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Preface

One- and Two-Family Dwelling Electrical Systems has been developed for those involved in design, installation, or inspection of electrical systems in new and existing dwellings. This ninth edition covers the subject in detail and provides information relative to application of not only the 2014 National Electrical Code, but also Part VIII of the 2015 International Residential Code. Every effort has been made to update the references and material in this book to be consistent with those code editions. L. Keith Lofland was the principal contributor to this ninth edition as well as the previous two editions.

IAEI acknowledges the contributions of Joseph A. Tedesco and J. Philip Simmons in the original co-development and authoring of this publication in 1992, based on the 1990 edition of the NEC. Ed Lawry and Simmons were involved as authors and contributors in the second edition; Simmons, in the third, and fourth editions. The fifth and sixth editions were developed from contributions of Michael J. Johnston, Thomas Garvey, and L. Keith Lofland. As with any lasting and valuable publication, each edition has been improved and grown through the contributions of many dedicated individuals. IAEI intends that this publication live on as a classic textbook of residential electrical systems, with each new edition being updated and improved in each subsequent code cycle. This edition carries on these objectives and is certain to continue to be a valuable training and instructional resource about electrical installations in residential occupancies.

Who will find this publication to be a valuable asset? No doubt, the entire electrical and building inspection community—electrical contractors, electricians, foremen, estimators, plans examiners, electrical utilities and others—will appreciate this handy guidebook. This textbook should be especially valuable to combination inspectors or home inspectors who might not have the hands-on electrical experience as an installer that electrical inspectors typically possess.

Please feel free to contact IAEI with any suggestions or comments for improving One- and Two-Family Dwelling Electrical Systems, as your comments are always welcomed.
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1 General Requirements
Safe electrical installations require several key components: design, listing requirements, qualified personnel, code-compliance and inspection. In fact, there are more specific requirements for one- and two-family dwellings than for any other type of occupancy referenced in the NEC. Anyone who designs, installs, or inspects electrical systems in one- and two-family dwellings must be thoroughly familiar with these requirements for safe installations, as found in electrical codes and product safety standards. These codes and standards must be followed carefully to provide an installation that is essentially free from electrical hazards. It is important that qualified persons perform the installation. A qualified person has the necessary skills, knowledge, and experience needed to ensure a safe installation. It is equally important that the installation be inspected. The inspectors are obligated to verify that applicable code rules have been followed. Knowledge of the electrical code is not an option, but a necessity in residential wiring.

This book focuses on the requirements for electrical installations based on the electrical code and includes information relative to making proper electrical inspections of residential wiring systems. The scope of this book covers one- and two-family dwelling electrical systems from the perspective of both the installer and inspector.

Structural requirements for one- and two-family dwellings are provided in the applicable building code and must be utilized in addition to the rules in the applicable electrical code. For example, NFPA-5000, *The Building Construction and Safety Code, 2015 edition*, provides structural requirements for one- and two-family dwellings and in Chapter 52 refers specifically to the National Electrical Code (NEC) for all electrical requirements (see 52.1). The 2015 *International Residential Code* includes electrical requirements in Part VIII, which is based on the provisions of the 2014 NEC. The building code generally refers to the requirements found in the NEC for all electrical requirements. One should verify which code is adopted and enforced in his or her particular area.

Electrical requirements for one-and two-family dwellings are found in the NEC-2014. There are also electrical requirements found in Part VIII of the *International Residential Code* (IRC), 2015 edition. Ten chapters in Part...
VIII of the IRC (Chapters 34–43) are dedicated to electrical code requirements, which are derived from the NEC and, for the most part, are very similar. However, there are a few differences.

The IRC is limited to coverage of the most commonly encountered wiring methods and materials in the construction of one- and two-family dwellings. IRC Section E3401.2 includes the scope and limitations of the IRC. Electrical services for one- and two-family dwellings within the scope of the IRC are limited to those rated at 120/240-volts, single-phase, and not exceeding 400 amperes. Any services beyond those ratings will fall under the requirements of the NEC. Many of the rules included in the IRC are provided in tabular form, such as applicable wiring methods, and support requirements for the applied wiring methods. Electrical systems, equipment or components that are not specifically covered in Chapters 34 through 43 of the IRC are required to comply with the applicable provisions of the National Electrical Code, NFPA 70 (see IRC E3401.2).

Most jurisdictions responsible for building safety and enforcement are adopting the NEC. Some jurisdictions are adopting the latest edition of the IRC as the governing code for one- and two-family residential dwelling electrical systems and installations. Many jurisdictions adopt the IRC without the electrical requirements (found in IRC Part VIII), and refer to the requirements of the NEC. Other jurisdictions adopt another building code and use the NEC for the electrical requirements. Consequently, the majority of electrical installations today are made in accordance with the applicable requirements of the NEC.

In an effort to be thorough in dealing with a common concern for electrical safety, this book includes information from both codes. Because the provisions of the IRC are primarily derived from the dwelling unit requirements of the NEC, the general information on what is required is the same. Therefore, the text explains the requirements generally, and refers the reader to the appropriate sec-

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- The purpose of this Code is the practical safeguarding of persons and property from hazards arising from the use of electricity

- This Code is not intended as a design specification or an instruction manual for untrained persons

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![Figure 1.1. Purpose of the Code](image-url)
tion of the applicable code for the specific rules. It should be emphasized once again that the electrical provisions of the IRC have been derived from the NEC by permission of the National Fire Protection Association, which produced and copyrighted Part VIII of the IRC (see Chapter 34 of the IRC 2015 edition). A more in-depth look at the electrical provisions contained in the *International Residential Code*, along with a comparison to the NEC, is available in chapter 18 of this book. Handy cross-references between the IRC and the NEC are included in Appendix A. For metric conversions, this publication utilizes those provided in the NEC as specified by Section 90.9, which differ from the conversions used by the IRC (see chapter 18 for additional information and a more complete comparison).

The Purpose of the Code

Electricity is a powerful force. When under control, like fire, electricity is a dependable servant and performs endless tasks. When uncontrolled, both electricity and fire become terrible villains that can harm people and their property.

Therefore, one of the primary purposes of the electrical code is electrical safety. An essential aspect of any safe wiring installation is conformity to the electrical code. Usually, local safety regulations in the form of a municipal ordinance or state law are based upon the latest edition of the electrical code. The primary purpose of the NEC, as outlined in Section 90.1, is “The practical safeguarding of persons and property from hazards arising from the use of electricity.” While installing electrical equipment in compliance with the Code does not guarantee the system will be free from risk or electrical hazard, doing so reduces the likelihood of fires from electrical origin. Fire and electric shock hazards, often present in premises wiring systems, are minimized by proper installation and use.

Another key element in providing a safe electrical installation is to follow manufacturers’ instructions and fully comply with any limitations placed on the installation or use of the equipment. In many cases, these instructions accompany the product and give requirements such as temperature rating of supply conductors, minimum circuit size, the maximum rating of overcurrent protection or grounding, or bonding needs. Compliance with these instructions is required by the Code and product standards.

The NEC is intended to apply to premises wiring systems. Other codes govern the installation of the utility transmission, distribution and supply systems. A premises wiring system comprises interior and exterior wiring, including outside branch circuits and feeders installed on or between buildings used for power that supplies energy to motors, lighting, control, and signal circuit wiring that are combined or used with any hardware, fittings, and wiring devices that may be either temporarily or permanently installed. The premises wiring system typically begins at the service point at the load end of the service drop (drip loop) or load end of the underground service lateral and ends at the branch circuit outlet(s).

Electrical Codes and Inspection

In many areas, electrical inspection services are provided to determine conformance with the Code and other applicable safety regulations and building codes. In most cases, these inspections are required by state, county or municipal laws or ordinances. These jurisdictions adopt an electrical code, which then becomes a legally enforceable document. It is also somewhat common that these inspection agencies produce and adopt local electrical installation requirements that supplement or amend the NEC for their jurisdiction. It is important that the installer contact the local inspection jurisdiction before beginning an electrical installation or modification to determine which edition has been adopted and to obtain a copy of local wiring rules, if any.

An electrical installation permit is usually required where an inspection program is in place. It is commonly required that the permit, which must be obtained prior to beginning the installation, be posted in a visible location on the project.

Inspections Required

Several inspections are typically required during the course of construction. Most jurisdictions require an electrical inspection
prior to covering or “closing in” any work. The IRC includes a section on inspection and approvals, which requires all new electrical work and parts of existing electrical systems that may be affected by new work or alterations to be inspected by the building official, often the building inspector or electrical inspector, to ensure compliance with the applicable electrical code.

Electrical inspections to determine code-compliance are commonly performed at three critical stages of construction. These three stages of completion of the project are referred to as the rough-in, service, and final inspections. Checklists and cross-references will provide the reader additional information relative to what is intended by the Code for the various aspects of one- and two-family dwelling electrical systems. Rough-in inspection is performed after all feeder and branch-circuit wiring, including boxes and cables, is installed and before building finish conceals any of the wiring. Conductors have been spliced inside of boxes and enclosures. The required provisions for grounding devices and equipment are in place. The wiring should not be energized at this point since the inspector will be examining the exposed wiring inside of boxes and enclosures. Installation of the electrical service, including grounding and bonding, is inspected and must be approved before most electrical utilities will connect power to the service. Final inspection is performed after all wiring is complete, including wiring devices, and after luminaires, heating and air-conditioning equipment, and appliances are installed and connected. Some inspection agencies issue a certificate of final inspection or an occupancy permit before the building or the space being added or remodeled can be used.

In an area where an electrical licensing and inspection service is not required or available, other safeguards may be available. For both installer and independent electrical inspector, the owner should insist on seeing documentation that they are qualified to perform the electrical installation and inspection. This may be in the form of a registration by a controlling agency such as an electric utility, by passing one or more certification examinations, or by training and experience. The installer and private inspection firm should also be bonded and insured. Insist on documentation in writing from the installer and inspector that the installation is compliant with the applicable electrical code. This is an extremely important and required element of our electrical safety system. Four critical components of the electrical safety system are: (1) quality electrical safety codes and standards; (2) qualified electrical testing laboratories; (3) qualified and competent electrical inspectors; and (4) qualified persons performing the installation.

### Approval Factors for Authority Having Jurisdiction

The authority having jurisdiction (AHJ) has the responsibility to enforce the Code as well as to interpret and apply its requirements to the electrical installation under consideration. As mentioned previously, local laws or ordinances set out the requirements for electrical wiring.

An AHJ also has the responsibility for approving electrical
equipment that will be used in the electrical installation. The Code specifies, “The conductors and equipment required or permitted by this Code shall be acceptable only if approved” [NEC 110.2 or IRC E3403.1]. Approved is defined as “acceptable to the authority having jurisdiction.” Thus, the electrical inspection authority has the responsibility of determining which equipment is acceptable for the electrical project. The AHJ may be the building official, an organization, or an electrical inspector. Authority having jurisdiction is defined in the NEC as “An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.” IRC R104.1 generally designates the building official as the authority having jurisdiction.

The term authority having jurisdiction is broad in scope, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the entity with this responsibility may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the AHJ. In some circumstances, the property owner or his or her designated agent assumes the role of the AHJ; at government installations, the commanding officer or departmental official may be the AHJ.

**Listed or Labeled Equipment**

Many electrical inspection authorities rely heavily on labeling of equipment under the program of a qualified electrical products testing laboratory. Some jurisdictions operate under a law or ordinance where it is required that only listed and labeled equipment be used in a project. Other jurisdictions require listing or labeling only where such requirements are contained in the Code for a specific product.

Equipment used in electrical installations should be listed or labeled by a qualified third-party electrical products testing laboratory. The Code requires electrical installations and equipment to be approved [NEC 110.2 or IRC E3403.1]. Inspectors are required to approve installations and generally base the approvals on the use of listed products.

The IRC has a mandatory requirement that all electrical materials, components, devices, luminaires, and equipment be listed [IRC E3403.3]. Equipment is also required to bear a listing label and to be installed, used, or both, in accordance with any instructions from the manufacturer. Product examination should be performed by a third party, independent and qualified testing organization having the facilities, testing equipment and qualified staff to perform these examinations. This organization should also perform ongoing inspection of the production of this electrical equipment. The primary role of the inspector is to ensure that the listed product is installed in accordance with the manner the product has been tested to be installed and used. The NEC provides additional guidance, in that factory-installed internal wiring or the construction of equipment that is listed by a qualified electrical products testing laboratory need not be inspected at the time of installation, except to detect alterations or damage [NEC 90.7].

**Installation and Use**

Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling and supplied by the manufacturer. It is important to apply these instructions properly in the field. Just because a device or a unit of electrical equipment is listed does not mean the installation of the equipment is acceptable. The product must be installed and used within the limitations of the listing. For example, if an electrical enclosure is limited to dry locations only, then it cannot be installed in a damp or wet location. This would be a violation of the Code; in addition, it would violate a listing requirement [NEC 110.3(B) and IRC E3403.3].

These Code sections provide important requirements that should be carefully followed. Another example directly related to dwellings is recessed incandescent luminaires that are manufactured in a variety of styles. Some of these luminaires are suitable for embedding in thermal insulation, while
others are not. In addition, manufacturers’ instructions are specific as to which trims are permitted to be installed on which rough-in housing. All these markings and instructions must be followed to ensure a safe installation.

Many inspectors understand these listing installation instructions and incorporate the Guide Card information from the Underwriters Laboratories Electrical Construction Equipment Directory (UL White book) and similar directories into the requirements of the Code. Others feel the information from these directories supplements the requirements of the Code and is enforced where applicable. These product requirements provide conditions for safe installation of equipment that make compliance necessary. The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The AHJ should utilize the system employed by the listing organization to identify a listed product.

**Qualified Persons**

Electrical wiring and equipment should be installed by competent, qualified, and knowledgeable individuals. An improper installation will increase the risk of fire and injury. However, the best-designed and manufactured electrical products can be installed improperly and become an electrical hazard. Good intentions are not always enough. Qualified and experienced individuals select equipment that is designed for the use and environment and install circuits that are suitable for the load to be carried by the equipment.

The definition of *qualified person* is found in NEC Article 100, “One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.” Many areas where electrical inspection programs are in place require that those persons installing electrical equipment demonstrate their qualifications or credentials to do so by passing an examination. Often, one must show evidence of completing training in an apprenticeship or vocational training program before the person is permitted to take an examination. After he or she passes an examination, it is common that electricians and/or electrical contractors are licensed by these inspection jurisdictions or by a state agency. Licenses usually must be renewed on a regular basis, most often from one to three years. Where licensing requirements are in place, continuing education to maintain one’s knowledge and skills in the trade is very common.

Where improper types of equipment or materials are installed, or where proper equipment or materials are not installed in accordance with the manufacturer’s instructions, electricity can become a serious threat that may lead to a severe hazard to life and property.

It also becomes a threat when electrical equipment or material is handled by those who are unfamiliar with its installation or who are not properly trained. The Code gives guidance on the type of safety training which qualifies...
individuals to plan and perform the basic tasks that sometimes necessarily involve energized equipment. NFPA 70E, *Standard for Electrical Safety in the Workplace*, serves as the foundation for safety training requirements and safe work practices. One cannot learn design specification, installation or inspection just from reading the *Code*. The *Code* is not intended as a design specification or training manual. There is no substitute for the experience gained while working as an electrician, designer, inspector, or engineer.

**Mechanical Execution of Work**

In spite of all the rules and regulations governing the design, manufacture, testing and installation of electrical equipment, much of the responsibility for a safe and adequate installation depends upon the integrity of the installer and proper electrical inspection. The old truism, “If it’s worth doing, it’s worth doing right,” certainly applies to electrical wiring and inspection. In the final analysis, much of the success or failure of an installation depends upon the pride taken by both the installer and the inspector, and their commitment to making a safe and code-compliant installation.

**Neat and Workmanlike**

The *NEC* requires that electrical equipment “be installed in a neat and workmanlike manner.” Determining that an electrical installation has been installed in a neat and workmanlike manner is subjective. However, it can be said that usually “Good work looks good.” Inspectors know that where they find equipment, like conduit and boxes, not installed plumb, or cables twisted and installed in a random and careless manner, other parts of the installation are likely to be deficient as well [NEC 110.12]. *Equipment* is defined by the *Code* as, “A general term including materials, fittings, devices, appliances, luminaires, apparatus, machinery, and the like used as part of, or in connection with, an electrical installation.” Thus, the requirement that equipment be installed in a neat and workmanlike manner is broad and intended to be applicable to the entire electrical installation.

Here are ten basic steps that exemplify good mechanical execution of electrical work:

1. Unused openings in outlet, device, pull and junction boxes, conduit bodies and fittings, raceways, auxiliary gutters, cabinets, equipment cases or housings are effectively closed with knockout seals or other materials that provide substantial protection that is equivalent to that of the wall of a box or piece of equipment.

2. Conductor insulation is not damaged and wires are not nicked or damaged at terminations. Care is exercised and proper tools are used when the insulation is stripped.

3. Cable assemblies are not kinked or excessively bent sharper than the permitted radius. Bends in cable assemblies do not have a radius that is less than five times the diameter of the cable.

4. Staples used to secure cable assemblies are not driven too tightly. In some cases, insulated types of staples may provide better protection against damage.

5. All terminations are made in accordance with the manufacturer’s instructions provided on

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*Photo 1.2. Typical listing marks and labels on electrical equipment*
the equipment. Screws that engage fewer than two threads and the screws used to mount devices are not used to terminate conductors.

6. Proper tools were used to end raceways. The scorch and burn marks on nonmetallic conduit are evidence of overheating and may indicate permanent damage was done to the conduit.

7. Exposed wiring and equipment were protected from contamination during construction. All equipment was cleaned both inside and outside before it was energized.

8. Connections of all metal sheathing of electrical cables, raceways and equipment are made up wrenchtight. This helps to ensure an effective fault-current path.

9. Insulation integrity for all wiring was verified. This was done to be sure that the system will not suffer from short circuits or ground faults when energized.

10. Protection against physical damage is provided for exposed electrical wiring and equipment. The potential use of the area after construction has been completed and the premises occupied was considered in making this judgment.

Ohm’s Law and Basic Electrical Theory

Electrical current flowing through any electrical circuit can be compared with water under pressure flowing through a fire hose. Water flowing through a fire hose is measured in gallons per minute (GPM), and electricity flowing through a circuit is measured in amperes (A).

Water flows through a hose when pressure is exerted upon it and a valve is opened. Water pressure is measured in pounds per square inch (psi). An electrical current flows along an electrical conductor when electrical pressure is applied to it and a path is provided for the current flow. Just as the pounds per square inch (pressure) cause gallons per minute to flow, so the volts (pressure) cause amperes (current) to flow. It takes more pressure to force the same amount of water through a small hose than through a larger hose. A small hose, with the same pressure applied to it in comparison to a larger hose, will pass much less water in a given period. It therefore follows that the small hose offers a greater resistance to the flow of water.

In an electric circuit, a greater electrical pressure (volts) will force a given amount of current (amperes) through a small conductor (resistance) than that required to force the same amount of current (amperes) through a larger conductor (resistance). A smaller-sized conductor will allow less current (amperes) to pass than a larger-sized conductor will if the...
same electrical pressure (volts) is applied to each conductor for the same period. The smaller conductor can only be assumed to offer greater resistance (ohms) than the larger conductor. Thus, we may define resistance as the “property of a body that resists or limits the flow of electricity through it.” Resistance is measured in ohms—a term similar to friction in a hose or pipe.

**Theory Terms and Definitions**

The following definitions relate to basic electrical theory. It is important that installers and inspectors have a working knowledge of electrical theory. Such knowledge is often vital in determining proper size of conductors for circuits of various loads.

**Volt** — the unit of electrical pressure — is the pressure required to force one ampere through a resistance of one ohm; abbreviated as “E,” the first letter of the term electromotive force.

**Ampere** is the unit of electrical current that will flow through one ohm under a pressure of one volt in one second; abbreviated as “I,” the first letter of the term intensity of current.

**Ohm** — the unit of electrical resistance — is the resistance through which one volt will force one ampere; abbreviated as “R,” the first letter of the term resistance.

**Watts** is the unit of measurement of the energy flowing in an electrical circuit at any given moment. It is also the amount of work being performed in the electrical circuit. The terms watts or kilowatt have been used more commonly to express the amount of work done in the electrical circuit rather than the term joule. Watts is the product of multiplying volts and amperes and is sometimes referred to as volt-amperes. One thousand volt-amperes are referred to as one kilovolt-ampere or one kVA.

**Ohm’s Law**

George Simon Ohm discovered the relationship between current, voltage, and resistance in an electric circuit in 1826. He found, by experiment, that pressure equaled the product of current and resistance; this relationship is referred to as Ohm’s law. This law is the practical basis on which most electrical calculations are determined. The formula may be expressed in various forms and by its use, as in the three examples shown in figure 1.5.

If any two values are known, the third can be found by use of the formula. For example, if the resistance and the voltage are known, the current can be determined by dividing the voltage by the resistance. This can be valuable in determining the amount of current that will flow in the circuit to properly size conductors as well as overcurrent devices.

**Watts Wheel**

The Watts wheel has been developed and published in many manuals and in several variations to illustrate watts or power and its relationship to the elements of Ohm’s law. As shown in this text, it is accurate for dc circuits and for resistive loads of ac circuits where the power factor is near 100 percent or unity (see figure 1.4). Do not attempt to use it for motor loads, as both power factor and motor efficiency must be factored into the formula (see figure 1.6). In ac circuits, we use the term impedance rather than ohms to represent resistance of the circuit. Impedance is the total opposition to current flow in an ac circuit; it is measured in ohms. Impedance includes resistance, capacitive reac-
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... and inductive reactance. The last two factors are unique to ac circuits and can usually be ignored in circuits such as incandescent lighting loads and heater circuits consisting of resistive loads. A detailed explanation of capacitive reactance and inductive reactance is beyond the scope of this text but can be found in many excellent texts on electrical theory.

Definitions and Trade Terminology

The NEC and IRC both include some unique definitions that must be clearly understood in order for one to apply the rules, install, and inspect electrical systems and equipment. Each chapter throughout this publication will address applicable definitions found in Article 100 of the NEC or Chapter 35 of the IRC. Some definitions apply to all electrical installations, and others apply only to specific portions of the electrical installation. For example, the definitions specific to swimming pools can be found in Article 680 of the NEC or Chapter 42 of the IRC. Let’s take a closer look at the following definitions of general terms in the Code.

Labeled. “Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is 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, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that the equipment, material, or services either meets appropriate designated standards or has been tested and found suitable for a specified purpose.”

Identified (as applied to equipment) “Recognizable as suitable for the specific purpose, function, use, environment, application, and so forth, where described in a particular Code requirement.”

Equipment. “A general term including material, fittings, devices, appliances, luminaires, apparatus, machinery, and the like used as a part of, or in connection with, an electrical installation.”

In Sight From (Within Sight From, Within Sight). “Where this Code specifies that one equipment shall be “in sight from,” “within sight from,” or “within sight of,” and so forth, another equipment, the specified equipment is to be visible and not more than 15 m (50 ft) distant from the other.”

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