ELECTRICAL WIRING RESIDENTIAL

CODE • THEORY • PLANS
SPECIFICATIONS • INSTALLATION METHODS

Based on 1981 National Electrical Code
Seventh Edition

RAY C. MULLIN

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Preface

The seventh edition of *Electrical Wiring – Residential* is based on the 1981 National Electrical Code (NEC). The many changes in the new Code relating to residential wiring are thoroughly explained in this text. Two new units have been added to this edition. Unit 26 discusses the wiring and installation requirements for heat and smoke detectors. Unit 30 covers in detail the many exacting regulations and safety precautions for the wiring and installation of swimming pools, spas, and hot tubs. A plan-size diagram summarizing the Code's pool wiring requirements (figure 30-6) accompanies the residential plans in the tear-out section at the back of the text.

Many new drawings and updated illustrations and related information make *Electrical Wiring – Residential* the most up-to-date guide to household wiring.

The most recent edition of the National Electrical Code is used as the basic standard for the layout and construction of electrical systems. To gain the greatest benefit from this book, the reader must use and refer to the National Electrical Code on a continuing basis. Certain modifications to the Code rules may be necessary because of the requirements of state and local electrical codes. The reader is encouraged to obtain any variations from the Code as they affect this residential installation.

The 1981 edition of the National Electrical Code represents a major revision over the previous edition. Code changes affecting the following topics are fully explained in the text:

- swimming pools
- spas
- hot tubs
- aluminum conductors
- aluminum connections and terminals on wiring devices
- kilowatt-hour consumption calculations
- smoke and heat detectors
- submersible pumps
- wiring through cold air returns
- installations in closets
- ground-fault circuit interruption in garages
- insulation around recessed fixtures
- open neutrals
- conduit bodies
- grounding ranges and dryers
- microwave ovens and other modern appliances

The 1981 edition of the National Electrical Code introduces metric (SI) measurements in addition to the traditional English measurements. Accordingly, metric measurements are included in this book where applicable. Metric conversions are now shown for the dimensions on the residential plans which accompany the text. Such conversions are considered to be the responsibility of the designer.

This book was prepared by Ray C. Mullin, former electrical circuit instructor for the Electrical Trades, Wisconsin Schools of Vocational, Technical and Adult Education. Mr. Mullin, a former member of the International Brotherhood of Electrical Workers, is presently a member of the International Association of Electrical Inspectors, the Institute of Electrical and Electronic Engineers, Inc., and the National Fire Protection Association, Electrical Section. Mr. Mullin completed his apprenticeship training and has worked as a journeyman and supervisor. He has taught both day and night electrical apprentice and journeyman trade extension courses and has conducted engineering seminars. He is knowledgeable in the what-when-where-why-and-how of electrical installations. Mr. Mullin presents his accumulated knowledge and experience in this book to assist the reader in learning residential wiring in an orderly step-by-step manner. He is currently the Vice President for a large electrical components manufacturer.

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Applicable tables from the National Electric Code are reproduced with the permission of the National Fire Protection Association, 470 Atlantic Avenue, Boston, Massachusetts 02210.

Contents

unit 1

General Information for Electrical Installations

OBJECTIVES

After studying this unit, the student will be able to

- explain how electrical wiring information is conveyed to the electrician at the construction or installation site.
- demonstrate how the specifications are used in estimating costs and in making electrical installations.
- explain why symbols and notations are used on electrical drawings.
- list the agencies that are responsible for establishing electrical standards and insuring that materials meet the standards.

THE WORKING DRAWINGS

The architect uses a set of working drawings or plans to make the necessary instructions available to the skilled crafts which are to build the structure shown in the plans. The sizes, quantities, and locations of the materials required and the construction features of the structural members are shown at a glance. These details of construction must be studied and interpreted by each skilled construction craft – masons, carpenters, electricians, and others – before the actual work is started.

The electrician must be able to: (1) convert the two-dimensional plans into an actual electrical installation, and (2) visualize the many different views of the plans and coordinate them into a three-dimensional picture, as shown in figure 1-1.

The ability to visualize an accurate three-dimensional picture requires a thorough knowledge of blueprint reading. Since all of the skilled trades use a common set of plans, the electrician must be able to interpret the lines and symbols which refer to the electrical installation and also those which are

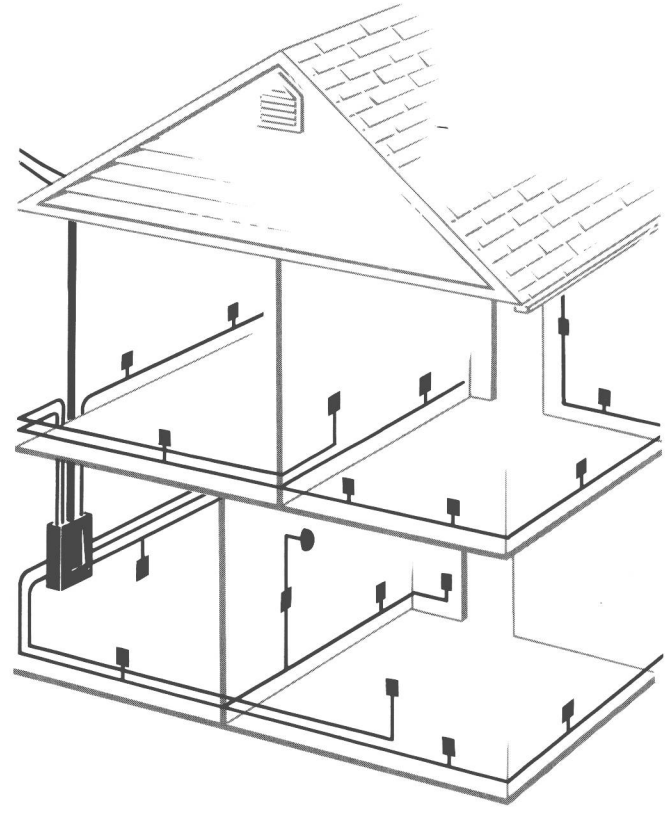


Fig. 1-1 Three-dimensional view of house wiring.

used by the other construction trades. The electrician must know the structural makeup of the building and the construction materials to be used.

SPECIFICATIONS

Working drawings are usually complex because of the amount of information which must be included. To prevent confusing detail, it is standard practice to include with each set of plans a set of detailed written specifications prepared by the architect.

These specifications provide general information to be used by all trades involved in the construction. In addition, specialized information is given for the individual trades. The specifications include information on the sizes, the type, and the desired quality of the standard parts which are to be used in the structure.

Typical specifications include a section on "General Clauses and Conditions" which is applicable to all trades involved in the construction. This section is followed by detailed requirements for the various trades – excavating, masonry, carpentry, plumbing, heating, electrical work, painting, and others.

The plan drawings for the residence used as an example for this text are included in the back of the text. The specifications for the electrical work indicated on the plans are given in the Appendix.

In the electrical specifications, the listing of standard electrical parts and supplies frequently includes the manufacturers' names and the catalog numbers of the specified items. Such information insures that these items will be of the correct size, type, and electrical rating, and that the quality will meet a certain standard. To allow for the possibility that the contractor will not always be able to obtain the specified item, the phrase "or equivalent" is usually added after the manufacturer's name and catalog number.

The specifications are also useful to the electrical contractor in that all of the items needed for a specific job are grouped together and the type or size of each item is indicated. This information allows the contractor to prepare an accurate cost estimate without having to find all of the data in the plans.

SYMBOLS AND NOTATIONS

The architect uses symbols and notations to simplify the drawing and the presentation of information concerning electrical devices and arrangements. One such symbol and notation is shown in the following example.

SYMBOL	NOTATION
WP	WEATHERPROOF OUTLET

Symbols are described in detail in unit 2. Most of these symbols and notations have a standard interpretation throughout the country. The notation, which is placed on the drawing next to a specific symbol, provides information on the type, size, and quantity of the device required. The notation may be an abbreviation. It may also refer to a specific table for details.

The electrician must be able to interpret these symbols and notations so that the various components can be grouped into the proper circuits. The electrician must be able to visualize the circuits, the distribution centers, the service entrance, and the metering facilities as a complete, three-dimensional installation. Then, this picture must be converted into a completed installation which will meet the approval of the owner, the architect, and the local inspecting authority.

NATIONAL ELECTRICAL CODE (NEC)

Because of the ever-present danger of fire through some failure of the electrical system, the electrician and the electrical contractor must use approved materials and must perform all work in accordance with recognized standards. The National Electrical Code is the basic standard which governs electrical work. The Code contains provisions considered necessary for safety. It states that the installation must be essentially hazard-free, but that such an installation is not necessarily efficient, convenient, or adequate, *Section 90-1(b)*. It is the electrician's responsibility to insure that the installation meets these criteria. In addition to the National Electrical Code, the electrician must also consider local and state codes. The purpose and scope of the National Electrical Code are discussed in *Article 90* of the Code book and should be

studied by the student at this time. The Code is revised and updated every three years; the articles and section numbers usually remain the same, as does the subject covered, but the wording may be deleted, changed, or expanded.

Code Terms

The following terms are used throughout the Code. It is important to understand the meanings of these terms.

Identified: (As applied to equipment.) Recognizable as suitable for a specific purpose, function, use, environment, or application, where described in a particular Code requirement. Suitability of use, marked on or provided with the equipment, may include labeling or listing.

Labeled: Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed: Equipment or materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

Approved: Acceptable to the authority having jurisdiction.

Authority Having Jurisdiction: An organization, office, or individual responsible for "approving" equipment, an installation, or a procedure.

Shall: Indicates a mandatory requirement.

Should: Indicates a recommendation or that which is advised but not required.

One of the most far reaching NEC rules is *Section 110-3(b)*. This section states that the use and installation of listed or labeled equipment must conform to any instructions included in the listing or labeling. This means that an electrical system and its associated electrical equipment must be installed and used in accordance with both the National Electrical Code and the Underwriters' Laboratories standards.

In the past, programs such as *Adequate Wiring, House Power, Live Better Electrically, Bronze Medallion,* and *Gold Medallion*, were instituted to supplement established Code standards. The purpose of these programs was to promote the installation of efficient, convenient, and useful home wiring systems. After a period of time, as the recommendations of these programs were gradually written into the National Electrical Code, the programs were phased out.

The NEC tells what is permitted and what is not permitted by using certain key words, as follows:

shall be	compulsory; mandatory; a requirement; must be.
shall have.	the same as "shall be."
shall not	not allowed; not permitted to be done; must not be; against the Code.
shall be permitted	is allowed; may be done; not against the Code.

The National Electrical Code refers to a residence as a *dwelling unit.*

CODE USE OF METRIC (SI) MEASUREMENTS

For the first time, the 1981 National Electrical Code includes both English and metric measurements. The metric system is known as the *International System of Units* (SI).

Metric measurements appear in the Code as follows:

- in the Code paragraphs, the approximate metric measurement appears in parentheses following the English measurement.
- in the Code tables, a footnote shows the SI conversion factors.

A metric measurement is not shown for conduit size, box size, wire size, horsepower designation for motors, and other "trade sizes" that do not reflect actual measurements.

The National Electrical Code is following this conversion schedule:

mega	1 000 000	(one million)
kilo	1 000	(one thousand)
hecto	100	(one hundred)
deka	10	(ten)
the unit	1	(one)
deci	0.1	(one-tenth) (1/10)
centi	0.01	(one-hundredth) (1/100)
milli	0.001	(one-thousandth) (1/1 000)
micro	0.000 001	(one-millionth) (1/1 000 000)
nano	0.000 000 001	(one-billionth) (1/1 000 000 000)

Fig. 1-2 Metric prefixes and their values.

1981 edition – English measurement first, with metric (SI) measurement in parentheses ().

1984 edition – metric measurement first, with English measurement in parentheses ().

Guide to Metric Usage

In the metric system, the units increase or decrease in multiples of 10, 100, 1 000, and so on. For instance, one megawatt (1 000 000 watts) is 1 000 times greater than one kilowatt (1 000 watts).

By assigning a name to a measurement, such as a *watt*, the name becomes the unit. Adding a prefix to the unit, such as *kilo*, forms the new name *kilowatt*, meaning 1 000 watts. Refer to figure 1-2 for prefixes used in the metric system.

The prefixes used most commonly are: *centi, kilo,* and *milli.* Consider that the basic unit is a meter (one). Therefore, a centimeter is 0.01 meter, a kilometer is 1 000 meters, and a millimeter is 0.001 meter.

Some common measurements of length in the English system are shown with their metric equivalents in figure 1-3.

Electricians will find it useful to refer to the conversion factors and their abbreviations shown in figure 1-4.

one inch	=	2.54	centimeters
	=	25.4	millimeters
	=	0.025 4	meter
one foot	=	12	inches
	=	0.304 8	meter
	=	30.48	centimeters
	=	304.8	millimeters
one yard	=	3	feet
	=	36	inches
	=	0.914 4	meter
	=	914.4	millimeters
one meter	=	100	centimeters
	=	1 000	millimeters
	=	1.093	yards
	=	3.281	feet
	=	39.370	inches

Fig. 1-3 Some common measurements of length and their metric equivalents.

inches (in) × 0.025 4	= meters (m)
inches (in) × 0.254	= decimeters (dm)
inches (in) × 2.54	= centimeters (cm)
centimeters (cm) × 0.393 7	= inches (in)
inches (in) × 25.4	= millimeters (mm)
millimeters (mm) × 0.039 37	= inches (in)
feet (ft) × 0.304 8	= meters (m)
meters (m) × 3.280 8	= feet (ft)
square inches (in^2) × 6.452	= square centimeters (cm^2)
square centimeters (cm^2) × 0.155	= square inches (in^2)
square feet (ft^2) × 0.093	= square meters (m^2)
square meters (m^2) × 10.764	= square feet (ft^2)
square yards (yd^2) × 0.836 1	= square meters (m^2)
square meters (m^2) × 1.196	= square yards (yd^2)
kilometers (km) × 1 000	= meters (m)
kilometers (km) × 0.621	= miles (mi)
miles (mi) × 1.609	= kilometers (km)

Fig. 1-4 Useful conversions (English/SI - SI/English) and their abbreviations.

UNDERWRITERS' LABORATORIES, INC. (UL)

Underwriters' Laboratories (UL) is a highly qualified, nationally recognized testing laboratory. Most reputable manufacturers of electrical equipment submit their products to the Underwriters' Laboratories where the equipment is subjected to numerous tests. These tests determine if the products can perform safely under normal and abnormal conditions to meet published standards.

After UL determines that a product complies with the specific standard, a manufacturing firm is then permitted to *label* its product with the UL logo. The products are then *listed* in a UL publication.

It must be noted that UL does not *approve* any product. Rather, UL *lists* those products that conform to its safety standards.

Two very useful UL publications are the *Electrical Appliance and Utilization Equipment Directory* and the *Electrical Construction Materials Directory*. If the answer to a question cannot be found readily in the National Electrical Code, then it generally can be found in these two UL publications.

REVIEW

Note: Refer to the National Electrical Code or the plans where necessary.

1. What is the purpose of specifications? _____

2. In what additional way are the specifications particularly useful to the electrical contractor? _____

3. To prevent a plan from becoming confusing because of too much detail, what is done? _____

4. Name four requirements contained in the specifications regarding material.
   a. _____ c. _____
   b. _____ d. _____

5. Name three cautions regarding workmanship found in the specifications. _____

6. What phrase is used when a substitution is permitted for a specific item? _____

7. What is the purpose of an electrical symbol? _____

8. What is a notation? _____

9. Where are notations found? _____

10. List at least twelve electrical notations found on the plans. _____

11. What three parties must be satisfied with the completed electrical installation?
    a. _____ b. _____ c. _____

12. What code sets standards for electrical installation work? _____

13. What authority enforces the standards set by the Code? _____

14. Does the Code provide minimum or maximum standards? _____

15. What do the letters *UL* signify? _____

16. What section of the Code states that all listed or labeled equipment shall be used or installed in accordance with any instructions included in the listing or labeling? _____

17. When the words "shall be" appear in a Code reference, they mean that it (must)(may) be done. (Underline the correct word.)

unit 2

Electrical Symbols and Outlets

OBJECTIVES

After studying this unit, the student will be able to

- identify and explain the electrical outlet symbols used in the plans of the single-family dwelling.
- discuss the types of outlets, boxes, fixtures, and switches used in the residence.
- explain the methods of mounting the various electrical devices used in the residence.

ELECTRICAL SYMBOLS

Electrical symbols used on an architectural plan show the location and type of electrical device required. A typical electrical installation as taken from a plan is shown in figure 2-1.

The National Electrical Code describes an outlet as a point on a wiring system which supplies current to utilization equipment. The term outlet is used broadly by electricians to include noncurrent-consuming switches and similar control devices in a wiring system when estimating the cost of the installation. Each type of outlet is represented on the plans as a symbol. In figure 2-1, the outlets are shown by the symbols ⊖ and ⊹. The standard electrical symbols are shown in figure 2-2.

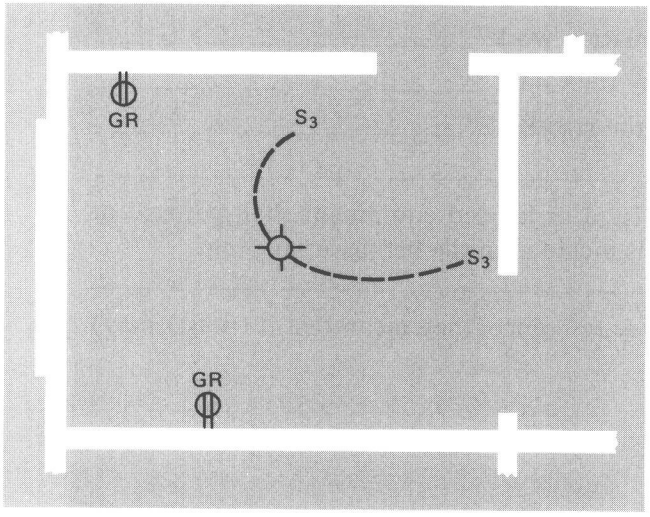


Fig. 2-1 Use of electrical symbols and notations on a floor plan.

The dash lines in figure 2-1 run from the outlet to the switch or switches which control the outlet. These dash lines are usually curved so they cannot be mistaken for invisible edge lines. Outlets shown on the plan without curved dash lines are independent outlets and have no switch control.

A study of the plans for the single-family dwelling shows that many different electrical symbols are used to represent the electrical devices and equipment used in the building.

In drawing electrical plans, most architects, designers, and electrical engineers use symbols approved by the American National Standards Institute (ANSI) wherever possible. However, plans may contain symbols that are not found in these standards. When such unlisted (nonstandard) symbols are used, the electrician must refer to a legend which interprets these symbols. The legend may be included on the plans or in the specifications. In many instances, a notation on the plan will clarify the meaning of the symbol.

Figure 2-2 lists the standard, approved electrical symbols and their meanings. Many of these

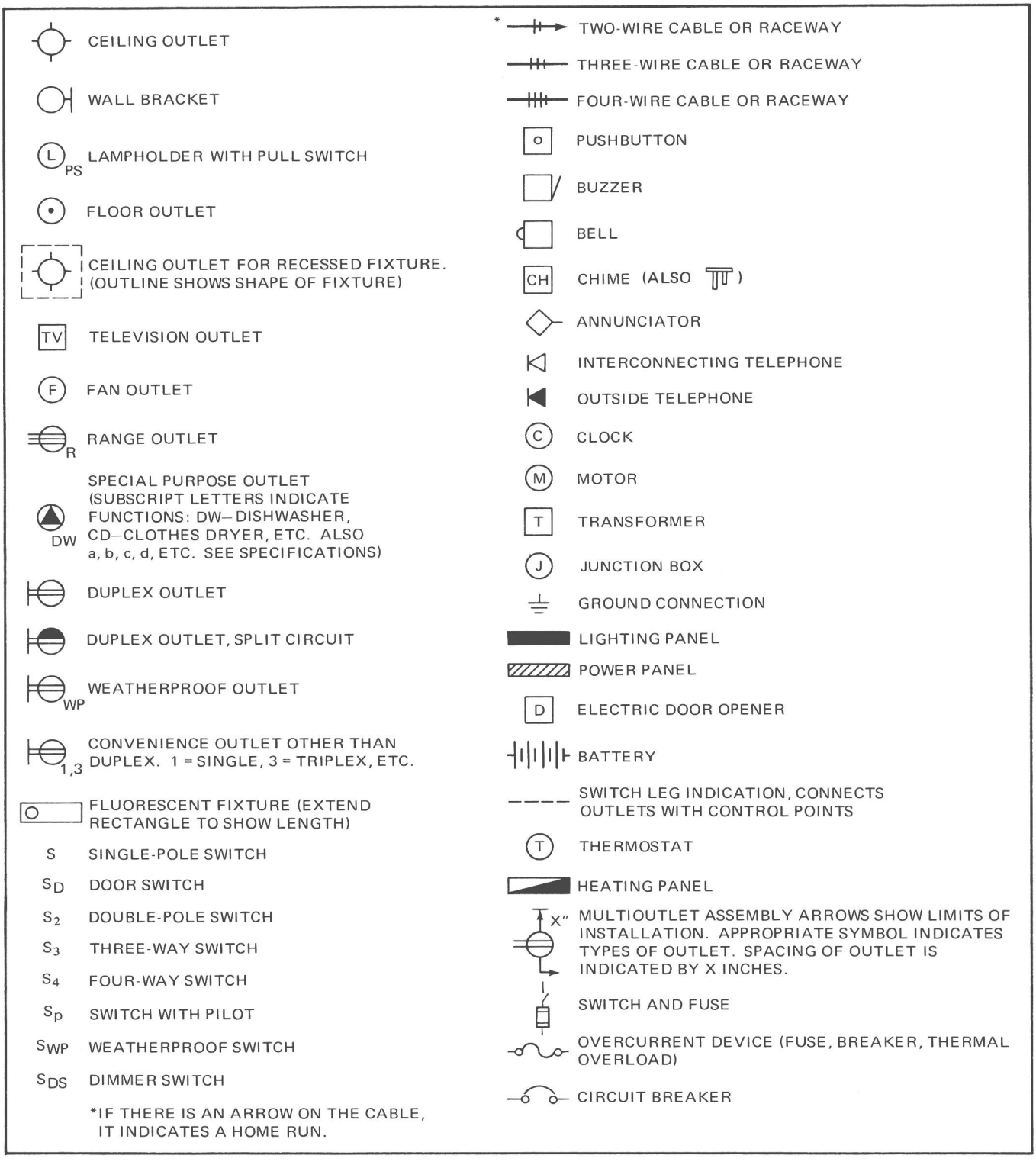


Fig. 2-2 Electrical wiring symbols.

Fig. 2-3 Variations in significance of outlet symbols.

symbols can be found on the accompanying plans of the residence. Note in figure 2-2 that several symbols have the same shape. However, differences in the interior presentation indicate that the meanings of the symbols are different. For example, different meanings are shown in figure 2-3 for the outlet symbol. A good practice to follow in studying symbols is to learn the basic forms first and then add the supplemental information to obtain different meanings.

FIXTURES AND OUTLETS

Architects often include in the specifications a certain amount of money for the purchase of electrical fixtures. The electrical contractor includes this amount in the bid and the choice of fixtures is then left to the homeowner. If the owner selects fixtures whose total cost exceeds the fixture allowance, the owner is expected to pay the difference between the actual cost and the specification allowance. If the fixtures are not selected before the roughing-in stage of wiring the house, the electrician usually installs outlet boxes having standard fixture mounting studs. Most modern lighting fixtures can be fastened to a fixture stud. Other fixtures can be mounted either to an outlet box or plaster cover, using a strap or bar and No. 8-32 screws. In addition, fixtures can be mounted on a standard switch box using No. 6-32 screws. A box must be installed at each outlet or switch location, *Section 300-15*. (Note: All National Electrical Code section references are printed in italics.)

If the owner selects fixtures prior to construction, the architect can specify these fixtures in the plans and/or specifications. Thus, the electrician is provided with advance information on any special framing, recessing, or mounting requirements for the fixtures. This information must be provided in the case of recessed fixtures which require a specific wall or ceiling opening.

Many types of lighting fixtures are presently available. Figure 2-4 shows several typical lighting fixtures that may be found in a dwelling unit. Also shown are the electrical symbols used on plans to designate these fixtures and the type of outlet boxes or switch boxes on which the lighting fixtures can be mounted. A standard convenience outlet is shown, as well. The switch boxes shown here are made of steel. Switch boxes may also be made of plastic, as shown later in the text in figure 22-1. Other types of outlets are covered in later units.

FLUSH SWITCHES

Some of the standard symbols for various types of switches are shown in figure 2-5. Typical connection diagrams are also given. Any sectional switch box or 4-inch square box with a side mounting bracket and raised switch cover can be used to install these switches.

JUNCTION BOXES AND SWITCH BOXES (*ARTICLE 370*)

Junction boxes are sometimes placed in a circuit for convenience in joining two or more cables or conduits. All conductors entering a junction box are joined to other conductors entering the same box to form the proper hookups so that the circuit will operate in the manner intended.

All electrical installations must conform to the National Electrical Code standards requiring that junction boxes be installed in such a manner that the wiring contained in them shall be accessible without removing any part of the building. In house wiring, this requirement limits the use of junction boxes to cellars and open attic spaces because flush blank covers exposed to view detract from the appearance of a room. Of course, an outlet box, such as the one used in the bedroom ceiling fixture, is really a junction box because it contains splices. Removing the fixture makes the box accessible, thereby meeting the Code requirements.

The house wiring system usually is formed of a number of specific circuits. Each circuit consists of a continuous run of cable from outlet to outlet, or from box to box. The residence plans show many branch circuits for general lighting, appliances, electric heating baseboard panels, and other requirements. The specific Code rules for each of these circuits are covered in a later unit.

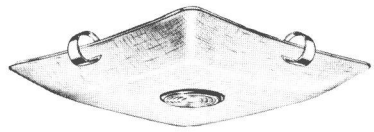
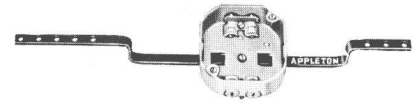
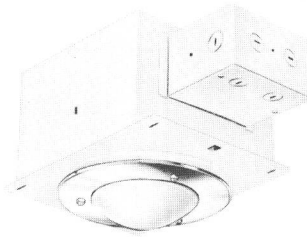
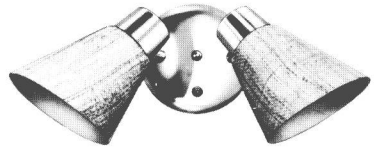
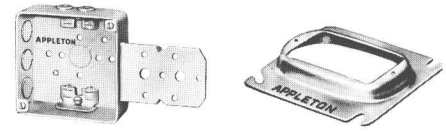
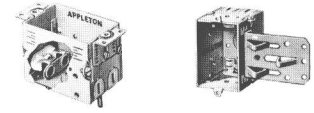
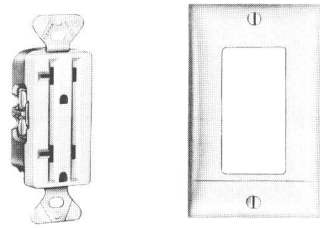
SYMBOL	TYPE OF FIXTURE OR OUTLET	OUTLET BOXES THAT MAY BE USED
OR CEILING OUTLET	 SURFACE MOUNTED	 OCTAGON BOX AND OFFSET BAR HANGER. BOXES ARE AVAILABLE WITH EITHER INTERNAL OR EXTERNAL CLAMPS.
CEILING OUTLET	 FLUSHED RECESSED TYPE	CABLE TERMINATES IN BOX THAT IS FURNISHED WITH FIXTURE. SPECIAL CODE RULES GOVERNING THE INSTALLATION ARE FOUND IN *SECTIONS 410-64* THROUGH *410-72* OF THE NATIONAL ELECTRICAL CODE.
WALL OUTLET		 4" SQUARE BOX WITH SIDE BRACKET AND PROPER RAISED PLASTER COVER.  SECTIONAL SWITCH BOXES
DUPLEX RECEPTACLE OUTLET		SAME AS ABOVE

Fig. 2-4 Types of fixtures and outlets.

Ganging Switch Boxes

A flush switch or convenience outlet for residential use fits into a standard 2" x 3" sectional switch box (sometimes called a device box). When two or more switches (or outlets) are located at the same point, the switch boxes are *ganged* or fastened together to provide the required mounts, figure 2-6. Three switch boxes can be ganged together by removing and discarding one side from both the first and third switch boxes and both sides from the second (center) switch box. The boxes are then joined together as shown in figure 2-6. After the switches are installed, the gang is trimmed with a gang plate having the required number of switch handle or convenience outlet openings. These plates are called two-gang wall plates, three-gang wall plates, and so on, depending upon the number of openings.