chapter 44

AUTOMOTIVE WIRING AND WIRE REPAIR

OBJECTIVES: After studying Chapter 44, the reader should be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronic Systems Diagnosis). • Explain the wire gauge number system. • Describe how fusible links and fuses protect circuits and wiring. • Discuss electrical terminals and connectors • Describe how to solder • Discuss circuit breakers and PTC electronic circuit protection devices. • Explain the types of electrical conduit. • List the steps for performing a proper wire repair.

KEY TERMS: Adhesive-lined heat shrink tubing 476 • American wire gauge (AWG) 467 • Auto link 471 • Battery cables 469 • Braided ground straps 468 • Circuit breakers 472 • Cold solder joint 476 • Connector 474 • CPA 474 • Crimp-and-seal connectors 476 • Fuse link 471 • Fuses 469 • Fusible link 473 • Heat shrink tubing 476 • Jumper cables 469 • Lock tang 474 • Metric wire gauge 467 • Pacific fuse element 471 • Primary wire 468 • PTC circuit protectors 472 • Rosin-core solder 475 • Skin effect 468 • Terminal 474 • Twisted pair 469

AUTOMOTIVE WIRING

DEFINITION AND TERMINOLOGY Most automotive wire is made from strands of copper covered by plastic insulation. Copper is an excellent conductor of electricity that is reasonably priced and very flexible. However, solid copper wire can break when moved repeatedly; therefore, most copper wiring is constructed of multiple small strands that allow for repeated bending and moving without breaking. Solid copper wire is generally used for components such as starter armature and alternator stator windings that do not bend or move during normal operation. Copper is the best electrical conductor besides silver, which is a great deal more expensive. The conductivity of various metals is rated. ● **SEE CHART 44–1**.

1.	Silver
2.	Copper
3.	Gold
4.	Aluminum
5.	Tungsten
6.	Zinc
7.	Brass (copper and zinc)
8.	Platinum
9.	Iron
10.	Nickel
11.	Tin
12.	Steel
13.	Lead

CHART 44–1

The list of relative conductivity of metals, showing silver to be the best.

AMERICAN WIRE GAUGE Wiring is sized and purchased according to gauge size as assigned by the **American wire gauge (AWG)** system. AWG numbers can be confusing because as the gauge number *increases,* the size of the conductor wire *decreases.* Therefore, a 14 gauge wire is smaller than a 10 gauge wire. The *greater* the amount of current (in amperes) that is flowing through a wire, the *larger the diameter (smaller gauge number)* that will be required. ● **SEE CHART 44–2**, which compares the AWG number to the actual wire diameter in inches. The diameter refers to the diameter of the metal conductor and does not include the insulation.

Following are general applications for the most commonly used wire gauge sizes. Always check the installation instructions or the manufacturer's specifications for wire gauge size before replacing any automotive wiring.

- 20 to 22 gauge: radio speaker wires
- 18 gauge: small bulbs and short leads
- 16 gauge: taillights, gas gauge, turn signals, windshield wipers
- 14 gauge: horn, radio power lead, headlights, cigarette lighter, brake lights
- 12 gauge: headlight switch-to-fuse box, rear window defogger, power windows and locks
- 10 gauge: alternator-to-battery
- 4, 2, or 0 (1/0) gauge: battery cables

METRIC WIRE GAUGE Most manufacturers indicate on the wiring diagrams the **metric wire gauge** sizes measured in square millimeters (mm^2) of cross-sectional area. The following chart gives conversions or comparisons between metric gauge and AWG sizes. Notice that the metric wire size increases with size (area), whereas the AWG size gets smaller with larger size wire. ● **SEE CHART 44–3**.

The AWG number should be decreased (wire size increased) with increased lengths of wire. ● **SEE CHART 44–4**.

WIRE GAUGE DIAMETER TABLE	
AMERICAN WIRE GAUGE (AWG)	WIRE DIAMETER IN INCHES
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.08080810
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

CHART 44–2

American wire gauge (AWG) number and the actual conductor diameter in inches.

METRIC SIZE (MM^2)	AWG SIZE
0.5	20
0.8	18
1.0	16
2.0	14
3.0	12
5.0	10
8.0	8
13.0	6
19.0	4
32.0	2
52.0	0

CHART 44–3

Metric wire size in squared millimeters (mm^2) conversion chart to American wire gauge (AWG).

? FREQUENTLY ASKED QUESTION

Do They Make 13 Gauge Wire?

Yes. AWG sizing of wire includes all gauge numbers, including 13, even though the most commonly used sizes are even numbered, such as 12, 14, or 16.

Because the sizes are so close, wire in every size is not commonly stocked, but can be ordered for a higher price. Therefore, if a larger wire size is needed, it is common practice to select the next lower, even-numbered gauge.

12 V	RECOMMENDED WIRE GAUGE (AWG) (FOR LENGTH IN FEET)*						
AMPS	3′	5′	7′	10′	15′	20′	25′
5	18	18	18	18	18	18	18
7	18	18	18	18	18	18	16
10	18	18	18	18	16	16	16
12	18	18	18	18	16	16	14
15	18	18	18	18	14	14	12
18	18	18	16	16	14	14	12
20	18	18	16	16	14	12	10
22	18	18	16	16	12	12	10
24	18	18	16	16	12	12	10
30	18	16	16	14	10	10	10
40	18	16	14	12	10	10	8
50	16	14	12	12	10	10	8
100	12	12	10	10	6	6	4
150	10	10	8	8	4	4	2
200	10	8	8	6	4	4	2

CHART 44–4

Recommended AWG wire size increases as the length increases because all wire has internal resistance. The longer the wire is, the greater the resistance. The larger the diameter is, the lower the resistance.
*When mechanical strength is a factor, use the next larger wire gauge.

For example, a trailer may require 14 gauge wire to light all the trailer lights, but if the wire required is over 25 ft long, 12 gauge wire should be used. Most automotive wire, except for spark plug wire, is often called **primary wire** (named for the voltage range used in the primary ignition circuit) because it is designed to operate at or near battery voltage.

GROUND WIRES

PURPOSE AND FUNCTION All vehicles use ground wires between the engine and body and/or between the body and the negative terminal of the battery. The two types of ground wires are:

- Insulated copper wire
- Braided ground straps

Braided grounds straps are uninsulated. It is not necessary to insulate a ground strap because it does not matter if it touches metal, as it already attaches to ground. Braided ground straps are more flexible than stranded wire. Because the engine will move slightly on its mounts, the braided ground strap must be able to flex without breaking. ● **SEE FIGURE 44–1**.

SKIN EFFECT The braided strap also dampens out some radio-frequency interference that otherwise might be transmitted through standard stranded wiring due to the skin effect.

The **skin effect** is the term used to describe how high-frequency AC electricity flows through a conductor. Direct current flows through

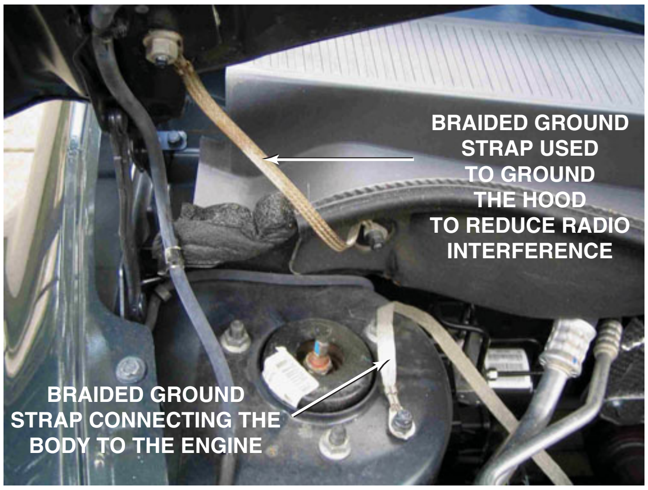


FIGURE 44–1 All lights and accessories ground to the body of the vehicle. Body ground wires such as this one are needed to conduct all of the current from these components back to the negative terminal of the battery. The body ground wire connects the body to the engine. Most battery negative cables attach to the engine.

FIGURE 44–2 Battery cables are designed to carry heavy starter current and are therefore usually 4 gauge or larger wire. Note that this battery has a thermal blanket covering to help protect the battery from high underhood temperatures. The wiring is also covered with plastic conduit called split-loom tubing.

? FREQUENTLY ASKED QUESTION

What Is a Twisted Pair?

A **twisted pair** is used to transmit low-voltage signals using two wires that are twisted together. Electromagnetic interference can create a voltage in a wire and twisting the two signal wires cancels out the induced voltage. A twisted pair means that the two wires have at least nine turns per foot (turns per meter). A rule of thumb is a twisted pair should have one twist per inch of length.

a conductor, but alternating current tends to travel through the outside (skin) of the conductor. Because of the skin effect, most audio (speaker) cable is constructed of many small-diameter copper wires instead of fewer larger strands, because the smaller wire has a greater surface area and therefore results in less resistance to the flow of AC voltage.

NOTE: Body ground wires are necessary to provide a circuit path for the lights and accessories that ground to the body and flow to the negative battery terminal.

BATTERY CABLES

Battery cables are the largest wires used in the automotive electrical system. The cables are usually 4 gauge, 2 gauge, or 1 gauge wires (19 mm^2 or larger). ● **SEE FIGURE 44–2**.

Wires larger than 1 gauge are called 0 gauge (pronounced "ought"). Larger cables are labeled 2/0 or 00 (2 ought) and 3/0 or 000 (3 ought). Electrical systems that are 6 volts require battery cables two sizes larger than those used for 12 volt electrical systems, because the lower voltage used in antique vehicles resulted in twice the amount of current (amperes) to supply the same electrical power.

JUMPER CABLES

Jumper cables are 4 to 2/0 gauge electrical cables with large clamps attached and are used to connect a vehicle that has a discharged battery to a vehicle that has a good battery. Good-quality jumper cables are necessary to prevent excessive voltage drops caused by cable resistance. Aluminum wire jumper cables should not be used, because even though aluminum is a good electrical conductor (although not as good as copper), it is less flexible and can crack and break when bent or moved repeatedly. The size should be 6 gauge or larger.

1/0 AWG welding cable can be used to construct an excellent set of jumper cables using welding clamps on both ends. Welding cable is usually constructed of many very fine strands of wire, which allow for easier bending of the cable as the strands of fine wire slide against each other inside the cable.

NOTE: Always check the wire gauge of any battery cables or jumper cables and do not rely on the outside diameter of the wire. Many lower cost jumper cables use smaller gauge wire, but may use thick insulation to make the cable look as if it is the correct size wire.

FUSES AND CIRCUIT PROTECTION DEVICES

CONSTRUCTION **Fuses** should be used in every circuit to protect the wiring from overheating and damage caused by excessive current flow as a result of a short circuit or other malfunction. The symbol for a fuse is a wavy line between two points: —∿—

A fuse is constructed of a fine tin conductor inside a glass, plastic, or ceramic housing. The tin is designed to melt and open the circuit if excessive current flows through the fuse. Each fuse is rated according to its maximum current-carrying capacity.

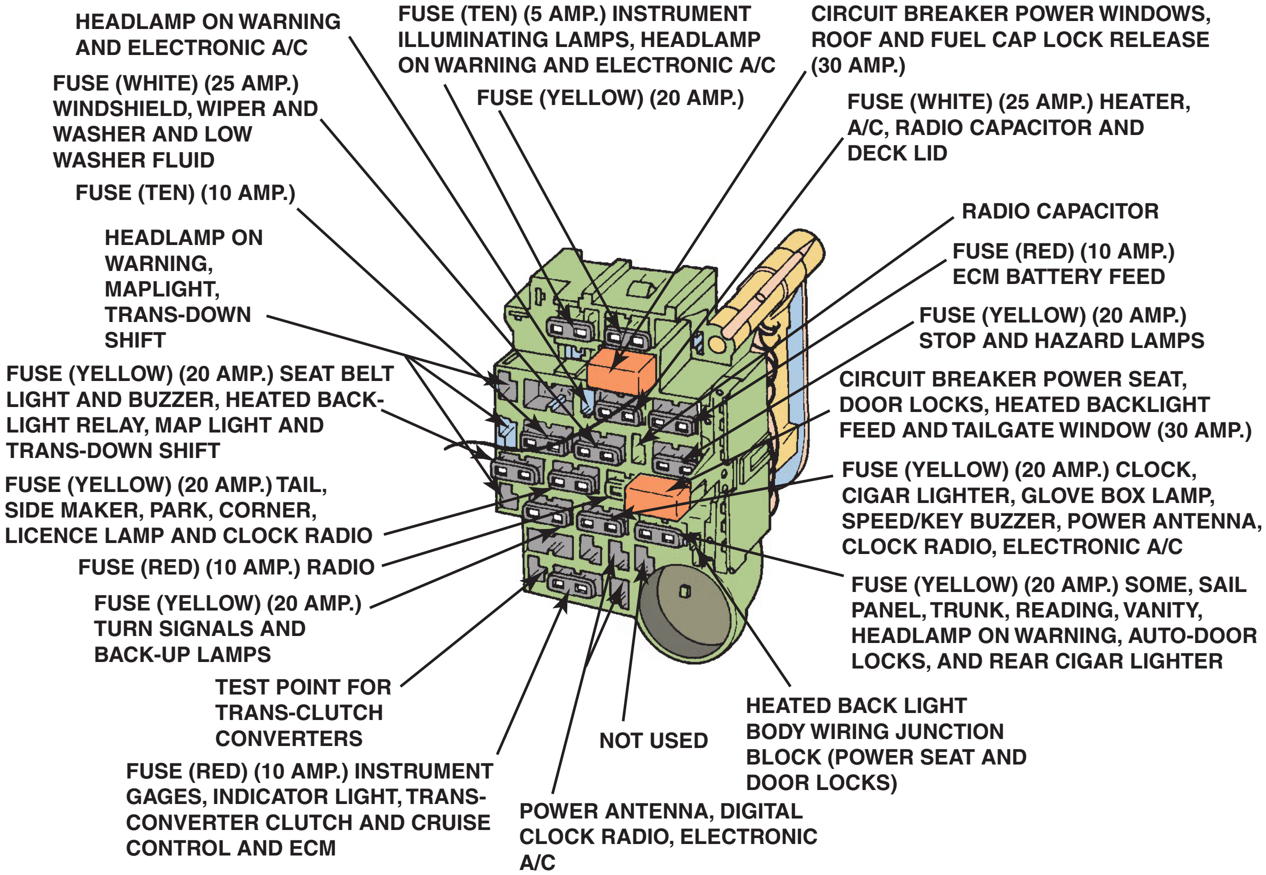


FIGURE 44–3 A typical automotive fuse panel.

NORMAL CURRENT IN THE CIRCUIT (AMPERES)	FUSE RATING
7.5 A	10 A
16 A	20 A
24 A	30 A

CHART 44–5

The fuse rating should be 20% higher than the maximum current in the circuit to provide the best protection for the wiring and the component being protected.

Many fuses are used to protect more than one circuit of the automobile. ● **SEE FIGURE 44–3.**

A typical example is the fuse for the cigarette lighter that also protects many other circuits, such as those for the courtesy lights, clock, and other circuits. A fault in one of these circuits can cause this fuse to melt, which will prevent the operation of all other circuits that are protected by the fuse.

NOTE: The SAE term for a cigarette lighter is *cigar lighter* because the diameter of the heating element is large enough for a cigar. The term *cigarette lighter* will be used throughout this book because it is the most common usage.

FUSE RATINGS

Fuses are used to protect the wiring and components in the circuit from damage if an excessive amount of current flows. The fuse rating is normally about 20% higher than the normal current in the circuit. ● **SEE CHART 44–5** for a typical fuse rating based on the normal current in the circuit. In other words, the normal current flow should be about 80% of the fuse rating.

AMPERAGE RATING	COLOR
1	Dark green
2	Gray
2.5	Purple
3	Violet
4	Pink
5	Tan
6	Gold
7.5	Brown
9	Orange
10	Red
14	Black
15	Blue
20	Yellow
25	White
30	Green

CHART 44–6

The amperage rating and the color of the blade fuse are standardized.

BLADE FUSES

Colored blade-type fuses are also referred to as ATO fuses and have been used since 1977. The color of the plastic of blade fuses indicates the maximum current flow, measured in amperes.

● **SEE CHART 44–6** for the color and the amperage rating of blade fuses.

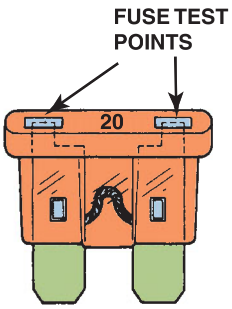


FIGURE 44–4 Blade-type fuses can be tested through openings in the plastic at the top of the fuse.

FIGURE 44–5 Three sizes of blade-type fuses: mini on the left, standard or ATO type in the center, and maxi on the right.

AMPERAGE RATING	COLOR
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Natural
30	Green

CHART 44–7

Mini fuse amperage rating and colors.

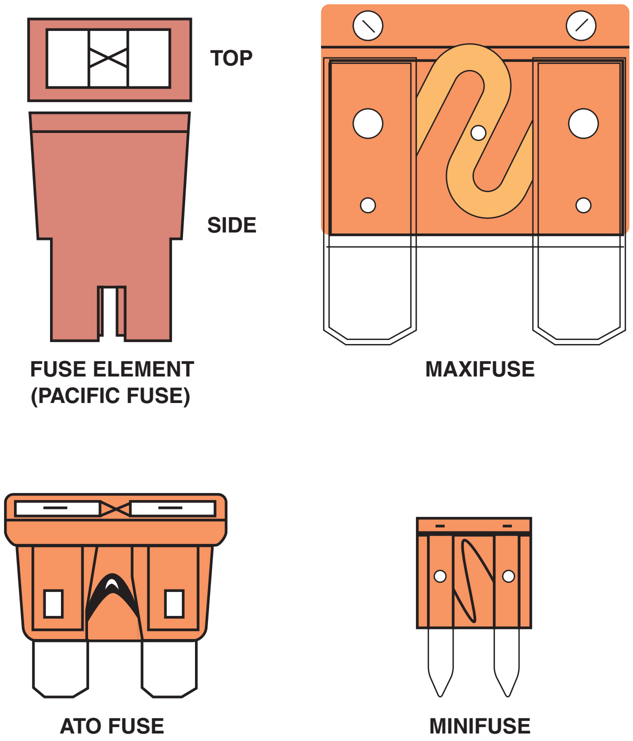


FIGURE 44–6 A comparison of the various types of protective devices used in most vehicles.

AMPERAGE RATING	COLOR
20	Yellow
30	Green
40	Amber
50	Red
60	Blue
70	Brown
80	Natural

CHART 44–8

Maxi fuse amperage rating and colors.

Each fuse has an opening in the top of its plastic portion to allow access to its metal contacts for testing purposes. ● **SEE FIGURE 44–4.**

MINI FUSES To save space, many vehicles use mini (small) blade fuses. Not only do they save space but they also allow the vehicle design engineer to fuse individual circuits instead of grouping many different components on one fuse. This improves customer satisfaction because if one component fails, it only affects that one circuit without stopping electrical power to several other circuits as well. This makes troubleshooting a lot easier too, because each circuit is separate. ● **SEE CHART 44–7** for the amperage rating and corresponding fuse color for mini fuses.

MAXI FUSES Maxi fuses are a large version of blade fuses and are used to replace fusible links in many vehicles. Maxi fuses are rated up to 80 amperes or more. ● **SEE CHART 44–8** for the amperage rating and corresponding color for maxi fuses.

● **SEE FIGURE 44–5** for a comparison of the various sizes of blade-type fuses.

PACIFIC FUSE ELEMENT First used in the late 1980s, **Pacific fuse elements** (also called a **fuse link** or **auto link**) are used to protect wiring from a direct short-to-ground. The housing contains a short link of wire sized for the rated current load. The transparent top allows inspection of the link inside. ● **SEE FIGURE 44–6.**

TESTING FUSES It is important to test the condition of a fuse if the circuit being protected by the fuse does not operate. Most blown fuses can be detected quickly because the center conductor is melted. Fuses can also fail and open the circuit because of a poor connection in the fuse itself or in the fuse holder. Therefore, just because a fuse "looks okay" does not mean that it *is* okay. All fuses should be tested with a test light. The test light should be connected to first one side of the fuse and then the other. A test light should light on both sides. If the test light only lights on one side, the fuse is blown or open. If the test light does not light on either side of the fuse, then that circuit is not being supplied power. ● **SEE FIGURE 44–7**. An ohmmeter can be used to test fuses.

FIGURE 44–7 To test a fuse, use a test light to check for power at the power side of the fuse. The ignition switch and lights may have to be on before some fuses receive power. If the fuse is good, the test light should light on both sides (power side and load side) of the fuse.

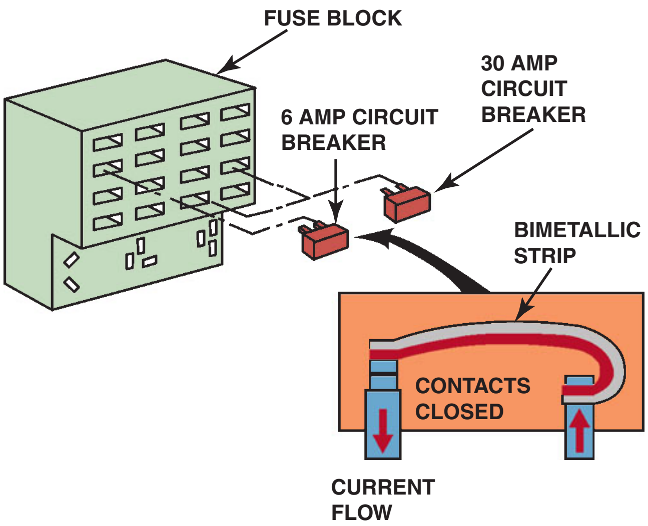


FIGURE 44–8 Typical blade circuit breaker fits into the same space as a blade fuse. If excessive current flows through the bimetallic strip, the strip bends and opens the contacts and stops current flow. When the circuit breaker cools, the contacts close again, completing the electrical circuit.

CIRCUIT BREAKERS

Circuit breakers are used to prevent harmful overload (excessive current flow) in a circuit by opening the circuit and stopping the current flow to prevent overheating and possible fire caused by hot wires or electrical components. **Circuit breakers** are mechanical units made of two different metals (bimetallic) that deform when heated and open a set of contact points that work in the same manner as an "off" switch. ● **SEE FIGURE 44–8**.

Cycling-type circuit breakers, therefore, are reset when the current stops flowing, which causes the bimetallic strip to cool and the circuit to close again. A circuit breaker is used in circuits that could affect the safety of passengers if a conventional nonresetting fuse were used. The headlight circuit is an excellent example of the use of a circuit breaker rather than a fuse. A short or grounded circuit anywhere in the headlight circuit could cause excessive current flow and, therefore, the opening of the circuit. Obviously, a sudden loss of headlights at night could have disastrous results. A circuit breaker opens and closes the circuit rapidly, thereby protecting the circuit from overheating and also providing sufficient current flow to maintain at least partial headlight operation.

Circuit breakers are also used in other circuits where conventional fuses could not provide for the surges of high current commonly found in those circuits. ● **SEE FIGURE 44–9** for the electrical symbols used to represent a circuit breaker.

Examples are the circuits for the following accessories.

1. Power seats
2. Power door locks
3. Power windows

FIGURE 44–9 Electrical symbols used to represent circuit breakers.

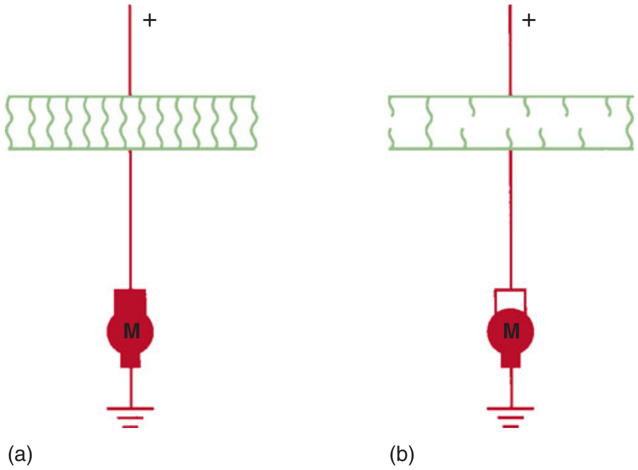


FIGURE 44–10 (a) The normal operation of a PTC circuit protector such as in a power window motor circuit showing the many conducting paths. With normal current flow, the temperature of the PTC circuit protector remains normal. (b) When current exceeds the amperage rating of the PTC circuit protector, the polymer material that makes up the electronic circuit protector increases in resistance. As shown, a high-resistance electrical path still exists even though the motor will stop operating as a result of the very low current flow through the very high resistance. The circuit protector will not reset or cool down until voltage is removed from the circuit.

PTC CIRCUIT PROTECTORS

Positive temperature coefficient (PTC) circuit protectors are solid state (without moving parts). Like all other circuit protection devices, PTCs are installed in series in the circuit being protected. If excessive current flows, the temperature and resistance of the PTC increase.

This increased resistance reduces current flow (amperes) in the circuit and may cause the electrical component in the circuit not to function correctly. For example, when a PTC circuit protector is used in a power window circuit, the increased resistance causes the operation of the power window to be much slower than normal.

Unlike circuit breakers or fuses, PTC circuit protection devices do *not* open the circuit, but rather provide a very high resistance between the protector and the component. ● **SEE FIGURE 44–10**.

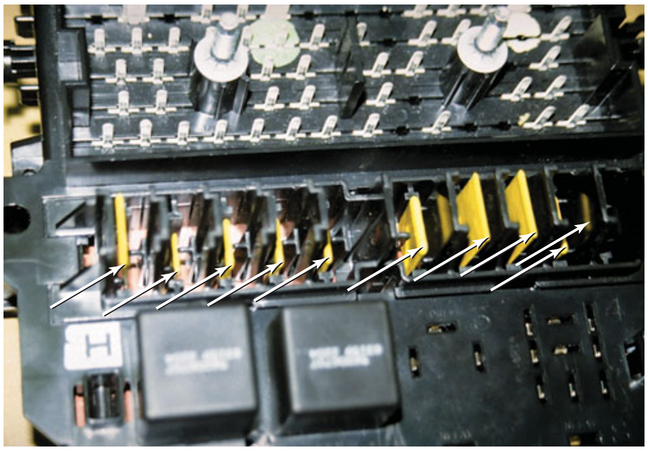


FIGURE 44–11 PTC circuit protectors are used extensively in the power distribution center of this Chrysler vehicle.

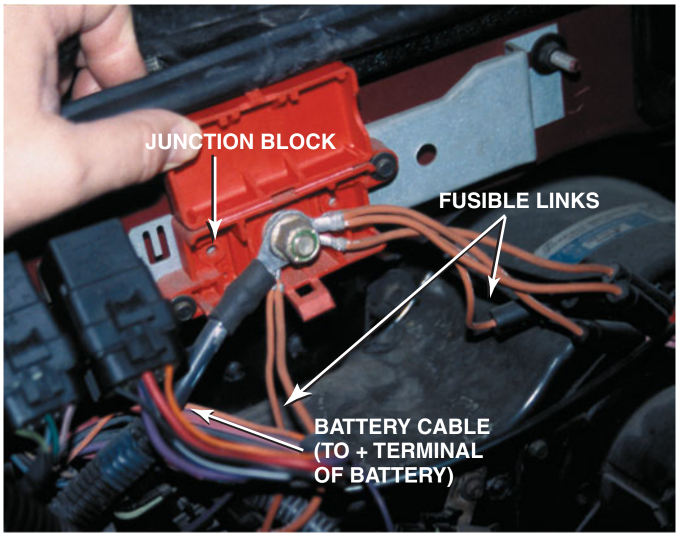


FIGURE 44–12 Fusible links are usually located close to the battery and are usually attached to a junction block. Notice that they are only 6 to 9 in. long and feed more than one fuse from each fusible link.

In other words, voltage will be available to the component. This fact has led to a lot of misunderstanding about how these circuit protection devices actually work. It is even more confusing when the circuit is opened and the PTC circuit protector cools down. When the circuit is turned back on, the component may operate normally for a short time; however, the PTC circuit protector will again get hot because of too much current flow. Its resistance again increases to limit current flow.

The electronic control unit (computer) used in most vehicles today incorporates thermal overload protection devices. ● **SEE FIGURE 44–11**.

Therefore, when a component fails to operate, do not blame the computer. The current control device is controlling current flow to protect the computer. Components that do not operate correctly should be checked for proper resistance and current draw.

FUSIBLE LINKS A **fusible link** is a type of fuse that consists of a short length (6 to 9 in. long) of standard copper-strand wire covered with a special nonflammable insulation. This wire is usually four wire numbers smaller than the wire of the circuits it protects. For example, a 12 gauge circuit is protected by a 16 gauge fusible link. The special thick insulation over the wire may make it look larger than other wires of the same gauge number. ● **SEE FIGURE 44–12**.

If excessive current flow (caused by a short-to-ground or a defective component) occurs, the fusible link will melt in half and open the circuit to prevent a fire hazard. Some fusible links are identified with "fusible link" tags at the junction between the fusible link and the standard chassis wiring, which represent only the junction. Fusible links are the backup system for circuit protection. All current except the current used by the starter motor flows through fusible links and then through individual circuit fuses. It is possible that a fusible link will melt and not blow a fuse. Fusible links are installed as close to the battery as possible so that they can protect the wiring and circuits coming directly from the battery.

MEGA FUSES Many newer vehicles are equipped with mega fuses instead of fusible links to protect high-amperage circuits. Circuits often controlled by mega fuses include:

- Charging circuit
- HID headlights
- Heated front or rear glass

FIGURE 44–13 A 125 ampere rated mega fuse used to control the current from the alternator.

TECH TIP

Find the Root Cause

If a mega fuse or fusible link fails, find the root cause before replacing it. A mega fuse can fail due to vibration or physical damage as a result of a collision or corrosion. Check to see if the fuse itself is loose and can be moved by hand. If loose, then simply replace the mega fuse. If a fusible link or mega fuse has failed due to excessive current, check for evidence of a collision or any other reason that could cause an excessive amount of current to flow. This inspection should include each electrical component being supplied current from the fusible link. After being sure that the root cause has been found and corrected, then replace the fusible link or mega fuse.

- Multiple circuits usually protected by mega fuses
- Mega fuse rating for vehicles, including 80, 100, 125, 150, 175, 200, 225, and 250 amperes

  ● **SEE FIGURE 44–13**.

CHECKING FUSIBLE LINKS AND MEGA FUSES Fusible links and mega fuses are usually located near where electrical power is sent to other fuses or circuits, such as:

- Starter solenoid battery terminals
- Power distribution centers

- Output terminals of alternators
- Positive terminals of the battery

Fusible links can melt and not show any external evidence of damage. To check a fusible link, gently pull on each end to see if it stretches. If the insulation stretches, then the wire inside has melted and the fusible link must be replaced after determining what caused the link to fail.

Another way to check a fusible link is to use a test light or a voltmeter and check for available voltage at both ends of the fusible link. If voltage is available at only one end, then the link is electrically open and should be replaced.

REPLACING A FUSIBLE LINK If a fusible link is found to be melted, perform the following steps.

STEP 1 Determine why the fusible link failed and repair the fault.

STEP 2 Check service information for the exact length, gauge, and type of fusible link required.

STEP 3 Replace the fusible link with the specified fusible link wire and according to the instructions found in the service information.

CAUTION: Always use the *exact* length of fusible link wire required because if it is too short, it will not have enough resistance to generate the heat needed to melt the wire and protect the circuits or components. If the wire is too long, it could melt during normal operation of the circuits it is protecting. Fusible link wires are usually longer than 6 in. and shorter than 9 in.

TERMINALS AND CONNECTORS

A **terminal** is a metal fastener attached to the end of a wire, which makes the electrical connection. The term **connector** usually refers to the plastic portion that snaps or connects together, thereby making the mechanical connection. Wire terminal ends usually snap into and are held by a connector. Male and female connectors can then be snapped together, thereby completing an electrical connection. Connectors exposed to the environment are also equipped with a weather-tight seal. ● **SEE FIGURE 44–14**.

Terminals are retained in connectors by the use of a **lock tang**. Removing a terminal from a connector includes the following steps.

STEP 1 Release the **connector position assurance (CPA)**, if equipped, that keeps the latch of the connector from releasing accidentally.

STEP 2 Separate the male and female connector by opening the lock. ● **SEE FIGURE 44–15**.

STEP 3 Release the secondary lock, if equipped. ● **SEE FIGURE 44–16**.

STEP 4 Using a pick, look for the slot in the plastic connector where the lock tang is located, depress the lock tang, and gently remove the terminal from the connector. ● **SEE FIGURE 44–17**.

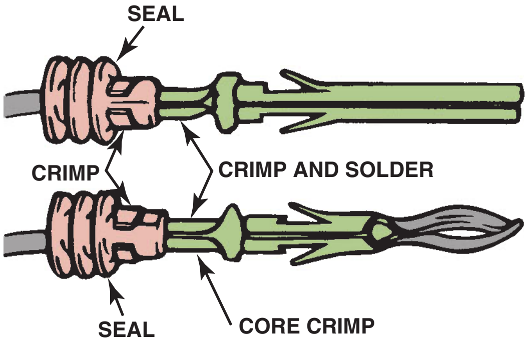


FIGURE 44–14 Some terminals have seals attached to help seal the electrical connections.

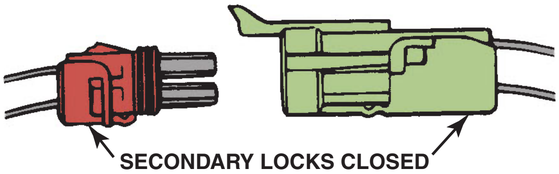


FIGURE 44–15 Separate a connector by opening the lock and pulling the two apart.

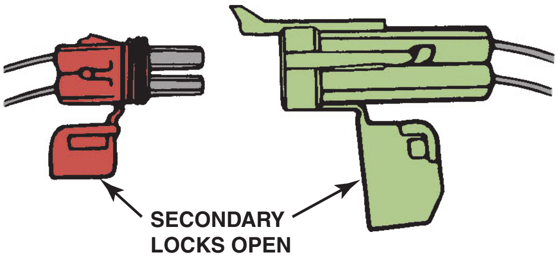


FIGURE 44–16 The secondary locks help retain the terminals in the connector.

TECH TIP

Look for the "Green Crud"

Corroded connections are a major cause of intermittent electrical problems and open circuits. The usual sequence of conditions is as follows:

1. **Heat causes expansion.** This heat can be from external sources such as connectors being too close to the exhaust system. Another possible source of heat is a poor connection at the terminal, causing a voltage drop and heat due to the electrical resistance.
2. **Condensation occurs when a connector cools.** The moisture in the condensation causes rust and corrosion.
3. **Water gets into the connector.** The solution is, if corroded connectors are noticed, the terminal should be cleaned and the condition of the electrical connection to the wire terminal end(s) confirmed. Many vehicle manufacturers recommend using a dielectric silicone or lithium-based grease inside connectors to prevent moisture from getting into and attacking the connector.

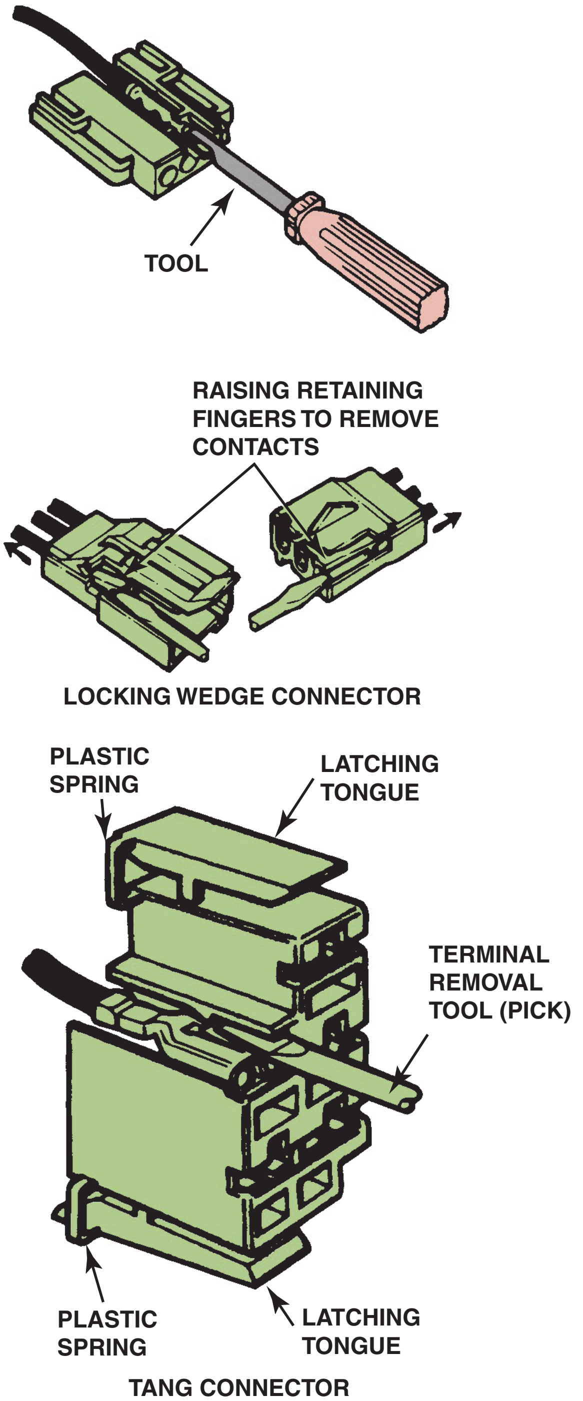


FIGURE 44–17 Use a small removal tool, sometimes called a pick, to release terminals from the connector.

FIGURE 44–18 Always use rosin-core solder for electrical or electronic soldering. Also, use small-diameter solder for small soldering irons. Use large-diameter solder only for large-diameter (large-gauge) wire and higher-wattage soldering irons (guns).

FIGURE 44–19 A butane-powered soldering tool. The cap has a built-in striker to light a converter in the tip of the tool. This handy soldering tool produces the equivalent of 60 watts of heat. It operates for about 1/2 hour on one charge from a commonly available butane refill dispenser.

WIRE REPAIR

SOLDER Many manufacturers recommend that all wiring repairs be soldered. Solder is an alloy of tin and lead used to make a good electrical contact between two wires or connections in an electrical circuit. However, a flux must be used to help clean the area and to help make the solder flow. Therefore, solder is made with a resin (rosin) contained in the center, called **rosin-core solder**.

CAUTION: Never use acid-core solder to repair electrical wiring as the acid will cause corrosion.

● **SEE FIGURE 44–18**.

An acid-core solder is also available but should only be used for soldering sheet metal. Solder is available with various percentages of tin and lead in the alloy. Ratios are used to identify these various types of solder, with the first number denoting the percentage of tin in the alloy and the second number giving the percentage of lead. The most commonly used solder is 50/50, which means that 50% of the solder is tin and the other 50% is lead. The percentages of each alloy primarily determine the melting point of the solder.

- 60/40 solder (60% tin/40% lead) melts at 361°F (183°C).
- 50/50 solder (50% tin/50% lead) melts at 421°F (216°C).
- 40/60 solder (40% tin/60% lead) melts at 460°F (238°C).

NOTE: The melting points stated here can vary depending on the purity of the metals used.

Because of the lower melting point, 60/40 solder is the most highly recommended solder to use, followed by 50/50.

SOLDERING GUNS When soldering wires, be sure to heat the wires (not the solder) using:

- An electric soldering gun or soldering pencil (60 to 150 watt rating)
- Butane-powered tool that uses a flame to heat the tip (about 60 watt rating)

● **SEE FIGURE 44–19**.

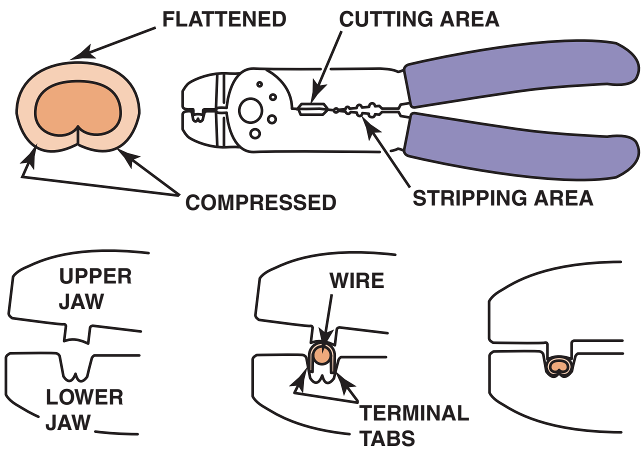


FIGURE 44–20 Notice that to create a good crimp the open part of the terminal is placed in the jaws of the crimping tool toward the anvil or the W-shape part.

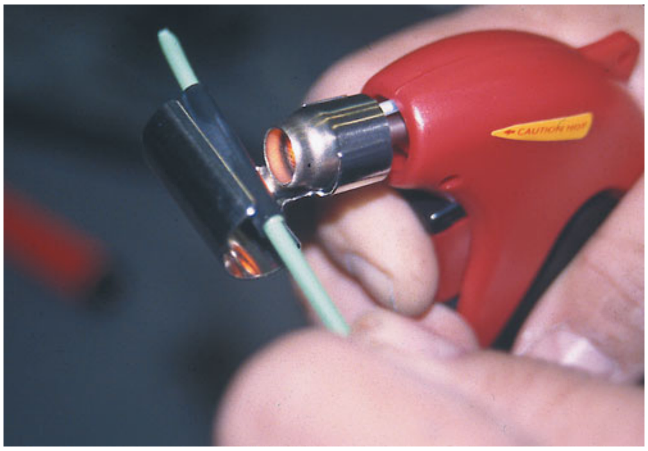


FIGURE 44–22 A butane torch especially designed for use on heat shrink applies heat without an open flame, which could cause damage.

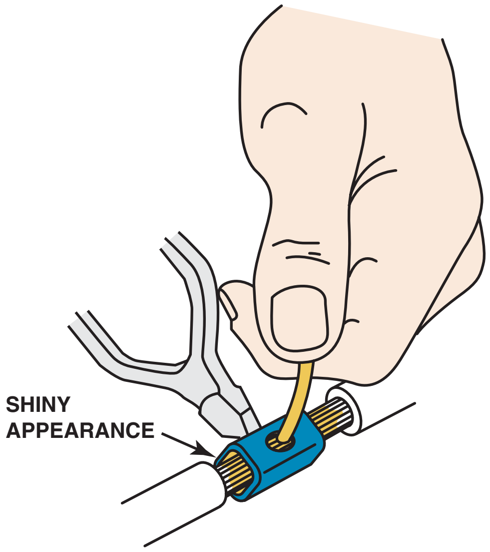


FIGURE 44–21 All hand-crimped splices or terminals should be soldered to be assured of a good electrical connection.

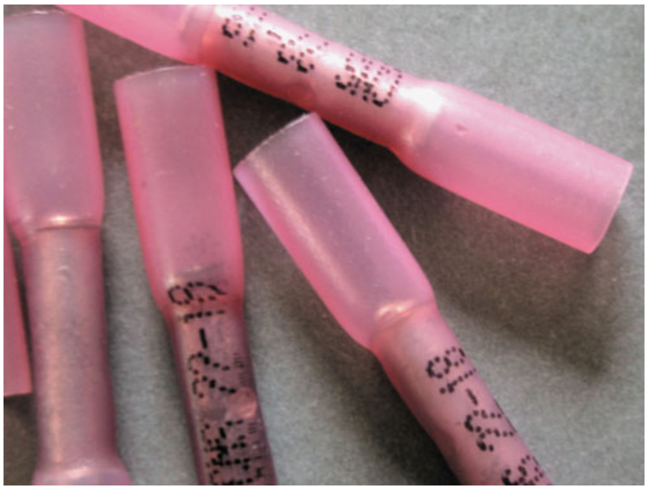


FIGURE 44–23 A typical crimp-and-seal connector. This type of connector is first lightly crimped to retain the ends of the wires and then it is heated. The tubing shrinks around the wire splice, and thermoplastic glue melts on the inside to provide an effective weather-resistant seal.

SOLDERING PROCEDURE Soldering a wiring splice includes the following steps.

STEP 1 While touching the soldering gun to the splice, apply solder to the junction of the gun and the wire.

STEP 2 The solder will start to flow. Do not move the soldering gun.

STEP 3 Just keep feeding more solder into the splice as it flows into and around the strands of the wire.

STEP 4 After the solder has flowed throughout the splice, remove the soldering gun and the solder from the splice and allow the solder to cool slowly.

The solder should have a shiny appearance. Dull-looking solder may be caused by not reaching a high enough temperature, which results in a **cold solder joint**. Reheating the splice and allowing it to cool often restores the shiny appearance.

CRIMPING TERMINALS Terminals can be crimped to create a good electrical connection if the proper type of crimping tool is used. Most vehicle manufacturers recommend that a W-shaped crimp be used to force the strands of the wire into a tight space. ● **SEE FIGURE 44–20**.

Most vehicle manufacturers also specify that all hand-crimped terminals or splices be soldered. ● **SEE FIGURE 44–21**.

HEAT SHRINK TUBING **Heat shrink tubing** is usually made from polyvinyl chloride (PVC) or polyolefin and shrinks to about half of its original diameter when heated; this is usually called a 2:1 shrink ratio. Heat shrink by itself does not provide protection against corrosion, because the ends of the tubing are not sealed against moisture. DaimlerChrysler Corporation recommends that all wire repairs that may be exposed to the elements be repaired and sealed using **adhesive-lined heat shrink tubing**. The tubing is usually made from flame-retardant flexible polyolefin with an internal layer of special thermoplastic adhesive. When heated, this tubing shrinks to one-third of its original diameter (3:1 shrink ratio) and the adhesive melts and seals the ends of the tubing. ● **SEE FIGURE 44–22**.

CRIMP-AND-SEAL CONNECTORS General Motors Corporation recommends the use of crimp-and-seal connectors as the method for wire repair. **Crimp-and-seal connectors** contain a sealant and shrink tubing in one piece and are not simply butt connectors. ● **SEE FIGURE 44–23**.

The usual procedure specified for making a wire repair using a crimp-and-seal connector is as follows:

STEP 1 Strip the insulation from the ends of the wire (about 5/16 in., or 8 mm).

FIGURE 44–24 Heating the crimp-and-seal connector melts the glue and forms an effective seal against moisture.

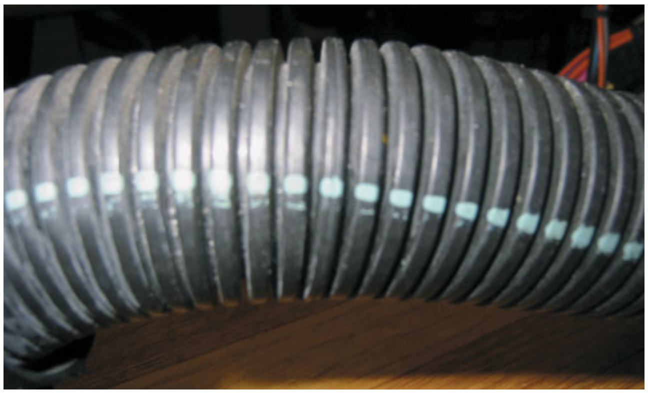


FIGURE 44–25 Conduit that has a paint strip is constructed of plastic that can withstand high underhood temperatures.

? FREQUENTLY ASKED QUESTION

What Method of Wire Repair Should I Use?

Good question. Vehicle manufacturers recommend all wire repairs performed under the hood, or where the repair could be exposed to the elements, be weatherproof. The most commonly recommended methods include:

- **Crimp and seal connector.** These connectors are special and are not like low cost insulated-type crimp connectors. This type of connector is recommended by General Motors and others and is sealed using heat after the mechanical crimp has secured the wire ends together.
- **Solder and adhesive-lined heat shrink tubing.** This method is recommended by Chrysler and it uses the special heat shrink that has glue inside that melts when heated to form a sealed connection. Regular heat shrink tubing can be used inside a vehicle, but should not be used where it can be exposed to the elements.
- **Solder and electrical tape.** This is acceptable to use inside the vehicle where the splice will not be exposed to the outside elements. It is best to use a crimp and seal even on the inside of the vehicle for best results.

STEP 2 Select the proper size of crimp-and-seal connector for the gauge of wire being repaired. Insert the wires into the splice sleeve and crimp.

NOTE: Only use the specified crimping tool to help prevent the pliers from creating a hole in the cover.

STEP 3 Apply heat to the connector until the sleeve shrinks down around the wire and a small amount of sealant is observed around the ends of the sleeve, as shown in ● **FIGURE 44–24**.

ALUMINUM WIRE REPAIR Some vehicle manufacturers used plastic-coated solid aluminum wire for some body wiring. Because aluminum wire is brittle and can break as a result of vibration, it is only used where there is no possible movement of the wire, such as along the floor or sill area. This section of wire is stationary, and the wire changes back to copper at a junction terminal after the trunk or rear section of the vehicle, where movement of the wiring may be possible.

? FREQUENTLY ASKED QUESTION

What Is in Lead-Free Solder?

Lead is an environmental and a health concern and all vehicle manufacturers are switching to lead-free solder. Lead free solder does not contain lead but usually a very high percentage of tin. Several formulations of lead-free solder include:

- 95% Tin; 5% Antimony (melting temperature 450°F (245°C)
- 97% Tin; 3% Copper (melting temperature 441°F (227°C)
- 96% Tin; 4% Silver (melting temperature 443°F (228°C)

If any aluminum wire must be repaired or replaced, the following procedure should be used to be assured of a proper repair. The aluminum wire is usually found protected in a plastic conduit. This conduit is then normally slit, after which the wires can easily be removed for repair.

STEP 1 Carefully strip only about 1/4 in. (6 mm) of insulation from the aluminum wire, being careful not to nick or damage the aluminum wire case.

STEP 2 Use a crimp connector to join two wires together. Do not solder an aluminum wire repair. Solder will not readily adhere to aluminum because the heat causes an oxide coating on the surface of the aluminum.

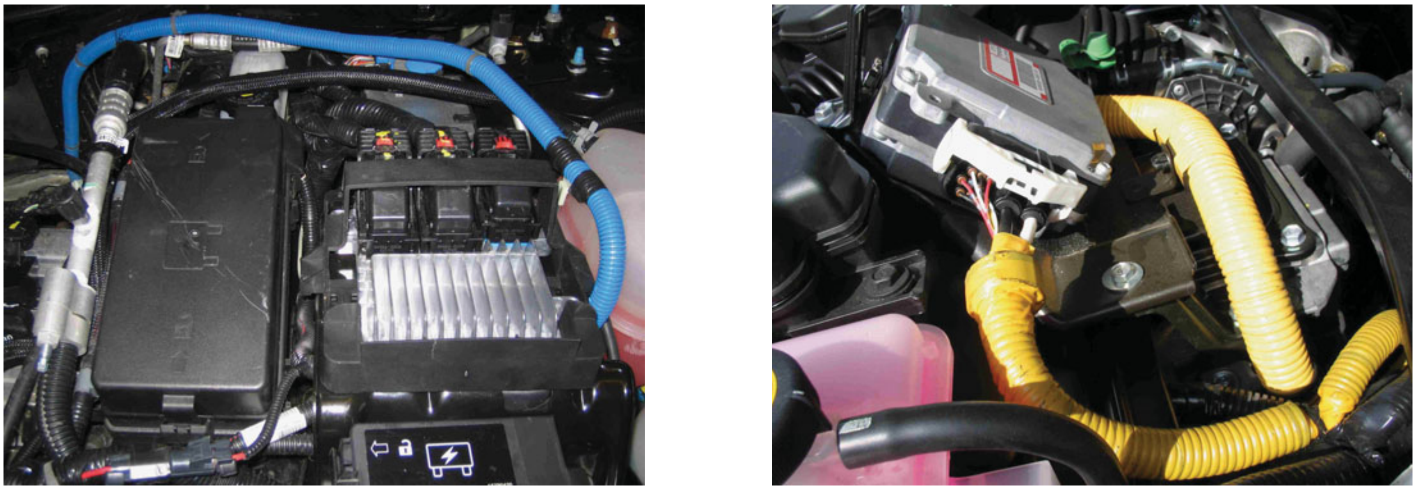
STEP 3 The spliced, crimped connection must be coated with petroleum jelly to prevent corrosion.

STEP 4 The coated connection should be covered with shrinkable plastic tubing or wrapped with electrical tape to seal out moisture.

ELECTRICAL CONDUIT

Electrical conduit covers and protects wiring. The color used on electrical convoluted conduit tells the technician a lot if some information is known, such as the following:

- **Black conduit with a green or blue stripe.** This conduit is designed for high temperatures and is used under the hood and near hot engine parts. Do not replace high-temperature conduit with low-temperature conduit that does not have a stripe when performing wire repairs. ● **SEE FIGURE 44–25**.



(a) (b)

FIGURE 44–26 (a) Blue conduit is used to cover circuits that carry up to 42 volts. (b) Yellow conduit can also be used to cover 42 volt wiring.

- **Blue or yellow conduit.** This color conduit is used to cover wires that have voltages ranging from 12 to 42 volts. Circuits that use this high voltage usually are for the electric power steering. While 42 volts does not represent a shock hazard, an arc will be maintained if a line circuit is disconnected. Use caution around these circuits. ● **SEE FIGURE 44–26**.
- **Orange conduit.** This color conduit is used to cover wiring that carries high-voltage current from 144 to 650 volts. These circuits are found in hybrid electric vehicles (HEVs). An electric shock from these wires can be fatal, so extreme caution has to be taken when working on or near the components that have orange conduit. Follow the vehicle manufacturer's instruction for de-powering the high-voltage circuits before work begins on any of the high-voltage components. ● **SEE FIGURE 44–27**.

FIGURE 44–27 Always follow the vehicle manufacturer's instructions which include the use of linesman's (high-voltage) gloves if working on circuits that are covered in orange conduit.

REVIEW QUESTIONS

1. What is the difference between the American wire gauge (AWG) system and the metric system?
2. What is the difference between a wire and a cable?
3. What is the difference between a terminal and a connector?
4. How do fuses, PTC circuit protectors, circuit breakers, and fusible links protect a circuit?
5. How should a wire repair be done if the repair is under the hood where it is exposed to the outside?

CHAPTER QUIZ

1. The higher the AWG number, ______________.
   a. The smaller the wire diameter
   b. The larger the wire diameter
   c. The thicker the insulation
   d. The more strands in the conductor core
2. Metric wire size is measured in units of ______________.
   a. Meters
   b. Cubic centimeters
   c. Square millimeters
   d. Cubic millimeters
3. Which statement is true about fuse ratings?
   a. The fuse rating should be less than the maximum current for the circuit.
   b. The fuse rating should be higher than the normal current for the circuit.
   c. Of the fuse rating, 80% should equal the current in the circuit.
   d. Both b and c

4. Which statements are true about wire, terminals, and connectors?
   a. Wire is called a lead, and the metal end is a connector.
   b. A connector is usually a plastic piece where terminals lock in.
   c. A lead and a terminal are the same thing.
   d. Both a and c
5. The type of solder that should be used for electrical work is ______________.
   a. Rosin core
   b. Acid core
   c. 60/40 with no flux
   d. 50/50 with acid paste flux
6. A technician is performing a wire repair on a circuit under the hood of the vehicle. Technician A says to use solder and adhesive-lined heat shrink tubing or a crimp and seal connector. Technician B says to solder and use electrical tape. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Two technicians are discussing fuse testing. Technician A says that a test light should light on both test points of the fuse if it is okay. Technician B says the fuse is defective if a test light only lights on one side of the fuse. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
8. What is true about the plastic conduit covering the wiring?
   a. The color stripe is used to identify the temperature rating of the conduit
   b. The color identifies the voltage level of the circuits being protected.
   c. Protects the wiring.
   d. All of the above
9. Many ground straps are uninsulated and braided because ______________.
   a. They are more flexible to allow movement of the engine without breaking the wire.
   b. They are less expensive than conventional wire.
   c. They help dampen radio-frequency interference (RFI).
   d. Both a and c
10. What causes a fuse to blow?
   a. A decrease in circuit resistance
   b. An increase in the current flow through the circuit
   c. A sudden decrease in current flow through the circuit
   d. Both a and b

chapter 45 WIRING SCHEMATICS AND CIRCUIT TESTING

OBJECTIVES: After studying Chapter 45, the reader should be able to: • Prepare for ASE Electrical/Electronic Systems (A6) certification test content area "A" (General Electrical/Electronics System Diagnosis). • Interpret wiring schematics. • Explain how relays work. • Discuss the various methods that can be used to locate a short circuit. • List the electrical troubleshooting diagnosis steps.

KEY TERMS: Coil 485 • DPDT 484 • DPST 484 • Gauss gauge 490 • Momentary switch 484 • N.C. 484 • N.O. 484 • Poles 484 • Relay 485 • Short circuit 489 • SPDT 484 • SPST 484 • Terminal 480 • Throws 484 • Tone generator tester 490 • Wiring schematic 479

WIRING SCHEMATICS AND SYMBOLS

TERMINOLOGY The service manuals of automotive manufacturers include wiring schematics of every electrical circuit in a vehicle. A **wiring schematic**, sometimes called a *diagram*, shows electrical components and wiring using symbols and lines to represent components and wires. A typical wiring schematic may include all of the circuits combined on several large foldout sheets, or they may be broken down to show individual circuits. All circuit schematics or diagrams include:

- Power-side wiring of the circuit
- All splices
- Connectors
- Wire size
- Wire color
- Trace color (if any)
- Circuit number
- Electrical components
- Ground return paths
- Fuses and switches

CIRCUIT INFORMATION Many wiring schematics include numbers and letters near components and wires that may confuse readers of the schematic. Most letters used near or on a wire identify the color or colors of the wire.

- The first color or color abbreviation is the color of the wire insulation.
- The second color (if mentioned) is the color of the stripe or tracer on the base color. ● **SEE FIGURE 45–1**.

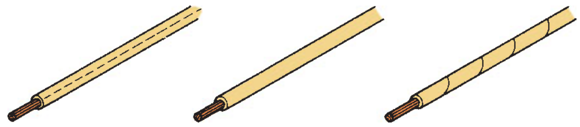


FIGURE 45–1 The center wire is a solid color wire, meaning that the wire has no other identifying tracer or stripe color. The two end wires could be labeled "BRN/WHT," indicating a brown wire with a white tracer or stripe.

ABBREVIATION	COLOR
BRN	Brown
BLK	Black
GRN	Green
WHT	White
PPL	Purple
PNK	Pink
TAN	Tan
BLU	Blue
YEL	Yellow
ORN	Orange
DK BLU	Dark blue
LT BLU	Light blue
DK GRN	Dark green
LT GRN	Light green
RED	Red
GRY	Gray
VIO	Violet

CHART 45–1

Typical abbreviations used on schematics to show wire color. Some vehicle manufacturers use two letters to represent a wire color. Check service information for the color abbreviations used.

Wires with different color tracers are indicated by both colors with a slash (/) between them. For example, BRN/WHT means a brown wire with a white stripe or tracer. ● **SEE CHART 45–1**.

WIRE SIZE Wire size is shown on all schematics. ● **FIGURE 45–2** illustrates a rear side-marker bulb circuit diagram where ".8" indicates the metric wire gauge size in square millimeters (mm^2) and "PPL" indicates a solid purple wire.

The wire diagram also shows that the color of the wire changes at the number C210. This stands for "connector #210" and is used for reference purposes. The symbol for the connection can vary depending on the manufacturer. The color change from purple (PPL) to purple with a white tracer (PPL/WHT) is not important except for knowing where the wire changes color in the circuit. The wire gauge has remained the same on both sides of the connection (0.8 mm^2 or 18 gauge). The ground circuit is the ".8 BLK" wire. ● **FIGURE 45–3** shows many of the electrical and electronic symbols that are used in wiring and circuit diagrams.

SCHEMATIC SYMBOLS

In a schematic drawing, photos or line drawings of actual components are replaced with a symbol that represents the actual component. The following discussion centers on these symbols and their meanings.

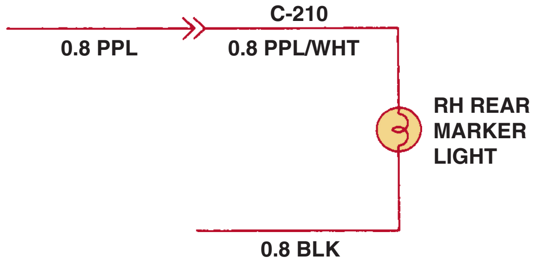


FIGURE 45–2 Typical section of a wiring diagram. Notice that the wire color changes at connection C210. The ".8" represents the metric wire size in square millimeters.

TECH TIP

Read the Arrows

Wiring diagrams indicate connections by symbols that look like arrows. ● **SEE FIGURE 45–4** on page 481.

Do *not* read these "arrows" as pointers showing the direction of current flow. Also observe that the power side (positive side) of the circuit is usually the female end of the connector. If a connector becomes disconnected, it will be difficult for the circuit to become shorted to ground or to another circuit because the wire is recessed inside the connector.

BATTERY The plates of a battery are represented by long and short lines. ● **SEE FIGURE 45–5**.

The longer line represents the positive plate of a battery and the shorter line represents the negative plate of the battery. Therefore, each pair of short and long lines represents one cell of a battery. Because each cell of a typical automotive lead-acid battery has 2.1 volts, a battery symbol showing a 12 volt battery should have six pairs of lines. However, most battery symbols simply use two or three pairs of long and short lines and then list the voltage of the battery next to the symbol. As a result, the battery symbols are shorter and yet clear, because the voltage is stated. The positive terminal of the battery is often indicated with a plus sign (+), representing the positive post of the battery, and is placed next to the long line of the end cell. The negative terminal of the battery is represented by a negative sign (−) and is placed next to the shorter cell line. The negative battery terminal is connected to ground. ● **SEE FIGURE 45–6**.

WIRING Electrical wiring is shown as straight lines and with a few numbers and/or letters to indicate the following:

- **Wire size.** This can be either AWG, such as 18 gauge, or in square millimeters, such as 0.8 mm^2.
- **Circuit numbers.** Each wire in part of a circuit is labeled with the circuit number to help the service technician trace the wiring and to provide an explanation of how the circuit should work.
- **Wire color.** Most schematics also indicate an abbreviation for the color of the wire and place it next to the wire. Many wires have two colors: a solid color and a stripe color. In this case, the solid color is listed, followed by a dark slash (/) and the color of the stripe. For example, Red/Wht would indicate a red wire with a white tracer. ● **SEE FIGURE 45–7**.
- **Terminals.** The metal part attached at the end of a wire is called a **terminal**. A symbol for a terminal is shown in ● **FIGURE 45–8**.

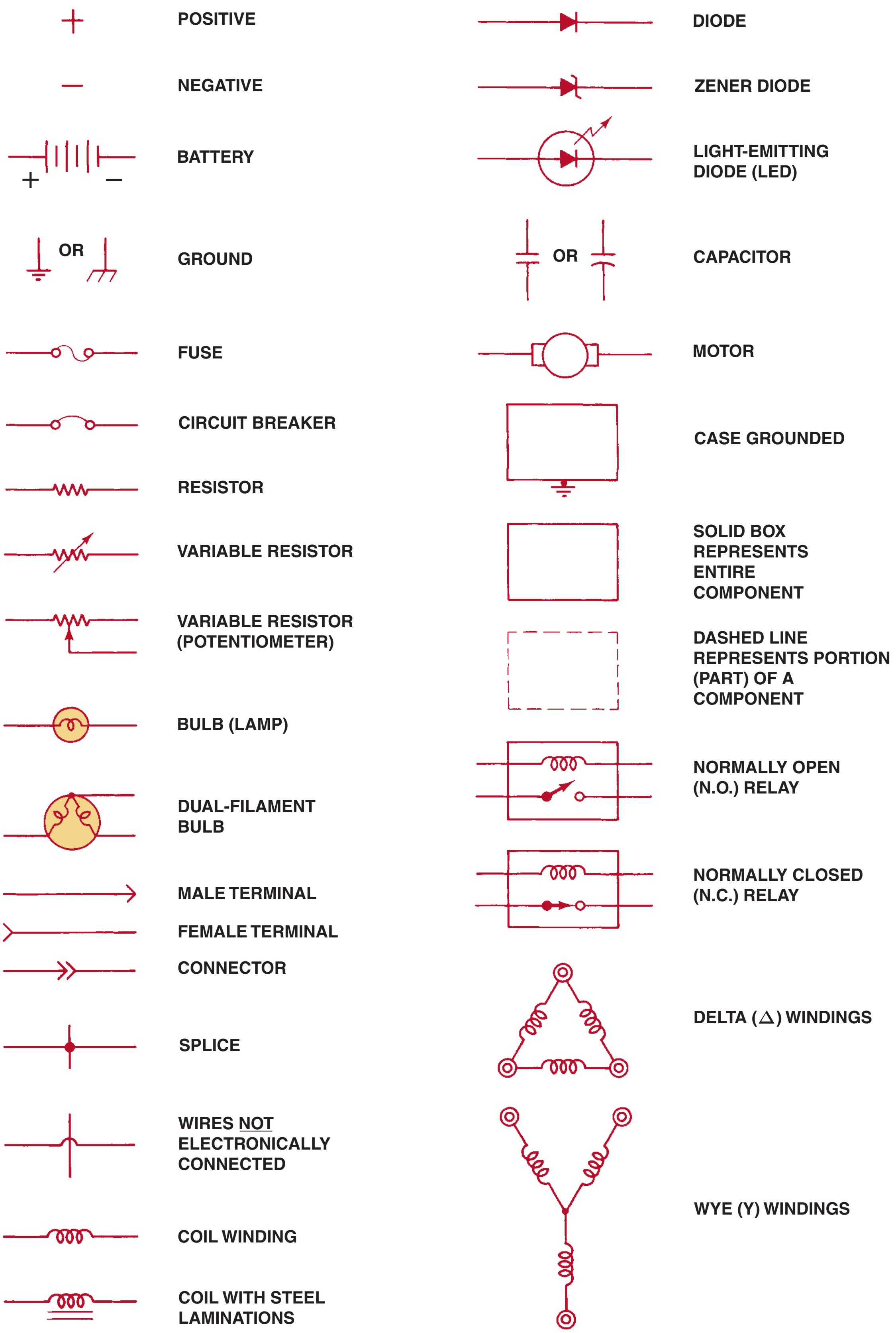


FIGURE 45–3 Typical electrical and electronic symbols used in automotive wiring and circuit diagrams.

FIGURE 45–4 In this typical connector, note that the positive terminal is usually a female connector.

FIGURE 45–5 The symbol for a battery. The positive plate of a battery is represented by the longer line and the negative plate by the shorter line. The voltage of the battery is usually stated next to the symbol.

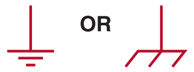


FIGURE 45–6 The ground symbol on the left represents earth ground. The ground symbol on the right represents a chassis ground.

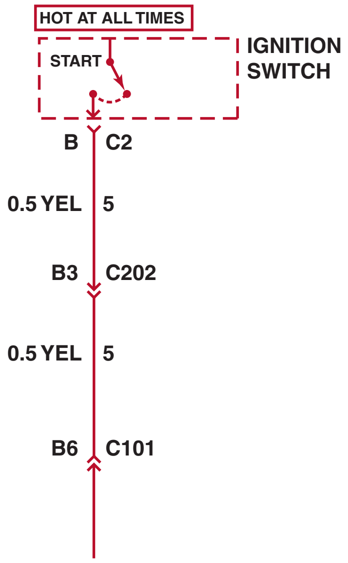


FIGURE 45–7 Starting at the top, the wire from the ignition switch is attached to terminal B of connector C2, the wire is 0.5 mm² (20 gauge AWG), and is yellow. The circuit number is 5. The wire enters connector C202 at terminal B3.

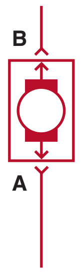


FIGURE 45–8 The electrical terminals are usually labeled with a letter or number.

FIGURE 45–9 Two wires that cross at the dot indicate that the two are electrically connected.

FIGURE 45–10 Wires that cross, but do not electrically contact each other, are shown with one wire bridging over the other.

- **Splices.** When two wires are electrically connected, the junction is shown with a black dot. The identification of the splice is an "S" followed by three numbers, such as S103. ● **SEE FIGURE 45–9**. When two wires cross in a schematic that are not electrically connected, one of the wires is shown as going over the other wire and does not connect. ● **SEE FIGURE 45–10**.
- **Connectors.** An electrical connector is a plastic part that contains one or more terminals. Although the terminals provide the electrical connection in a circuit, it is the plastic connector that keeps the terminals together mechanically.

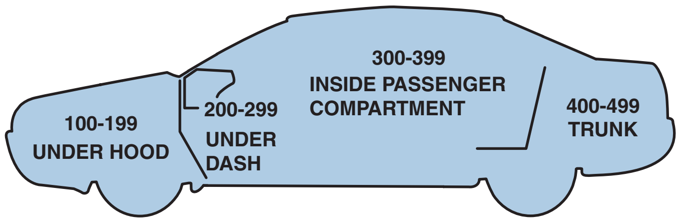


FIGURE 45–11 Connectors (C), grounds (G), and splices (S) are followed by a number, generally indicating the location in the vehicle. For example, G209 is a ground connection located under the dash.

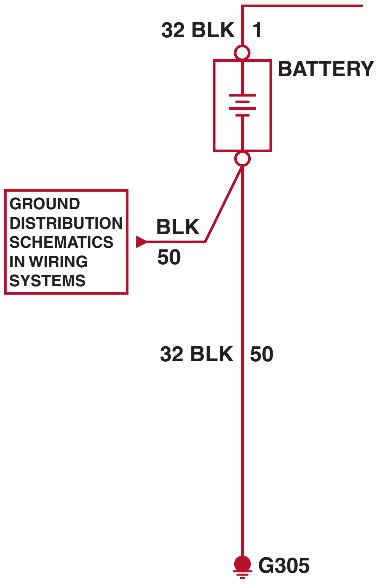


FIGURE 45–12 The ground for the battery is labeled G305 indicating the ground connector is located in the passenger compartment of the vehicle. The ground wire is black (BLK), the circuit number is 50, and the wire is 32 mm² (2 gauge AWG).

- **Location.** Connections are usually labeled "C" and then three numbers. The three numbers indicate the general location of the connector. Normally, the connector number represents the general area of the vehicle, including:

100 to 199	Under the hood
200 to 299	Under the dash
300 to 399	Passenger compartment
400 to 499	Rear package or trunk area
500 to 599	Left-front door
600 to 699	Right-front door
700 to 799	Left-rear door
800 to 899	Right-rear door

Even-numbered connectors are on the right (passenger side) of the vehicle and odd-numbered connectors are on the left (driver's side) of the vehicle. For example, C102 is a connector located under the hood (between 100 and 199) on the right side of the vehicle (even number 102). ● **SEE FIGURE 45–11**.

- **Grounds and splices.** These are also labeled using the same general format as connectors. Therefore, a ground located under the dash on the driver's side could be labeled G305 (*G* means "ground" and the "305" means that it is located in the passenger compartment). ● **SEE FIGURE 45–12**.

ELECTRICAL COMPONENTS Most electrical components have their own unique symbol that shows the basic function or parts.

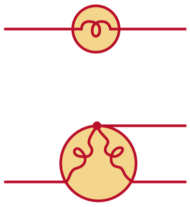


FIGURE 45–13 The symbol for light bulbs shows the filament inside a circle, which represents the glass ampoule of the bulb.

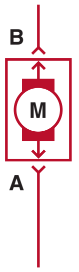


FIGURE 45–14 An electric motor symbol shows a circle with the letter *M* in the center and two black sections that represent the brushes of the motor. This symbol is used even though the motor is a brushless design.

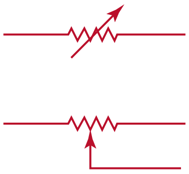


FIGURE 45–15 Resistor symbols vary depending on the type of resistor.

FIGURE 45–16 A rheostat uses only two wires—one is connected to a voltage source and the other is attached to the movable arm.

- **Bulbs.** Light bulbs often use a filament, which heats and then gives off light when electrical current flows. The symbol used for a light bulb is a circle with a filament inside. A dual-filament bulb, such as is used for taillights and brake light/turn signals, is shown with two filaments. ● **SEE FIGURE 45–13**.

ELECTRIC MOTORS An electric motor symbol shows a circle with the letter *M* in the center and two electrical connections, one to the top and one at the bottom. ● **SEE FIGURE 45–14** for an example of a cooling fan motor.

RESISTORS Although resistors are usually part of another component, the symbol appears on many schematics and wiring diagrams. A resistor symbol is a jagged line representing resistance to current flow. If the resistor is variable, such as a thermistor, an arrow is shown running through the symbol of a fixed resistor. A potentiometer is a three-wire variable resistor, shown with an arrow pointing toward the resistance part of a fixed resistor. ● **SEE FIGURE 45–15**.

A two-wire rheostat is usually shown as part of another unit, such as a fuel level sending unit. ● **SEE FIGURE 45–16**.

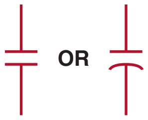


FIGURE 45–17 Symbols used to represent capacitors. If one of the lines is curved, this indicates that the capacitor being used has a polarity, while the one without a curved line can be installed in the circuit without concern about polarity.

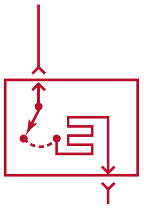


FIGURE 45–18 The gridlike symbol represents an electrically heated element. This symbol is used to represent a cigarette lighter or a heated rear window (rear window defogger)

FIGURE 45–19 A dashed outline represents a portion (part) of a component.

FIGURE 45–20 A solid box represents an entire component.

CAPACITORS Capacitors are usually part of an electronic component, but not a replaceable component unless the vehicle is an older model. Many older vehicles used capacitors to reduce radio interference and were installed inside alternators inside alternators or attached to or attached to wiring connectors. ● **SEE FIGURE 45–17**.

ELECTRIC HEATED UNIT Electric grid-type rear window defoggers and cigarette lighters are shown with a square box-type symbol. ● **SEE FIGURE 45–18**.

BOXED COMPONENTS If a component is shown in a box using a solid line, the box is the entire component. If a box uses dashed lines, it represents part of a component. A commonly used dashed-line box is a fuse panel. Often, just one or two fuses are shown in a dashed-line box. This means that a fuse panel has more fuses than shown. ● **SEE FIGURES 45–19 AND 45–20**.

SEPARATE REPLACEABLE PART Often components are shown on a schematic that cannot be replaced, but are part of a complete assembly. When looking at a schematic of General Motors vehicles, the following is shown.

- If a part name is underlined, it is a replaceable part.
- If a part is not underlined, it is not available as a replaceable part, but is included with other components shown and sold as an assembly.
- If the case itself is grounded, the ground symbol is attached to the component as shown in ● **FIGURE 45–21**.

SWITCHES Electrical switches are drawn on a wiring diagram in their normal position. This can be one of two possible positions.

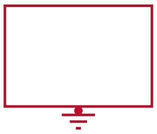


FIGURE 45–21 This symbol represents a component that is case grounded.

- **Normally open.** The switch is not connected to its internal contacts and no current will flow. This type of switch is labeled **N.O**.
- **Normally closed.** The switch is electrically connected to its internal contacts and current will flow through the switch. This type of switch is labeled **N.C**.

Other switches can use more than two contacts.

The **poles** refer to the number of circuits completed by the switch and the **throws** refer to the number of output circuits. A **single-pole, single-throw (SPST)** switch has only two positions, on or off. A **single-pole, double-throw (SPDT)** switch has three terminals, one wire in and two wires out. A headlight dimmer switch is an example of a typical SPDT switch. In one position, the current flows to the low-filament headlight; in the other, the current flows to the high-filament headlight.

NOTE: A SPDT switch is not an on or off type of switch but instead directs power from the source to either the high-beam lamps or the low-beam lamps.

There are also **double-pole, single-throw (DPST)** switches and **double-pole, double-throw (DPDT)** switches. ● **SEE FIGURE 45–22**.

NOTE: All switches are shown on schematics in their normal position. This means that the headlight switch will be shown normally off, as are most other switches and controls.

MOMENTARY SWITCH

A **momentary switch** is a switch primarily used to send a voltage signal to a module or controller to request that a device be turned on or off. The switch makes momentary contact and then returns to the open position. A horn switch is a commonly used momentary switch. The symbol that represents a momentary switch uses two dots for the contact with a switch above them. A momentary switch can be either normally open or normally closed. ● **SEE FIGURE 45–23**.

TECH TIP

Color-Coding Is Key to Understanding

Whenever diagnosing an electrical problem, it is common practice to print out the schematic of the circuit and then take it to the vehicle. A meter is then used to check for voltage at various parts of the circuit to help determine where there is a fault. The diagnosis can be made easier if the parts of the circuit are first color coded using markers or color pencils. A color-coding system that has been widely used is one developed by Jorge Menchu **(www.aeswave.com)**.

The colors represent voltage conditions in various parts of a circuit. Once the circuit has been color coded, then the circuit can be tested using the factory wire colors as a guide. ● **SEE FIGURE 45–24**.

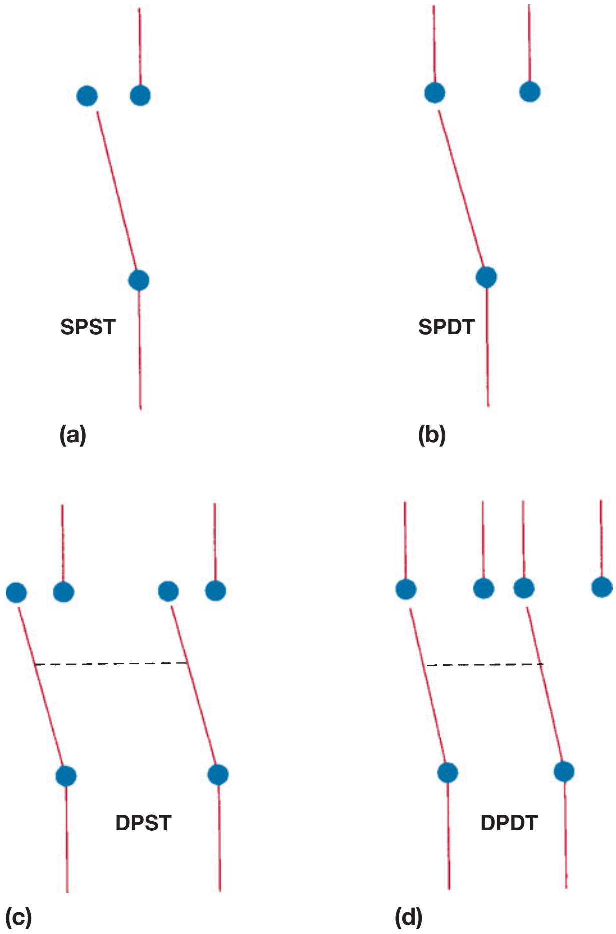


FIGURE 45–22 (a) A symbol for a single-pole, single-throw (SPST) switch. This type of switch is normally open (N.O.) because nothing is connected to the terminal that the switch is contacting in its normal position. (b) A single-pole, double-throw (SPDT) switch has three terminals. (c) A double-pole, single-throw (DPST) switch has two positions (off and on) and can control two separate circuits. (d) A double-pole, double-throw (DPDT) switch has six terminals—three for each pole. Note: Both (c) and (d) also show a dotted line between the two arms indicating that they are mechanically connected, called a "ganged switch".

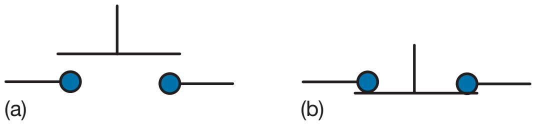


FIGURE 45–23 (a) A symbol for a normally open (N.O.) momentary switch. (b) A symbol for a normally closed (N.C.) momentary switch.

A momentary switch, for example, can be used to lock or unlock a door or to turn the air conditioning on or off. If the device is currently operating, the signal from the momentary switch will turn it off, and if it is off, the switch will signal the module to turn it on. The major advantage of momentary switches is that they can be lightweight and small, because the switch does not carry any heavy electrical current, just a small voltage signal. Most momentary switches use a membrane constructed of foil and plastic.

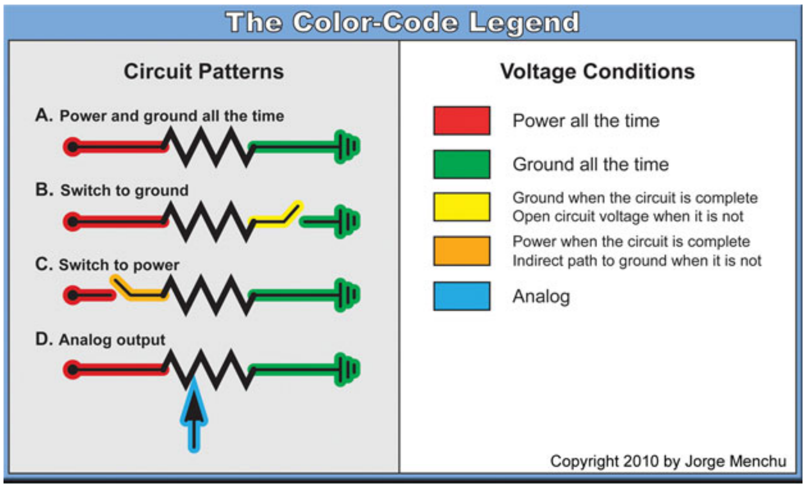


FIGURE 45–24 Using a marker and color-coding the various parts of the circuit makes the circuit easier to understand and helps diagnosing electrical problems easier. (*Courtesy of Jorge Menchu.*)

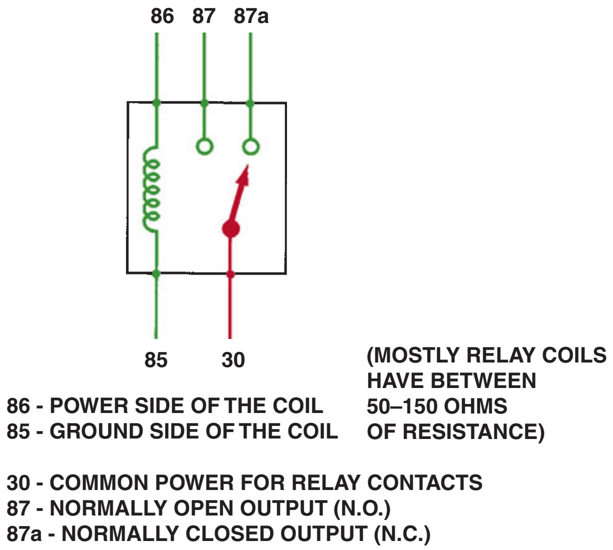


FIGURE 45–25 A relay uses a movable arm to complete a circuit whenever there is a power at terminal 86 and a ground at terminal 85. A typical relay only requires about 1/10 ampere through the relay coil. The movable arm then closes the contacts (#30 to #87) and can relay 30 amperes or more.

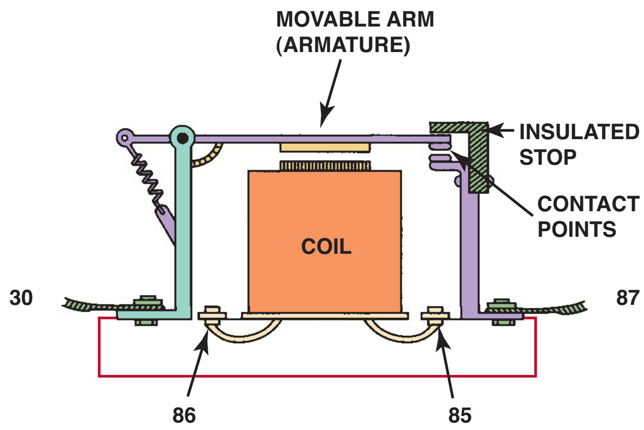


FIGURE 45–26 A cross-sectional view of a typical four-terminal relay. Current flowing through the coil (terminals 86 and 85) causes the movable arm (called the armature) to be drawn toward the coil magnet. The contact points complete the electrical circuit connected to terminals 30 and 87.

RELAY TERMINAL IDENTIFICATION

DEFINITION A **relay** is a magnetic switch that uses a movable armature to control a high-amperage circuit by using a low-amperage electrical switch.

ISO RELAY TERMINAL IDENTIFICATION Most automotive relays adhere to common terminal identification. The primary source for this common identification comes from the standards established by the International Standards Organization (ISO). Knowing this terminal information will help in the correct diagnosis and troubleshooting of any circuit containing a relay. ● **SEE FIGURES 45–25 AND 45–26**.

Relays are found in many circuits because they are capable of being controlled by computers, yet are able to handle enough current to power motors and accessories. Relays include the following components and terminals.

RELAY OPERATION

1. **Coil** (terminals 85 and 86)
   - A coil provides the magnetic pull to a movable armature (arm).
   - The resistance of most relay coils ranges from 50 to 150 ohms, but is usually between 60 and 100 ohms.
   - The ISO identification of the coil terminals are 86 and 85. The terminal number 86 represents the power to the relay coil and the terminal labeled 85 represents the ground side of the relay coil.
   - The relay coil can be controlled by supplying either power or ground to the relay coil winding.
   - The coil winding represents the control circuit which uses low current to control the higher current through the other terminals of the relay. ● **SEE FIGURE 45–27**.
2. Other terminals used to control the load current
   - The higher amperage current flow through a relay flows through terminals 30 and 87, and often 87a.
   - Terminal 30 is usually where power is applied to a relay. Check service information for the exact operation of the relay being tested.
   - When the relay is at rest without power and ground to the coil, the armature inside the relay electrically connects terminals 30 and 87a if the relay has five terminals. When

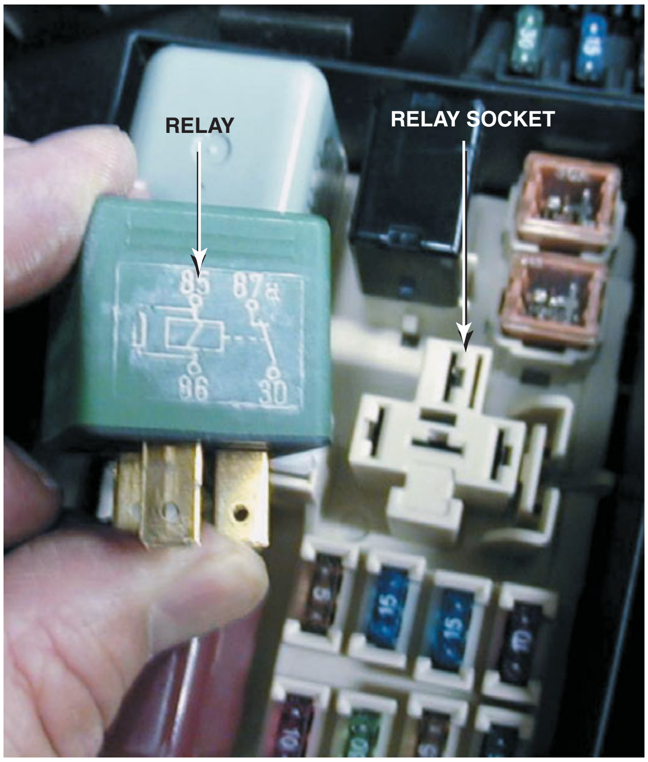


FIGURE 45–27 A typical relay showing the schematic of the wiring in the relay.

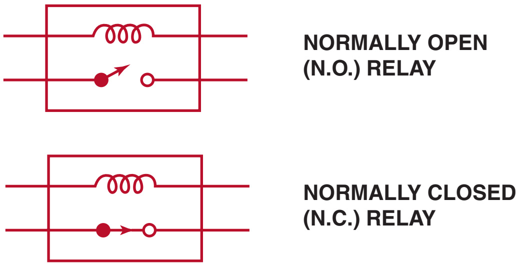


FIGURE 45–28 All schematics are shown in their normal, nonenergized position.

there is power at terminal 85 and a ground at terminal 86 of the relay, a magnetic field is created in the coil winding, which draws the armature of the relay toward the coil. The armature, when energized electrically, connects terminals 30 and 87.

The maximum current through the relay is determined by the resistance of the circuit, and relays are designed to safely handle the designed current flow. ● **SEE FIGURES 45–28 AND 45–29.**

RELAY VOLTAGE SPIKE CONTROL Relays contain a coil and when power is removed, the magnetic field surrounding the coil collapses, creating a voltage to be induced in the coil winding. This induced voltage can be as high as 100 volts or more and can cause problems with other electronic devices in the vehicle. For example, the short high-voltage surge can be heard as a "pop" in the radio. To reduce the induced voltage, some relays contain a diode connected across the coil. ● **SEE FIGURE 45–30.**

When the current flows through the coil, the diode is not part of the circuit because it is installed to block current. However, when the voltage is removed from the coil, the resulting voltage induced in the coil windings has a reversed polarity to the applied voltage. Therefore, the voltage in the coil is applied to the coil in a forward direction through the diode, which conducts the current back into the winding. As a result, the induced voltage spike is eliminated.

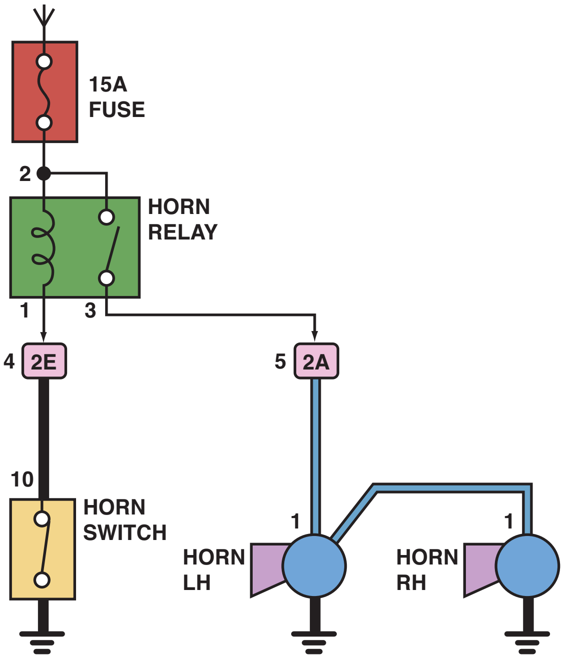


FIGURE 45–29 A typical horn circuit. Note that the relay contacts supply the heavy current to operate the horn when the horn switch simply completes a low-current circuit to ground, causing the relay contacts to close.

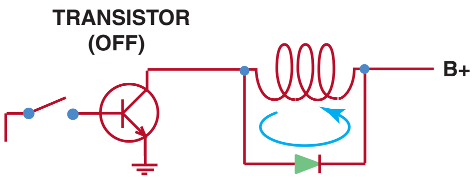


FIGURE 45–30 When the relay or solenoid coil current is turned off, the stored energy in the coil flows through the clamping diode and effectively reduces voltage spike.

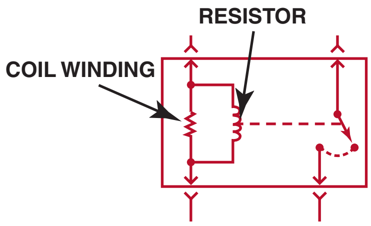


FIGURE 45–31 A resistor used in parallel with the coil windings is a common spike reduction method used in many relays.

Most relays use a resistor connected in parallel with the coil winding. The use of a resistor, typically about 400 to 600 ohms, reduces the voltage spike by providing a path for the voltage created in the coil to flow back through the coil windings when the coil circuit is opened. ● **SEE FIGURE 45–31.**

LOCATING AN OPEN CIRCUIT

TERMINOLOGY An open circuit is a break in the electrical circuit that prevents current from flowing and operating an electrical device. Examples of open circuits include:

- Blown (open) light bulbs
- Cut or broken wires
- Disconnected or partially disconnected electrical connectors

TECH TIP

Divide the Circuit in Half

When diagnosing any circuit that has a relay, start testing at the relay and divide the circuit in half.

- **High current portion:** Remove the relay and check that there are 12 volts at the terminal 30 socket. If there is, then the power side is okay. Use an ohmmeter and check between terminal 87 socket and ground. If the load circuit has continuity, there should be some resistance. If OL, the circuit is electrically open.
- **Control circuit (low current):** With the relay removed from the socket, check that there is 12 volts to terminal 86 with the ignition on and the control switch on. If not, check service information to see if power should be applied to terminal 86, then continue troubleshooting the switch power and related circuit.
- **Check the relay itself:** Use an ohmmeter and measure for continuity and resistance.
  - Between terminals 85 and 86 (coil), there should be 60 to 100 ohms. If not, replace the relay.
  - Between terminals 30 and 87 (high-amperage switch controls), there should be continuity (low ohms) when there is power applied to terminal 85 and a ground applied to terminal 86 that operates the relay. If OL is displayed on the meter set to read ohms, the circuit is open which requires that the reply be replaced.
  - Between terminals 30 and 87a (if equipped), with the relay turned off, there should be low resistance (less than 5 ohms).

FREQUENTLY ASKED QUESTION

What Is the Difference Between a Relay and a Solenoid?

Often, these terms are used differently among vehicle manufacturers, which can lead to some confusion.

Relay: A relay is an electromagnetic switch that uses a movable arm. Because a relay uses a movable arm, it is generally limited to current flow not exceeding 30 amperes.

Solenoid: A solenoid is an electromagnetic switch that uses a movable core. Because of this type of design, a solenoid is capable of handling 200 amperes or more and is used in the starter motor circuit and other high-amperage applications, such as in the glow plug circuit of diesel engines.

- Electrically open switches
- Loose or broken ground connections or wires
- Blown fuse

PROCEDURE TO LOCATE AN OPEN CIRCUIT The typical procedure for locating an open circuit involves the following steps.

STEP 1 **Perform a thorough visual inspection.** Check the following:
- Look for evidence of a previous repair. Often, an electrical connector or ground connection can be accidentally left disconnected.
- Look for evidence of recent body damage or body repairs. Movement due to a collision can cause metal to move, which can cut wires or damage connectors or components.

STEP 2 **Print out the schematic.** Trace the circuit and check for voltage at certain places. This will help pinpoint the location of the open circuit.

STEP 3 **Check everything that does and does not work.** Often, an open circuit will affect more than one component. Check the part of the circuit that is common to the other components that do not work.

STEP 4 **Check for voltage.** Voltage is present up to the location of the open circuit fault. For example, if there is battery voltage at the positive terminal and the negative (ground) terminal of a two-wire light bulb socket with the bulb plugged in, then the ground circuit is open.

REAL WORLD FIX

The Electric Mirror Fault Story

Often, a customer will notice just one fault even though other lights or systems may not be working correctly. For example, a customer noticed that the electric mirrors stopped working. The service technician checked all electrical components in the vehicle and discovered that the interior lights were also not working.

The interior lights were not mentioned by the customer as being a problem most likely because the driver only used the vehicle in daylight hours.

The service technician found the interior light and power accessory fuse blown. Replacing the fuse restored the proper operation of the electric outside mirror and the interior lights. However, what caused the fuse to blow? A visual inspection of the dome light, next to the electric sunroof, showed an area where a wire was bare. Evidence showed the bare wire had touched the metal roof, which could cause the fuse to blow. The technician covered the bare wire with a section of vacuum hose and then taped the hose with electrical tape to complete the repair.

COMMON POWER OR GROUND

When diagnosing an electrical problem that affects more than one component or system, check the electrical schematic for a common power source or a common ground. ● **SEE FIGURE 45–32** for an example of lights being powered by one fuse (power source).

- Underhood light
- Inside lighted mirrors
- Dome light
- Left-side courtesy light
- Right-side courtesy light

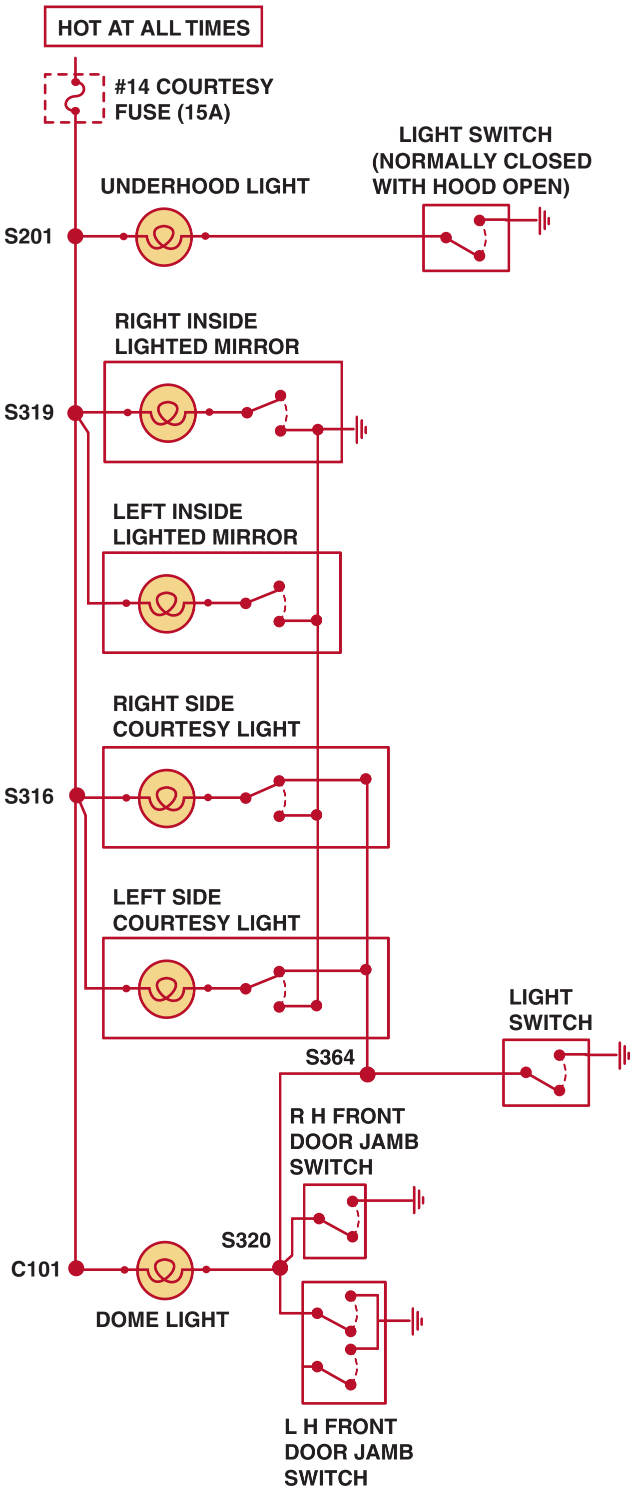


FIGURE 45–32 A typical wiring diagram showing multiple switches and bulbs powered by one fuse.

Therefore, if a customer complains about one or more of the items listed, check the fuse and the common part of the circuit that feeds all of the affected lights. Check for a common ground if several components that seem unrelated are not functioning correctly.

CIRCUIT TROUBLESHOOTING PROCEDURE

Follow these steps when troubleshooting wiring problems.

STEP 1 Verify the malfunction. If, for example, the backup lights do not operate, make certain that the ignition is on (key on, engine off), with the gear selector in reverse, and check for operation of the backup lights.

STEP 2 Check everything else that does or does not operate correctly. For example, if the taillights are also not working, the problem could be a loose or broken ground connection in the trunk area that is shared by both the backup lights and the taillights.

STEP 3 Check the fuse for the backup lights. ● **SEE FIGURE 45–34**.

STEP 4 Check for voltage at the backup light socket. This can be done using a test light or a voltmeter.

If voltage is available at the socket, the problem is either a defective bulb or a poor ground at the socket or a ground wire connection to the body or frame. If no voltage is available at the socket, consult a wiring diagram for the type of vehicle being tested. The wiring diagram should show all of the wiring and components

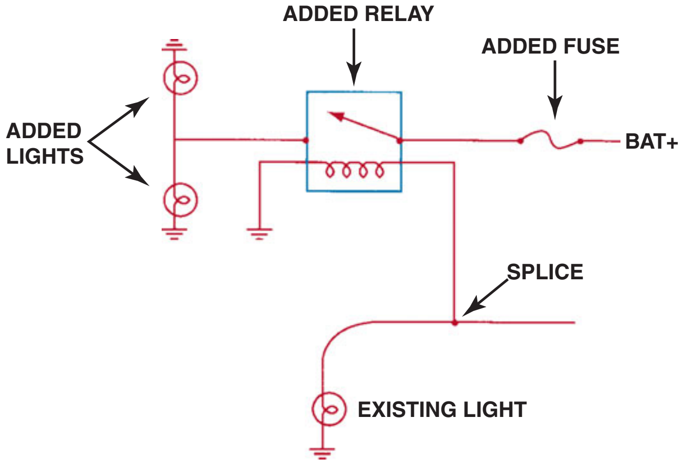


FIGURE 45–33 To add additional lighting, simply tap into an existing light wire and connect a relay. Whenever the existing light is turned on, the coil of the relay is energized. The arm of the relay then connects power from another circuit (fuse) to the auxiliary lights without overloading the existing light circuit.

TECH TIP

Do It Right—Install a Relay

Often the owners of vehicles, especially owners of pickup trucks and sport utility vehicles (SUVs), want to add additional electrical accessories or lighting. It is tempting in these cases to simply splice into an existing circuit. However, when another circuit or component is added, the current that flows through the newly added component is also added to the current for the original component. This additional current can easily overload the fuse and wiring. Do not simply install a larger amperage fuse; the wire gauge size was not engineered for the additional current and could overheat.

The solution is to install a relay, which uses a small coil to create a magnetic field that causes a movable arm to switch on a higher current circuit. The typical relay coil has from 50 to 150 ohms (usually 60 to 100 ohms) of resistance and requires just 0.24 to 0.08 ampere when connected to a 12 volt source. This small additional current will not be enough to overload the existing circuit. ● **SEE FIGURE 45–33** for an example of how additional lighting can be added.