover any unused outlets with electrical tape or with plastic caps to prevent the chance of a child making contact with the live circuit.
- Insert plugs fully so that no part of the prongs is exposed when an extension cord is in use.
- When disconnecting cords, pull the plug rather than the cord itself.
- Teach children not to play with plugs and outlets.
- Use only three-wire extension cords for appliances with three-prong plugs. Never remove the third (round or U-shaped) prong, which is a safety feature designed to reduce the risk for shock and electrocution.

- In locations where furniture or beds may be pushed against an extension cord where the cord joins the plug, use a special angle extension cord specifically designed for use in these instances.
- Check the plug and the body of the extension cord while the cord is in use. Noticeable warming of these plastic parts is expected when cords are being used at their maximum rating. If the cord feels hot or if there is a softening of the plastic, this is a warning that the plug wires or connections are failing and that the extension cord should be discarded and replaced.
- Never use an extension cord while it is coiled or looped. Never cover any part of an extension cord with newspapers, clothing, rugs, or any objects while the cord is in use. Never place an extension cord where it is likely to be damaged by heavy furniture or foot traffic.
- Do not use staples or nails to attach extension cords to a baseboard or to another surface. This could damage the cord and present a shock or fire hazard.
- Do not overload extension cords by plugging in appliances that draw a total of more watts than the rating of the cord.
- Use special heavy-duty extension cords for high-wattage appliances such as air conditioners, portable electric heaters, and freezers.
- When using outdoor tools and appliances, use only extension cords labeled for outdoor use.

Wiring

Open Wiring

Open wiring is a wiring method using knobs, nonmetallic tubes, cleats, and flexible tubing for the protection and support of insulated conductors in or on buildings and not concealed by the structure. The term “open wiring” does not mean exposed, bare wiring. In dry locations, when not exposed to severe physical damage, conductors may be separately encased in flexible tubing. Tubing should be in continuous lengths not exceeding 15 feet and secured to the surface by straps not more than 4½ feet apart. Tubing should be separated from other conductors by at least 2½ inches and should have a permanently maintained airspace between them and any and all pipes they cross.

Concealed Knob and Tube Wiring

Concealed knob and tube wiring is a wiring method using knobs, tubes, and flexible nonmetallic tubing for the protection and support of insulated wires concealed in hollow spaces of walls and ceilings of buildings. This wiring method is similar to open wiring and, like open wiring, is usually found only in older buildings.

Electric Service Panel

The service switch is a main switch that will disconnect the entire electrical system at one time. The main fuses or circuit breakers are usually located within the service switch box. The branch circuit fuse or circuit breaker may also be located within this box.

According to the code, the switch must be externally operable. This condition is fulfilled if the switch can be operated without the operator being exposed to electrically active parts. Figure 11.14 shows a 200-amp service box. Figure 11.15 shows an external “hinged switch” power shutoff installed on the outside of a home.

Most of today’s older homes do not have hinged switches. Instead, the main fuse is mounted on a small insulated block that can be pulled out of the switch. When this block is removed, the circuit is broken.

In some installations, the service switch is a “solid neutral” switch, meaning that the switch or a fuse does not break the neutral wire in the switch.

When circuit breakers are used in homes instead of fuses, main circuit breakers may or may not be required. If it takes more than six movements of the hand to open all the branch-circuit breakers, a main breaker, switch, or fuse will be required ahead of the branch-circuit breakers. Thus, a house with seven or more branch circuits requires a separate disconnect means or a main circuit breaker ahead of the branch-circuit breakers.

Over-current Devices

The amperage (current flow) in any wire is limited to the maximum permitted by using an over-current device of a size specified by the code. Four types of over-current devices are common: circuit breakers, ground fault circuit interrupters (GFCIs), arc fault circuit interrupters (AFCIs), and fuses. The over-current device of a specific size is specified by the code. The over-current device must be rated at equal or lower capacity than the wire of the circuit it protects.

Circuit Breakers (Fuseless Service Panels)

A circuit breaker looks something like an ordinary electric light switch. Figure 11.14 shows the service box in a 200-amp fuseless system. Figure 11.15 shows a service switch. There is a handle that may be used to turn power on or off. Inside is a simple mechanism that, in case of a circuit overload, trips the switch and breaks the circuit. The circuit breaker may be reset by turning the switch to off and then simply resetting the switch to the on position. A circuit breaker is capable of taking harmless short-period overloads (such as the heavy initial current required in the starting of a washing machine or air conditioner) without tripping, but protects against prolonged overloads. After the cause of trouble has been located and corrected, power is easily restored. Fuseless service panels or breaker boxes are usually broken up into the following circuits:

- A **100-ampere** or larger main circuit breaker that shuts off all power.
- A **40-ampere** circuit for an appliance such as an electric cooking range.
- A **30-ampere** circuit for a clothes dryer, water heater, heat pump, or central air conditioning.

- A **20-ampere** circuit for small appliances and power tools.
- A **15-ampere** circuit for general-purpose lighting, TVs, VCRs, computers, and vacuum cleaners.
- Space for new circuits to be added if needed for future use.

Ground Fault Circuit Interrupters

Unlike circuit breakers and fuses, GFCIs are installed to protect the user from electrocution. These devices provide protection against electrical shock and electrocution from ground faults or contact with live parts by a grounded individual. They constantly monitor electrical currents flowing into a product. If the electricity flowing through the product differs even slightly from that returning, the GFCI will quickly shut off the current. GFCIs detect amounts of electricity much smaller than those required for a fuse or circuit breaker to activate and shut off the circuit. UL lists three types of GFCIs designed for home use that are readily available and fairly inexpensive and simple to install:

- **Wall Receptacle GFCI**—This type of GFCI (Figure 11.16) is used in place of a standard receptacle found throughout the house. It fits into a standard outlet box and protects against ground faults whenever an electrical product is plugged into the outlet. If strategically located, it will also provide protection to downstream receptacles.
- **Circuit Breaker GFCI**—In homes equipped with circuit breakers, this type of GFCI may be installed in a panel box to protect selected circuits. A circuit breaker GFCI serves a dual purpose: it shuts off electricity in the event of a ground fault



Figure 11.14. 200-Amp Service Box



Figure 11.15. External Power Shutoff and Meter

and will also trip when a short circuit or an overload occurs.

- **Portable GFCI**—A portable GFCI requires no special knowledge or equipment to install. One type contains the GFCI circuitry in a self-contained enclosure with plug blades in the back and receptacle slots in the front. It can be plugged into a receptacle, and the electrical product plugged into the GFCI. Another type of portable GFCI is an extension cord combined with a GFCI. It adds flexibility in using receptacles that are not protected by GFCIs.

Once a GFCI is installed, it must be checked monthly to determine that it is operating properly. Pressing the test button can check units; the GFCI should disconnect the power to that outlet. Pressing the reset button reconnects the power. If the GFCI does not disconnect the power, have it checked by a qualified, certified electrician. GFCIs should be installed on circuits in the following areas: garages, bathrooms, kitchens, crawl spaces, unfinished basements, hot tubs and spas, pool electronics, and exterior outlets. However, they are not required on single outlets that serve major appliances.

Arc-fault Circuit Interrupters

Arc-fault circuit interrupters are new devices intended to provide fire protection by opening the circuit if an arcing fault is detected. An arcing fault is an electric spark or hot plasma field that extends from the hot wire to a ground. An arc is a luminous discharge of electricity across an insulating medium or simply a spark across an air gap. Arcs occur every day in homes. For example, an arc occurs inside the switch when a light is turned on. Toy racecars and trains create arcs. The motors inside hair dryers and power drills have tiny arcs. All of these are

controlled arcs. It is the uncontrolled or nondesigned arc that is a serious fire hazard in the home. The arc-fault circuit interrupter looks like the GFCI unit (Figure 11.17), but it is not designed to protect against electric shock.

Because most electrical wiring in a home is hidden from view, many arc faults go undetected and continue arcing indefinitely. If left in this arcing state, the potential



Figure 11.16. GFCI

for fire increases. It is estimated that about one third of fires are caused by arcing faults. Normal fuses and circuit breakers are not capable of detecting arc faults and therefore will not open the circuit and stop the flow of electricity.

Fused Ampere Service Panel (Fuse Box)

Fuse-type panel boxes are generally found in older homes. They are as safe and adequate as a circuit breaker of equivalent capacity, provided fuses of the proper size are used.

A fuse, like a circuit breaker, is designed to protect a circuit against overloading and short circuits and does so in two ways.

When a fuse is blown by a short circuit, the metal strip is instantly heated to an extremely high temperature, and this heat causes it to vaporize. A fuse blown by a short circuit may be easily recognized because the window of the fuse usually becomes discolored.

In a fuse blown by an overload, the metal strip is melted at its weakest point, breaking the flow of current to the load. In this case, the window of the fuse remains clear; therefore, a blown fuse caused by an overload may also be easily recognized.

Sometimes, although a fuse has not been blown, the bottom of the fuse may be severely discolored and pitted. This indicates a loose connection because the fuse was not screwed in properly.

It is critical to check that all fuses are properly rated for the designed amperage. The placing of a fuse with a higher amperage than recommended presents a significant fire hazard.

Generally, all fused panel boxes are wired similarly for two- and three-wire systems. In a two-wire-circuit panel box, the black or red hot wire is connected to a terminal of the main disconnect, and the white or light gray neutral wire is connected to the neutral strip, which is then grounded to the pipe on the street side of the water meter.



Figure 11.17. Arc Interrupter

In a three-wire system, the black and red hot wires are connected to separate terminals of the main disconnect, and the neutral wire is grounded the same as for a two-wire system. Below each fuse is a terminal to which a black or red wire is

connected. The white or light gray neutral wires are then connected to the neutral strip. Each fuse indicates a separate circuit (Figure 11.18).

- **Nontamperable fuses**—All ordinary plug fuses have the same diameter and physical appearance, regardless of their current capacity, whereas nontamperable fuses are sized by amperage load. Thus, with regular fuses, if a circuit designed for a 15-ampere fuse is overloaded so that the 15-ampere fuse blows out, nothing will prevent a person from replacing the 15-ampere fuse with a 20- or 30-ampere fuse, which may not blow out. If a circuit wired with 14-gauge wire (current capacity 15 amperes) is fused with a 20- or 30-ampere fuse and an overload develops, more current than the 14-gauge wire is safely capable of carrying could pass through the circuit. The result would be a heating of the wire and potential fire.
- **Type-S fuses**—Type-S fuses have different lengths and diameter threads for each amperage capacity. An adapter is first inserted into the ordinary fuse holder, which adapts the fuse holder for only one capacity fuse. Once the adapter is inserted, it cannot be removed.
- **Cartridge fuses**—A cartridge fuse protects an electric circuit in the same manner as an ordinary plug fuse, already described, protects an electric circuit. Cartridge fuses are often used as main fuses.

Electric Circuits

An electric circuit in good repair carries electricity through two or three wires from the source of supply to an outlet and back to the source. A branch circuit is an

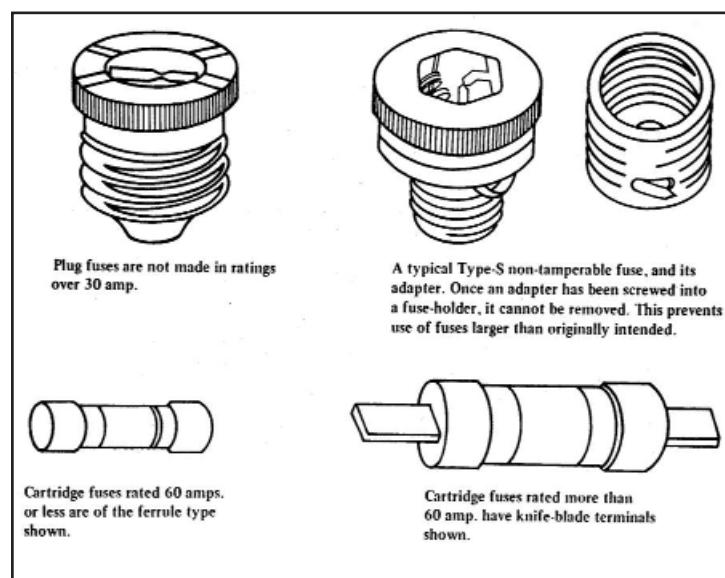


Figure 11.18. Types of Fuses

electric circuit that supplies current to a limited number of outlets and fixtures. A residence generally has many branch circuits. Each is protected against short circuits and overloads by a 15- or 20-ampere fuse or circuit breaker.

The number of outlets per branch circuit varies from building to building. The code requires enough light circuits so that 3 watts of power will be available for each square foot of floor area in a house. A circuit wired with 14-gauge wire and protected by a 15 ampere over-current protection device provides 15×115 (1,725 watts); each circuit is enough for 1,725 divided by 3 (575 square feet). Note that 575 is a minimum figure; if future use is considered, 500 or even 400 square feet per branch circuit should be used.

Special appliance circuits will provide electric power for lighting, radio, TV, and small portable appliances. However, the larger electric appliances usually found in the kitchen consume more power and must have their own special circuit.

Section 220-3b of the code requires two special circuits to serve only appliance outlets in the kitchen, laundry, pantry, family room, dining room, and breakfast room. Both circuits must be extended to the kitchen; either one or both of these circuits may serve the other rooms. No lighting outlets may be connected to these circuits, and they must be wired with 12-gauge wire and protected by a 20-ampere over-current device. Each circuit will have a capacity of 20×115 (2,300 watts), which is not too much when toasters often require more than 1,600 watts.

It is customary to provide a circuit for each of the following appliances: range, water heater, washing machine, clothes dryer, garbage disposal, dishwasher, furnace, water pump, air conditioner, heat pump, and air compressor. These circuits may be either 115 volts or 230 volts, depending on the particular appliance or motor installed.

Outlet Switches and Junction Boxes

The code requires that every switch, outlet, and joint in wire or cable be housed in a box. Every fixture must be mounted on a box. Most boxes are made of plastic or metal with a galvanized coating. When a cable of any style is used for wiring, the code requires that it be securely anchored with a connector to each box it enters.

Grounding Outlets

An electrical appliance may appear to be in good repair, and yet it might be a danger to the user. Older portable

electric drills consist of an electric motor inside a metal casing. When the switch is depressed, the current flows to the motor and the drill rotates. As a result of wear, however, the insulation on the wire inside the drill may deteriorate and allow the hot side of the power cord to come in contact with the metal casing. This will not affect the operation of the drill.

A person fully clothed using the drill in the living room, which has a dry floor, will not receive a shock, even though he or she is in contact with the electrified drill case. The operator's body is not grounded because of the dry floor. If standing on a wet basement floor, the operator's body might be grounded; and, when the electrified drill case is touched, current will pass through the operator's body.

To protect people from electrocution, the drill case is usually connected to the system ground by means of a wire called an appliance ground. In this instance, as the drill is plugged in, current will flow between the shorted hot wire and the drill case and cause the over-current device to break the circuit. Thus, the appliance ground has protected the human operator. Newer appliances and tools are equipped with two-prong polarized plugs, as discussed in the standards section of this manual.

The appliance ground (Figure 11.19) is the third wire found on many appliances. The appliance ground will be of no use unless the outlet into which the appliance is plugged is grounded. Being in physical contact with a ground outlet box grounds the outlet. Having a third ground wire, or a grounded conduit, as part of the circuit wiring grounds the outlet box.

All new buildings are required to have grounded outlets. A two-lead circuit tester can be used to test the outlet. The circuit tester lights when both of its leads are plugged into the two elongated parallel openings of the outlet. In addition, the tester lights when one lead is plugged into the round third opening and the other is plugged into the hot side of the outlet. Most problems can be resolved using inexpensive testers resembling a plug with three leads. These can be purchased in many stores and most hardware stores for very reasonable prices.

If the conventional two-opening outlet is used, it may be grounded if the screw that holds the outlet cover plate is electrically connected to the third-wire ground. The tester should light when one lead is in contact with a clean paint-free metal outlet cover plate screw and the hot side of the outlet. If the tester does not light, the outlet is not

grounded. If a two-opening outlet is grounded, it may be adapted for use by a three-wire appliance by using an adapter. The loose-wire portion or screw tab of the adapter should be secured behind the metal screw of the outlet plate cover. Many appliances, such as electric shavers and some new hand tools, are double insulated and are safe without having a third ground wire.

Polarized Plugs and Connectors

Plugs are polarized or unpolarized. Polarization helps reduce the potential for shock. Consumers can easily identify polarized plugs; one blade—the ground prong—is wider than the other. Three-conductor plugs are automatically polarized because they can only be inserted one way. Polarized plugs are used to connect the most-exposed part of an appliance to the ground wire so that if you are touching a ground (such as a pipe, bathtub, or faucet) and the exposed part of an appliance (the case, the threaded part of a light bulb socket, etc.), you will not get an electrical shock. Many appliances, such as electric drills, are doubly insulated so the probability of any exposed part of the appliance being connected, by a short or other problem in the appliance, to either wire is very small. Such devices often use unpolarized plugs where the two prongs of the plug are identical.

Common Electrical Violations

The most obvious things that a housing inspector must check are the power supply; the type, location, and condition of the wiring; and the number and conditions of wall outlets or ceiling fixtures required by the local code. In making an investigation, the following considerations will serve as useful guides.

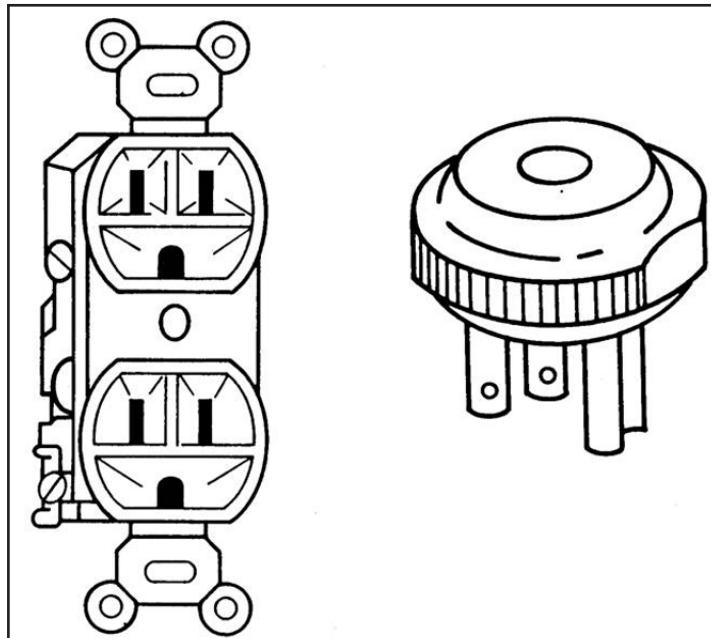


Figure 11.19. Appliance Ground and Grounded Plug

- **Power supply**—Where is it, is it grounded properly, and is it at least of the minimum capacity required to supply current safely for lighting and the major and minor appliances in the dwelling?
 - **Panel box covers or doors**—These should be accessible only from the front and should be sealed in such a way that they can be operated safely without the danger of contact with live or exposed parts of the wiring system.
 - **Switch, outlets, and junction boxes**—These also must be covered to protect against danger of electric shock.
 - **Frayed or bare wires**—These are usually the result of long use and drying out and cracking of the insulation, which leave the wires exposed, or of constant friction and rough handling of the wire, which cause it to fray or become bare. Wiring in this condition constitutes a safety hazard. Correction of such defects should be ordered immediately.
 - **Electric cords under rugs or other floor coverings**—Putting electric cords in locations such as these is prohibited because of the potential fire hazard caused by continuing contact over a period of time between these heat-bearing cords and the flammable floor coverings. Direct the occupant to shift the cords to a safe location, explain why, and make sure it is done before you leave.
 - **Ground fault circuit interrupter**—All bathroom, kitchen, and workroom outlets—where shock hazard is great—should have GFCI outlets. Check for lack of or nonuse of GFCI outlets.
 - **Bathroom lighting**—Bathrooms should include at least one permanently installed ceiling or wall light fixture with a wall switch and plate located and maintained so that there is no danger of short circuiting from use of other bathroom facilities or splashing water. Fixture or cover plates should be insulated or grounded.
 - **Lighting of public hallways, stairways, landings, and foyers**—A common standard is sufficient lighting to illuminate 10 foot-candles on every part of these areas at all times. Sufficient lighting means that people can clearly see their feet on all parts of the stairways and halls. Public halls and stairways in structures containing less than three dwelling units may be supplied with conveniently located light switches controlling an adequate lighting system that may be turned on when needed, instead of full-time lighting.
 - **Habitable room lighting**—The standard here may be two floor convenience outlets (although floor outlets are dangerous unless protected by proper dust and water covers) or one convenience outlet and one wall or ceiling electric light fixture. This number is an absolute and often inadequate minimum, given the contemporary widespread use of electricity in the home. The minimum should be the number required to provide adequate lighting and power to accommodate lighting and appliances normally used in each room.
 - **Octopus outlets or wiring**—This term is applied to outlets into which plugs have been inserted and are being used to permit more than two lights or portable appliances, such as a TV, lamp, or radio, to be connected to the electrical system. The condition occurs where the number of outlets is insufficient to accommodate the normal use of the room. This practice overloads the circuit and is a potential source of fire.
 - **Outlet covers**—Every outlet and receptacle must be covered by a protective plate to prevent contact of its wiring or terminals with the body, combustible objects, or water.
- Following are six situations that can cause danger and should also be corrected.
- ### **Excessive or Faulty Fusing**
- The wire's capacity must not be exceeded by the fuse or circuit breaker capacity or be left unprotected by faulty fusing or circuit breakers. Fuses and circuit breakers are safety devices designed to "blow" to protect against overloading the electrical system or one or more of its circuits. Pennies under fuses are there to bypass the fuse. These are illegal and must be removed. Overfusing is done for the same reason. The latter can be prevented by installing modern fusestats, which prevent use of any fuse of a higher amperage than can be handled by the circuit it serves.
- ### **Cords Run Through Walls or Doorways and Hanging Cords or Wires**
- This makeshift installation often is the work of an unqualified handyman or do-it-yourself occupant. The

inspector should check the local electrical code to determine the policy regarding this type of installation.

Temporary Wiring

Temporary wiring should not be allowed, with the exception of extension cords that go directly from portable lights and electric fixtures to convenience outlets.

Excessively Long Extension Cords

City code standards often limit the length of loose cords or extension lines to a maximum of 8 feet. This is necessary because cords that are too long will overheat if overloaded or if a short circuit develops and, thus, create a fire hazard. This requirement does not apply to specially designed extension cords for operating portable tools and trouble lights.

Dead or Dummy Outlets

These are sometimes installed to deceive the housing inspector. All outlets must be tested or the occupants questioned to see if these are live and functioning properly. A dead outlet cannot be counted to determine compliance with the code.

Aluminum Wiring Inside the Home

Although aluminum is an excellent conductor, it tends to oxidize on the conducting surface. The nonconductive oxidized face of the conductor will arc from the remaining conductive surfaces, and this arc can result in fire.

Inspection Steps

The basic tools required by a housing inspector for making an electrical inspection are fuse and circuit testers and a flashlight. The first thing to remember is that you are in a strange house, and the layout is unfamiliar to you. The second thing to remember is that you are dealing with electricity-take no chances. Go to the site of the ground, usually at the water meter, and check the ground. It should connect to the water line on the street side of the water meter or be equipped with a jumper wire. Do not touch any box or wire until you are sure of the ground. Go to the main fuse box or circuit breaker box and check all fuses and breakers for operational integrity (proper amperage range; functional). Note the condition of the wiring and of the box itself and check whether it is over-fused. Examine all wiring in the basement. Make sure you are standing in a dry spot (concrete poses a particular problem because you cannot determine its water content from visual examination) before touching any electrical device. Standing on a dry piece of wood is far safer than standing on concrete. Do

not disassemble the fuse box, circuit breaker, or other devices. Decisions must be made on what you see. If in doubt, consult your supervisor.

Note whether any fuse boxes, circuit breakers, or junction boxes are uncovered. Examine all wiring for frayed or bare spots; improper splicing; or rotted, worn, or inadequate insulation. Avoid all careless touching; when in doubt—DON'T! If you see bare wires, have the owner call an electrician. Look for wires or cords in use in the basement. Be certain all switch boxes and outlets are in a tight, sound condition. Make sure that the emergency switch for an oil burner is at the top of the basement stairs, not on top of the unit.

Bathrooms, kitchens, and utility rooms—where electric shock hazard is great—should have GFCI outlets.

While inspecting the bathroom, also check for dangerous items, such as radios that are not made for bathroom use or portable electric heaters. Have inappropriate items removed immediately. Such items have killed thousands of people who touched them after getting out of the bathtub or shower while still wet or because the appliance fell into water the person had contact with.

Electric washer and dryer combinations should have a 240-volt circuit, 30-ampere service connected to a separate fuse or circuit breaker. Washer and dryer combinations and other portable appliances should be served by sufficiently heavy electrical service. If either of these special lines is not available under the above-stated conditions, consult your supervisor.

An electric range needs a 50-ampere, 240-volt circuit. A dishwasher needs a 20-ampere, 120-volt circuit. A separate three-wire circuit must be installed for an electric water heater. Continue your inspection systematically through the house.

To sum up, the housing inspector investigates specified electrical elements in a house to detect any obvious evidence of an insufficient power supply, to ensure the availability of adequate and safe lighting and electrical facilities, and to discover and correct any obvious hazard. Because electricity is a technical, complicated field, the housing inspector, when in doubt, should consult his or her supervisor. The inspector cannot, however, close the case until appropriate corrective action has been taken on all such referrals.

References

1. National Fire Protection Association. National electrical code handbook 2005. Florence, KY: Thomson Delmar Learning; 2005.
2. Center for Disease Control. Basic housing inspection. Atlanta: US Department of Health and Human Services; 1976.
3. British Columbia Safety Authority. The facts about aluminum wiring in the home. New Westminster, British Columbia, Canada: British Columbia Safety Authority; no date. Available from URL: http://www.safetyauthority.ca/services/esp/The_Facts_About_Aluminum_Wiring_In_The_Home.pdf.
4. Consumer Product Safety Commission. May is National Electrical Safety Month: good news for homeowners-aluminum wiring fix still available. Washington, DC: Consumer Product Safety Commission; 2003. Available from URL: <http://www.cpsc.gov/CPSCPUB/PREREL/prhtml/03/03120.html>.
5. Consumer Product Safety Commission. CPSC safety recommendations for aluminum wiring in homes. Washington, DC: Consumer Product Safety Commission; 1974. Available from URL: <http://www.cpsc.gov/CPSCPUB/PREREL/prhtml/74/74040.html>.
6. AWG American wire gauge/diameter/resistance. Cologne, Germany: Bernd Noack; no date. Available from URL: <http://www.bnoack.com/data/wire-resistance.html>.
7. Consumer Product Safety Commission. Extension cords fact sheet. Washington, DC: Consumer Product Safety Commission; no date. CPSC #16. Available from URL: <http://www.cpsc.gov/CPSCPUB/PUBS/16.html>.

comprehensive manual, from basic repairs to advanced projects (Black & Decker Home Improvement Library; US edition). Chanhassen, MN: Creative Publishing International; 2001.

Sunset Publishing. Basic wiring. 3rd edition. Menlo Park, CA: Sunset Books, 1995.

Hometime.com. Electrical service panel: panel components, circuit breakers, fuses, electrical glossary. Hometime.com; no date. Available from URL: http://www.hometime.com/Howto_projects/electric/elec_2.htm.

Vandervort D. How your house works: electric systems. Glendale, CA: Hometips.com; no date. Available from URL: <http://www.hometips.com/hyhw/electrical/electric.html>.

PNM Resources. Residential subdivisions: electric service requirements. In: Electric service guide. Albuquerque, NM: PNM; 2004. Available from URL: <http://www.pnm.com/esg/chapters/56-63.pdf>.

Textor K. Extension cord basics. Fine Homebuilding 2000, 129: 84-9. Available from URL: <http://www.taunton.com/finehomebuilding/pages/h00010.asp>.

Consumer Product Safety Commission. Repairing aluminum wiring. Washington, DC: Consumer Product Safety Commission; 1994. CPSC #516. Available from URL: <http://www.cpsc.gov/CPSCPUB/PUBS/516.pdf>.

Additional Sources of Information

Croft T, Summers W. American electricians' handbook. 14th edition, New York: McGraw-Hill Professional; 2002.

Tuck D, Tuck G, Woodson RD. Electrician's instant answers. New York: McGraw-Hill Professional; 2003. Black and Decker. The complete guide to home wiring: a