Electrical Wiring FAQ (Part 1 of 2)


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Summary: A series of questions and answers about house wiring
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X-Posting-Frequency: Posted every 14 days
X-Content-Currency: This FAQ hasn't been updated in a number of years,
        and is somewhat out of date with the last revision or two of the NEC
        and CEC.  We anticipate this will be changing soon.

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Updated: WARNING

This FAQ has not been updated or posted in a number of years.  It
is intended that it will be updated to bring it more into compliance
with current code.  Comments welcome at wirefaq(@)ferret.ocunix.on.ca

            Frequently Asked Questions on Electrical Wiring

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            Comments to: wirefaq@ferret.ocunix.on.ca

The latest FAQ can always be obtained from:

    http://www.landfield.com/faqs/electrical-wiring
    ftp://rtfm.mit.edu/pub/usenet/news.answers/electrical-wiring/part1
    ftp://rtfm.mit.edu/pub/usenet/news.answers/electrical-wiring/part2

This FAQ is formatted as a digest.  Most news readers can skip from one
question to the next by pressing ^G.

Answers to many other topics related to houses can be obtained from the
misc.consumers.house archive; send an empty piece of mail to
house-archive@dg-rtp.dg.com for information.
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Changes to previous issue marked with "|" in left column.  Watch
particularly for "NEW" in the Questions list for new or substantively
changed answers.  "g^|" will get you to the changed sections quickly in
most newsreaders.
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Subject: Questions answered in this FAQ

Subject: Introduction/Disclaimers

Although we've done a fair bit of wiring, we are not electricians, and we cannot be responsible for what you do. If you're at all uncertain about what is correct or safe, *don't do it*. Contact someone qualified -- a licensed electrician, or your local electrical inspector. Electricity is no joke; mistakes can result in shocks, fires, or electrocution.

Furthermore, our discussion is based on the U.S. National Electrical Code (NEC) and the Canadian Electrical code (CEC). To the best of our abilities, we have confirmed every detail with the electrical code, but we don't quote sections simply to keep this thing readable. If you think we're wrong, we invite you to correct us, but please - quote references!

The NEC and the CEC do not, in and of themselves, have the force of law. Many municipalities adopt it en toto. Others, however, do not. Check your with your local building department (and <provincial> Hydro Inspection Offices in Canada) to find out what applies in your area. Also, your local electrical utility may also have special requirements for electrical service installation. Bear in mind, too, that we say here applies primarily to ordinary single-family residences. Multi-family dwellings, mobile homes, commercial establishments, etc., are sometimes governed by different rules.

Also note that, contrary to popular belief in the U.S. (and in some parts of Canada), Canada is not a wholly-owned subsidiary of the U.S. Consequently, the NEC does not apply in Canada. Lots of things are the same, including voltages, line frequencies, and the laws of physics. But there are a number of crucial differences in the regulations. Where we can, we've noted them, flagging the relevant passages with ``NEC'' or ``CEC''.

Remember that the CEC and NEC are minimal standards. It is often smart to go beyond their minimal requirements.

Subject: What is the NEC? Where can I get a copy?

The NEC is a model electrical code devised and published by the National Fire Protection Association, an insurance industry group. It's revised every three years. The 1993 version has been released. You can buy a copy at a decent bookstore, or by calling them directly at 800-344-3555. The code exists in several versions. There's the full text, which is fairly incomprehensible. There's an abridged edition, which has only the sections likely to apply to most houses. And there's the NEC Handbook, which contains the ``authorized commentary'' on the code, as well as the full text. That's the recommended version. Unfortunately, there's no handbook for the abridged edition. And the full handbook is expensive -- US$65 plus shipping and handling.

Subject: What is the CEC? Where can I get a copy?

The Canadian Standards Association is an organization made up of various government agencies, power utilities, insurance companies, electrical manufacturers and other organizations. The CSA publishes CSA Standard C22.1 which is updated every two or three years. Each province adopts, with some amendments, this standard and publishes a province-specific code book. Since each province publishes its own slightly modified standard, it would be somewhat confusing to obtain the CSA standard itself. In this FAQ, "CEC" really means the appropriate provincial standard. In particular, this FAQ is derived from the Ontario Hydro Electrical Safety Code, 20th edition (1990). Which is in turn based on CSA C22.1-1990 (16th edition). While differences exist between the provinces, an attempt has been made to avoid specific-to-Ontario detail.

The appropriate provincial code can be obtained from electrical inspection offices of your provincial power authority. In Ontario, it's Ontario Hydro. The Ontario Hydro book isn't overly fat. It's about C$25, and includes mailed updates. I hear that these standards are somewhat easier to read than the equivalent NEC publications.

Don't bother asking in Quebec - DIY wiring is banned throughout the province.

Subject: Can I do my own wiring? Extra pointers?

In most places, homeowners are allowed to do their own wiring. In some, they're not. Check with your local electrical inspector. Most places won't permit you to do wiring on other's homes for money without a license. Nor are you permitted to do wiring in "commercial" buildings. Multiple dwellings (eg: duplexes) are usually considered "semi-commercial" or "commercial". However, many jurisdictions will permit you to work on semi-commercial wiring if you're supervised by a licensed electrician - if you can find one willing to supervise.

If you do your own wiring, an important point:

Do it NEAT and WELL! What you really want to aim for is a better job than an electrician will do. After all, it's your own home, and it's you or your family that might get killed if you make a mistake. An electrician has time pressures, has the skills and knows the tricks of the trade to do a fast, safe job. In this FAQ we've consciously given a few recommendations that are in excess of code, because we feel that it's reasonable, and will impress the inspector.

The inspector will know that you're an amateur. You have to earn his trust. The best way of doing this is to spend your time doing as neat a job as possible. Don't cut corners. Exceed specifications. Otherwise, the inspector may get extremely picky and fault you on the slightest transgressions.

Don't try to hide anything from the inspector.

Use the proper tools. Ie: don't use a bread knife to strip wires, or twist wires with your fingers. The inspector won't like it, and the results won't be that safe. And it takes longer. And you're more likely to stick a hunk of 12ga wire through your hand that way.

Don't handle house wire when it's very cold (eg: below -10C or 16F). Thermoplastic house wire, particularly older types become very brittle.

Subject: What do I need in the way of tools?

First, there's the obvious -- a hammer, a drill, a few screwdrivers, both straight and Phillips-head. If you're lucky enough to live in Canada (or find a source of CSA-approved devices) you need Robertson ("square recess") screwdrivers (#1 and #2) instead of phillips.

For drilling a few holes, a 3/4" or 1" spade bit and 1/4" or 3/8" electric drill will do. If you're doing a lot, or are working with elderly lumber, we recommend a 1/2" drill (right-angle drills are wonderful. Can be rented) and 3/4" or 1" screw-point auger drill bits. These bits pull you through, so they're much faster and less fatiguing, even in 90 year old hardwood timbers.

Screw-driver bits are useful for drills, expecially if you install your electrical boxes using screws (drywall screws work well).

For stripping wire, use a real wire stripper, not a knife or ordinary wire cutters. Don't buy the $3 K-mart "combo stripper, crimper and bottle opener" types. You should expect to pay $15 to $20 for a good "plier-type" pair. It will have sized stripping holes, and won't nick or grab the wire - it should be easy to strip wire with it. One model has a small hole in the blade for forming exact wire loops for screw terminals. There are fancier types (autostrip/cut), but they generally aren't necessary, and pros usually don't use them.

A pair of diagonal side cutter pliers are useful for clipping ends in constricted places. Don't use these for stripping wire.

You will need linesman pliers for twisting wires for wire connectors.

You should have a pair of needle-nose pliers for fiddling inside boxes and closing loops, but it's better to form wire loops with a "loop former hole" on your wire stripper - more accurate.

If you're using non-metallic cable, get a cable stripper for removing the sheath. Or, do what some pros do, they nick the end of the sheath, grab the ground wire with a pair of pliers, and simply rip the sheath back using the ground wire as a "zipper", and cut the sheath off. You shouldn't try to strip the sheath with a knife point, because it's too easy to slash the insulation on the conductors. Apparently Stanley utility knives fitted with linoleum cutters (hooked blades) can be used to strip sheath, but there is still the possibility that you'll gouge the conductors.

For any substantial amount of work with armored cable, it's well worth your while to invest in a rotary cable splitter (~US$ 18). Hack saws are tricky to use without cutting into the wire or the insulation.

Three-prong outlet testers are a quick check for properly-wired outlets. About $6. Multimeters tell you more, but are a lot more expensive, and probably not worth it for most people. A simple voltage sensor, which can detect potential through an insulated wire not supplying any devices, is extremely helpful; they cost about US$ 10 at Radio Shack.

You should have a voltage detector - to check that the wires are dead before doing work on them. Neon-bulb version are cheap ($2-3) and work well. If you get more serious, a "audible alarm" type is good for tracing circuits without a helper. (Though I've been known to lock the drill on, and hit breakers until the scream stops ;-)

For running wires through existing walls, you need fish tape. Often, two tapes are needed, though sometimes, a bent hanger or a length of thin chain will suffice. Fish tapes can be rented.

Electrical tape. Lots of it ;-) Seriously, a good and competent wiring job will need very little tape. The tape is useful for wrapping dicy insulation in repair work. Another use is to wrap around the body of outlets and switches to cover the termination screws - I don't do this, but drywall contractors prefer it (to prevent explosions when the drywall knife collides with a live outlet that has no cover plate).

Subject: What is UL listing?

The UL stands for "Underwriters Laboratory". It used to be an Insurance Industry organization, but now it is independent and non-profit. It tests electrical components and equipment for potential hazards. When something is UL-listed, that means that the UL has tested the device, and it meets their requirements for safety - ie: fire or shock hazard. It doesn't necessarily mean that the device actually does what it's supposed to, just that it probably won't kill you.

The UL does not have power of law in the U.S. -- you are permitted to buy and install non-UL-listed devices. However, insurance policies sometimes have clauses in them that will limit their liability in case of a claim made in response to the failure of a non-UL-listed device. Furthermore, in many situations the NEC will require that a wiring component used for a specific purpose is UL-listed for that purpose. Indirectly, this means that certain parts of your wiring must be UL-listed before an inspector will approve it and/or occupancy permits issued.

Subject: What is CSA approval?

Every electrical device or component must be certified by the Canadian Standards Association (or recognized equivalent) before it can be sold in Canada. Implicit in this is that all wiring must be done with CSA-approved materials. They perform testing similar to the UL (a bit more stringent), except that CSA (or recognized equivalent) approval is required by law.

Again, like the UL, if a fire was caused by non-CSA-approved equipment, your insurance company may not have to pay the claim.

Note: strictly speaking, there usually is a legal way around the lack of a CSA sticker. In some cases (eg: Ontario), a local hydro inspection prior to purchase, or prior to use, is acceptable. The hydro inspector will affix a "hydro sticker" to the unit, which is as good as CSA approval. But it costs money - last I knew, $75 per unit inspected.

ULC (Underwriters Laboratory of Canada) is an independent organization that, amongst other things, undertakes the quarterly inspection of manufacturer's to ensure continued compliance of UL Listed/Recognized products to Agency reports and safety standards. This work is done under contract to UL Inc (Follow-up Services Division). They are not a branch or subsidiary of UL.

Subject: What impact does NAFTA have on wiring standards and approvals?

The North America Free Trade Agreement came into effect on January 1st, 1994. NAFTA attempts to bring down trade barriers between Mexico, Canada and the USA. One of the "barriers" has been that of approval of material. As of January first, CSA approval of a device is legally considered equivalent to UL approval in the USA. Conversely, UL is now accepted as equivalent to CSA approval in Canada. Theoretically, this means that devices marked only with UL approval are acceptable in the CEC, and conversely CSA approval by itself of a device is accepted by the NEC. This allows much freer trade in electrical materials between the two countries.

This doesn't affect the electrical codes themselves, so the differences in practice between the NEC and CEC will remain. It is also my understanding that bilateral acceptance of "approval" will only apply when the standards applied are reasonably the same. As an example, a cable approved by the NEC for a given purpose may not be acceptable by the CEC for the same purpose if the standards requirements are different. Eg: "NMD" ("non-metallic, damp") cable is usually required for residences in Canada. "NM" cable ("non-metallic, not damp locations) which is used in the same situations in the US, would probably not be acceptable in Canada. Also, municipalities can add additional requirements on top of the CEC, as they can in the US over the NEC.

Thus, Canadians will probably start seeing UL-only approved materials in stores, and Americans the same regarding CSA-only. But some differences will remain. When in doubt on major items, consult an inspector. At least in Canada, the fact that the material is available in a store usually means that it's okay to install.

Subject: Are there any cheaper, easier to read books on wiring?

USA: The following three books were suggested by our readers

Residential Wiring
by Jeff Markell,
Craftsman Books,
Carlsbad CA for $18.25. ISBN 0-934041-19-9.

Practical Electrical Wiring
Residential, Farm and Industrial, Based on the National

Electrical Code ANSI/NFPA 70
Herbert P. Richter and W. Creighton Schwan
McGraw-Hill Book Co.

Wiring Simplified
H. P. Richter and W. C. Schwan
Park Publishing Co.

The Electrician's Toolbox Manual
Rex Miller
Prentice Hall (ARCO) 1989
ISBN 0-13-247701-7 $11.00

Try to make sure that the book is based on the latest NEC revision. Which is currently 1993.

Canada: P.S. Knight authors and publishes a book called "Electrical Code Simplified". There appears to be a version published specific to each province, and is very tied into the appropriate provincial code. It focuses on residential wiring, and is indispensible for Canadian DIY'ers. It is better to get this book than the CEC unless you do a lot of wiring (or answer questions on the net ;-).

It is updated each time the provincial codes are. This book is available at all DIY and hardware stores for less than C$10.

Subject: Other Resources on Wiring

http://homewiring.tripod.com is a truly excellent site. It contains a fairly wide range of very detailed information. If you need pictures on how to do common things (like 3 or 4 way switches, ceiling fan installation etc), this is a great place to go. It doesn't cover as broad variety of things as this FAQ, but it's much more detailed, and more up to date in some areas.

It's particularly good for figuring out the wiring of complicated switch arrangements.

Note that this site is 1999 NEC specific. Which means that if you're not in the USA, you will have to be very careful about taking the rules as gospel. For example, the section on kitchens is entirely wrong for Canada.

Subject: Inspections how and what? Why should I get my wiring inspected?

Most jurisdictions require that you obtain a permit and inspections of any wiring that is done. Amongst other more mundane bureaucratic reasons (like insurance companies not liking to have to pay claims), a permit and inspections provides some assurance that you, your family, your neighbors or subsequent owners of your home don't get killed or lose their homes one night due to a sloppy wiring job.

Most jurisdictions have the power to order you to vacate your home, or order you to tear out any wiring done without a permit. California, for instance, is particularly nasty about this.

If fire starts in your home, and un-inspected wiring is at fault, insurance companies will often refuse to pay the damage claims.

In general, the process goes like this:

- you apply to your local inspections office or building department for a permit. You should have a sketch or detailed drawing of what you plan on doing. This is a good time to ask questions on any things you're not sure of. If you're doing major work, they may impose special conditions on you, require loading calculations and ask other questions. At this point they will tell you which inspections you will need.
- If you're installing a main panel, you will need to have the panel and service connections inspected before your power utility will provide a connection. This is sometimes done by the local power authority rather than the usual inspectors.
- After installing the boxes and wiring, but before the insulation/walls go up, you will need a "rough-in" inspection.
- After the walls are up, and the wiring is complete, you will need a "final inspection".

Subject: My house doesn't meet some of these rules and regulations. Do I have to upgrade?

In general, there is no requirement to upgrade older dwellings, though there are some exceptions (ie: smoke detectors in some cases). However, any new work must be done according to the latest electrical code. Also, if you do ``major'' work, you may be required to upgrade certain existing portions or all of your system. Check with your local electrical inspector.

Subject: A word on voltages: 110/115/117/120/125/220/240

One thing where things might get a bit confusing is the different numbers people bandy about for the voltage of a circuit. One person might talk about 110V, another 117V or another 120V. These are all, in fact, exactly the same thing... In North America the utility companies are required to supply a split-phase 240 volt (+-5%) feed to your house. This works out as two 120V +- 5% legs. Additionally, since there are resistive voltage drops in the house wiring, it's not unreasonable to find 120V has dropped to 110V or 240V has dropped to 220V by the time the power reaches a wall outlet. Especially at the end of an extension cord or long circuit run. For a number of reasons, some historical, some simple personal orneryness, different people choose to call them by slightly different numbers. This FAQ has chosen to be consistent with calling them "110V" and "220V", except when actually saying what the measured voltage will be. Confusing? A bit. Just ignore it.

One thing that might make this a little more understandable is that the nameplates on equipment ofen show the lower (ie: 110V instead of 120V) value. What this implies is that the device is designed to operate properly when the voltage drops that low.

208V is *not* the same as 240V. 208V is the voltage between phases of a 3-phase "Y" circuit that is 120V from neutral to any hot. 480V is the voltage between phases of a 3-phase "Y" circuit that's 277V from hot to neutral.

In keeping with 110V versus 120V strangeness, motors intended to run on 480V three phase are often labelled as 440V...

Subject: What does an electrical service look like?

There are logically four wires involved with supplying the main panel with power. Three of them will come from the utility pole, and a fourth (bare) wire comes from elsewhere.

The bare wire is connected to one or more long metal bars pounded into the ground, or to a wire buried in the foundation, or sometimes to the water supply pipe (has to be metal, continuous to where the main water pipe entering the house. Watch out for galvanic action conductivity "breaks" (often between copper and iron pipe). This is the "grounding conductor". It is there to make sure that the third prong on your outlets is connected to ground. This wire normally carries no current.

One of the other wires will be white (or black with white or yellow stripes, or sometimes simply black). It is the neutral wire. It is connected to the "centre tap" (CEC; "center tap" in the NEC ;-) of the distribution transformer supplying the power. It is connected to the grounding conductor in only one place (often inside the panel). The neutral and ground should not be connected anywhere else. Otherwise, weird and/or dangerous things may happen.

Furthermore, there should only be one grounding system in a home. Some codes require more than one grounding electrode. These will be connected together, or connected to the neutral at a common point - still one grounding system. Adding additional grounding electrodes connected to other portions of the house wiring is unsafe and contrary to code.

If you add a subpanel, the ground and neutral are usually brought as separate conductors from the main panel, and are not connected together in the subpanel (ie: still only one neutral-ground connection). However, in some situations (certain categories of separate buildings) you actually do have to provide a second grounding electrode - consult your inspector.

The other two wires will usually be black, and are the "hot" wires. They are attached to the distribution transformer as well.

The two black wires are 180 degrees out of phase with each other. This means if you connect something to both hot wires, the voltage will be 220 volts. If you connect something to the white and either of the two blacks you will get 110V.

Some panels seem to only have three wires coming into them. This is either because the neutral and ground are connected together at a different point (eg: the meter or pole) and one wire is doing dual-duty as both neutral and ground, or in some rare occasions, the service has only one hot wire (110V only service).

Subject: What is a circuit?

Inside the panel, connections are made to the incoming wires. These connections are then used to supply power to selected portions of the home. There are three different combinations:

1) one hot, one neutral, and ground: 110V circuit.
2) two hots, no neutral, and ground: 220V circuit.
3) two hots, neutral, and ground: 220V circuit + neutral, and/or two 110V circuits with a common neutral.

(1) is used for most circuits supplying receptacles and lighting within your house. (3) is usually used for supplying power to major appliances such as stoves, and dryers - they often have need for both 220V and 110V, or for bringing several circuits from the panel box to a distribution point. (2) is usually for special 220V motor circuits, electric heaters, or air conditioners.

[Important Note: In the US, the NEC used to permit a circuit similar to (2) be used for stoves and dryers - namely, three conductor wiring, with a ground wire doing dual duty as a neutral. As of the 1996 revision to the NEC, this is NO LONGER PERMITTED.]

(1) is usually wired with three conductor wire: black for hot, white for neutral, and bare for grounding.

(2) and (3) have one hot wire coloured red, the other black, a bare wire for grounding, and in (3) a white wire for neutral.

You will sometimes see (2) wired with just a black, white and ground wire. Since the white is "hot" in this case, both the NEC and CEC requires that the white wire be "permanently marked" at the ends to indicate that it is a live wire. Usually done with paint, nail polish or sometimes electrical tape.

Each circuit is attached to the main wires coming into the panel through a circuit breaker or fuse.

There are, in a few locales, circuits that look like (1), (2) or (3) except that they have two bare ground wires. Some places require this for hot tubs and the like (one ground is "frame ground", the other attaches to the motor). This may or may not be an alternative to GFCI protection.

Subject: "grounding" versus "grounded" versus "neutral".

According to the terminology in the CEC and NEC, the "grounding" conductor is for the safety ground, i.e., the green or bare or green with a yellow stripe wire. The word "neutral" is reserved for the white when you have a circuit with more than one "hot" wire. Since the white wire is connected to neutral and the grounding conductor inside the panel, the proper term is "grounded conductor". However, the potential confusion between "grounded conductor" and "grounding conductor" can lead to potentially lethal mistakes - you should never use the bare wire as a "grounded conductor" or white wire as the "grounding conductor", even though they are connected together in the panel.

[But not in subpanels - subpanels are fed neutral and ground separately from the main panel. Usually.]

Note: do not tape, colour or substitute other colour wires for the safety grounding conductor.

In the trade, and in common usage, the word "neutral" is used for "grounded conductor". This FAQ uses "neutral" simply to avoid potential confusion. We recommend that you use "neutral" too. Thus the white wire is always (except in some light switch applications) neutral. Not ground.

Subject: What does a fuse or breaker do? What are the differences?

Fuses and circuit breakers are designed to interrupt the power to a circuit when the current flow exceeds safe levels. For example, if your toaster shorts out, a fuse or breaker should "trip", protecting the wiring in the walls from melting. As such, fuses and breakers are primarily intended to protect the wiring -- UL or CSA approval supposedly indicates that the equipment itself won't cause a fire.

Fuses contain a narrow strip of metal which is designed to melt (safely) when the current exceeds the rated value, thereby interrupting the power to the circuit. Fuses trip relatively fast. Which can sometimes be a problem with motors which have large startup current surges. For motor circuits, you can use a "time-delay" fuse (one brand is "fusetron") which will avoid tripping on momentary overloads. A fusetron looks like a spring-loaded fuse. A fuse can only trip once, then it must be replaced.

Breakers are fairly complicated mechanical devices. They usually consist of one spring loaded contact which is latched into position against another contact. When the current flow through the device exceeds the rated value, a bimetallic strip heats up and bends. By bending it "trips" the latch, and the spring pulls the contacts apart. Circuit breakers behave similarly to fusetrons - that is, they tend to take longer to trip at moderate overloads than ordinary fuses. With high overloads, they trip quickly. Breakers can be reset a finite number of times - each time they trip, or are thrown when the circuit is in use, some arcing takes place, which damages the contacts. Thus, breakers should not be used in place of switches unless they are specially listed for the purpose.

Neither fuses nor breakers "limit" the current per se. A dead short on a circuit can cause hundreds or sometimes even thousands of amperes to flow for a short period of time, which can often cause severe damage.

Subject: Breakers? Can't I use fuses?

Statistics show that fuse panels have a significantly higher risk of causing a fire than breaker panels. This is usually due to the fuse being loosely screwed in, or the contacts corroding and heating up over time, or the wrong size fuse being installed, or the proverbial "replace the fuse with a penny" trick.

Since breakers are more permanently installed, and have better connection mechanisms, the risk of fire is considerably less.

Fuses are prone to explode under extremely high overload. When a fuse explodes, the metallic vapor cloud becomes a conducting path. Result? From complete meltdown of the electrical panel, melted service wiring, through fires in the electrical distribution transformer and having your house burn down. [This author has seen it happen.] Breakers won't do this.

Many jurisdictions, particularly in Canada, no longer permit fuse panels in new installations. The NEC does permit new fuse panels in some rare circumstances (requiring the special inserts to "key" the fuseholder to specific size fuses)

Some devices, notably certain large air conditioners, require fuse protection in addition to the breaker at the panel. The fuse is there to protect the motor windings from overload. Check the labeling on the unit. This is usually only on large permanently installed motors. The installation instructions will tell you if you need one.

Subject: What size wire should I use?

For a 20 amp circuit, use 12 gauge wire. For a 15 amp circuit, you can use 14 gauge wire (in most locales). For a long run, though, you should use the next larger size wire, to avoid voltage drops. 12 gauge is only slightly more expensive than 14 gauge, though it's stiffer and harder to work with.

Here's a quick table for normal situations. Go up a size for more than 100 foot runs, when the cable is in conduit, or ganged with other wires in a place where they can't dissipate heat easily:

Gauge	Amps
14	15
12	20
10	30
8	40
6	65

We don't list bigger sizes because it starts getting very dependent on the application and precise wire type.

Subject: Where do these numbers come from?

There are two considerations, voltage drop and heat buildup. The smaller the wire is, the higher the resistance is. When the resistance is higher, the wire heats up more, and there is more voltage drop in the wiring. The former is why you need higher-temperature insulation and/or bigger wires for use in conduit; the latter is why you should use larger wire for long runs.

Neither effect is very significant over very short distances. There are some very specific exceptions, where use of smaller wire is allowed. The obvious one is the line cord on most lamps. Don't try this unless you're certain that your use fits one of those exceptions; you can never go wrong by using larger wire.

Subject: What does "14-2" mean?

This is used to describe the size and quantity of conductors in a cable. The first number specifies the gauge. The second the number of current carrying conductors in the wire - but remember there's usually an extra ground wire. "14-2" means 14 gauge, two insulated current carrying wires, plus bare ground.

-2 wire usually has a black, white and bare ground wire. Sometimes the white is red instead for 220V circuits without neutral. In the latter case, the sheath is usually red too.

-3 wire usually has a black, red, white and bare ground wire. Usually carrying 220V with neutral.

Subject: What is a "wire-nut"/"marrette"/"marr connector"? How are they used?

A twist-on wire connector is a cone shaped threaded plastic thingummy that's used to connect wires together. "Marrette", "Marr connector", "IDEAL Wire-nut(R)" are trade names. You'll usually use a lot of them in DIY wiring.

In essence, you strip the end of the wires about an inch, twist them together, then twist the connector on.

While some connectors advertise that you don't need to twist the wire, do it anyways - it's more mechanically and electrically secure. Unless the instructions specifically state otherwise...

There are many different sizes of wire connector. You should check that the connector you're using is the correct size for the quantity and sizes of wire you're connecting together.

Don't just gimble the wires together with a pair of pliers or your fingers. Use a pair of blunt nose ("linesman") pliers, and carefully twist the wires tightly and neatly. Sometimes it's a good idea to trim the resulting end to make sure it goes in the connector properly.

After twisting the connector on, give each wire a tug, and make sure that nothing is loose.

Some people wrap the "open" end of the connector with electrical tape. This is probably not a good idea - the inspector may tear it off during an inspection. It's usually done because a bit of bare wire is exposed outside the connector - instead of taping it, the connection should be redone.

Subject: What is a GFI/GFCI?

A GFCI is a ``ground-fault circuit interrupter''. It measures the current current flowing through the hot wire and the neutral wire. If they differ by more than a few milliamps, the presumption is that current is leaking to ground via some other path. This may be because of a short circuit to the chassis of an appliance, or to the ground lead, or through a person. Any of these situations is hazardous, so the GFCI trips, breaking the circuit.

GFCIs do not protect against all kinds of electric shocks. If, for example, you simultaneously touched the hot and neutral leads of a circuit, and no part of you was grounded, a GFCI wouldn't help. All of the current that passed from the hot lead into you would return via the neutral lead, keeping the GFCI happy.

The two pairs of connections on a GFCI outlet are not symmetric. One is labeled LOAD; the other, LINE. The incoming power feed *must* be connected to the LINE side, or the outlet will not be protected. The LOAD side can be used to protect all devices downstream from it. Thus, a whole string of outlets can be covered by a single GFCI outlet.

Subject: Where should GFCIs be used?

The NEC mandates GFCIs for 110V, 15A or 20A single phase outlets, in bathrooms, kitchen counters within 6' of the sink, wet-bar sinks, roof outlets, garages, unfinished basements or crawl spaces, outdoors, near a pool, or just about anywhere else where you're likely to encounter water or dampness. There are exceptions for inaccessible outlets, those dedicated to appliances ``occupying fixed space'', typically refrigerators and freezers, and for sump pumps and laundry appliances.

The NEC now requires that if your replace an outlet in a location now requiring GFCI, you must install GFCI protection. Note in particular - kitchen and bathroom outlets.

When using the "fixed appliance" rule for avoiding GFCI outlets, single outlet receptacles must be used for single appliances, duplex receptacles may be used for two appliances.

The CEC does not mandate as many GFCIs. In particular, there is no requirement to protect kitchen outlets, or most garage or basement outlets. Basement outlets must be protected if you have a dirt floor, garage outlets if they're near the door to outside. Bathrooms and most exterior outlets must have GFCIs, as do pools systems and jacuzzi or whirlpool pumps.

There are many rules about GFCIs with pools and so on. This is outside of our expertise, so we're not covering it in detail. See your inspector.

When replacing an outlet, it must now be GFCI-protected if such would now be required for a new installation. That is, a kitchen outlet installed per the 1984 code need not have been protected, but if that outlet is ever replaced, GFCI protection must now be added (under NEC). This is explicit in the 1993 NEC, and inspector-imposed in Canada.

Even if you are not required to have GFCI protection, you may want to consider installing it anyway. Unless you need a GFCI breaker (see below), the cost is low. In the U.S., GFCI outlets can cost as little as US$8. (Costs are a bit higher in Canada: C$12.) Evaluate your own risk factors. Does your finished basement ever get wet? Do you have small children? Do you use your garage outlets to power outdoor tools? Does water or melted snow ever puddle inside your garage?

Subject: Where shouldn't I use a GFCI?

GFCIs are generally not used on circuits that (a) don't pose a safety risk, and (b) are used to power equipment that must run unattended for long periods of time. Refrigerators, freezers, and sump pumps are good examples. The rationale is that GFCIs are sometimes prone to nuisance trips. Some people claim that the inductive delay in motor windings can cause a momentary current imbalance, tripping the GFCI. Note, though, that most GFCI trips are real; if you're getting a lot of trips for no apparent reason, you'd be well-advised to check your wiring before deciding that the GFCI is broken or useless.

Subject: What is the difference between a GFCI outlet and a GFCI breaker?

For most situations, you can use either a GFCI outlet as the first device on the circuit, or you can install a breaker with a built-in GFCI. The former is generally preferred, since GFCI breakers are quite expensive. For example, an ordinary GE breaker costs ~US$5; the GFCI model costs ~US$35. There is one major exception: if you need to protect a ``multi-wire branch circuit'' (two or more circuits sharing a common neutral wire), such as a Canadian-style kitchen circuit, you'll need a multi-pole GFCI breaker. Unfortunately, these are expensive; the cost can range into the hundreds of dollars, depending on what brand of panel box you have. But if you must protect such a circuit (say, for a pool heater), you have no choice.

One more caveat -- GFCI outlets are bulky. You may want to use an oversize box when installing them. On second thought, use large (actually deep) boxes everywhere. You'll thank yourself for it.

Incidentally, if you're installing a GFCI to ensure that one specific outlet is protected (such as a bathroom), you don't really have to go to all of the trouble to find the first outlet in the circuit, you could simply find the first outlet in the bathroom, and not GFCI anything upstream of it. But protecting the whole circuit is preferred.

When you install a GFCI, it's a good idea to use the little "ground fault protected" stickers that come with it and mark the outlets downstream of the GFCI. You can figure out which outlets are "downstream", simply by tripping the GFCI with the test button and see which outlets are dead.

Note that the labels are mandatory for GFCI-protected-but-ungrounded three prong outlets according to the NEC.

Subject: What's the purpose of the ground prong on an outlet, then?

Apart from their use in electronics, which we won't comment on, and for certain fluorescent lights (they won't turn on without a good ground connection), they're intended to guard against insulation failures within the device. Generally, the case of the appliance is connected to the ground lead. If there's an insulation failure that shorts the hot lead to the case, the ground lead conducts the electricity away safely (and possibly trips the circuit breaker in the process). If the case is not grounded and such a short occurs, the case is live -- and if you touch it while you're grounded, you'll get zapped. Of course, if the circuit is GFCI-protected, it will be a very tiny zap -- which is why you can use GFCIs to replace ungrounded outlets (both NEC and CEC).

There are some appliances that should *never* be grounded. In particular, that applies to toasters and anything else with exposed conductors. Consider: if you touch the heating electrode in a toaster, and you're not grounded, nothing will happen. If you're slightly grounded, you'll get a small shock; the resistance will be too high. But if the case were grounded, and you were holding it, you'd be the perfect path to ground...

Subject: Grounding electrode system

Note that full coverage of how to install a grounding electrode system is well beyond the scope of this FAQ. The comments made here are primarily so that the reader understands what it is for, and some of its characteristics.

The grounding electrode system is a method by which the neutral and grounding conductors are connected to the common "earth" reference. The connection from the electrical system to the grounding system is made in only one place to avoid ground loops.

The grounding electrode system is _not_ intended to carry much current. Ground faults (Ie: hot to grounded case short) are conducted down the ground wire to where it is interconnected with the neutral and hopefully the breaker/fuse trips. The grounding electrode does not participate in such a situation. While the conductors involved in this are relatively large, they're sized for lightning strikes and other extremely short duration events. The grounding electrode system is specifically _not_ expected to have enough conductivity to trip a 15A breaker.

The grounding electrode often has a moderately high resistance. For example, according to the NEC, an acceptable ground electrode system may have 25 ohms of resistance - only 5A at 120V, not enough to trip a 15A breaker.

A grounding electrode system usually consists of a primary grounding electrode, plus possibly a secondary electrode. A primary electrode can be (if in direct contact with the earth): 10' of ground rod. 10' of well casing or metallic water pipe (must be connected within 5' of pipe entrance to house). 20' of copper wire buried in the bottom of the footings. A secondary electrode will be required if the primary is a water pipe or (NEC) if the primary electrode is >25 ohms to the dirt.

Subject: Bonding requirements

All "metallic systems" in a home that are capable of being energized are required to be bonded to the grounding system. This is usually taken to mean: metallic water supply, metallic drain-waste-vent pipe, metal ducting, gas lines, and sometimes metallic structural elements (eg: metal framing systems).

The rationale for this is simple: if somehow a hot conductor contacts a water pipe, say, you don't want every plumbing fixture in your home to become live. The bonding attempts to ensure that you have a low resistance path to the ground system at the panel, and thence to the neutral - ensuring that this ground fault is stopped by a breaker or fuse tripping. Remember that this is independent of the grounding electrode system's conductivity.

Normally the bonding of most of these systems are done by the equipment involved. Furnace ducting is grounded by the furnace connection. Gas line grounding is done by the gas man ;-) So we'll mainly talk about water line grounding here.

The NEC appears to insist that each electrically isolated section of metallic water pipe must be jumpered together. Take particular note that you are required to provide a jumper wire that bypasses the main water meter (especially if you're using the water supply line as a grounding electrode), and a jumper between hot and cold if the water heater is an electrical insulator. The CEC, for example, also requires that the frame of your clothes washer is bonded to the cold water supply pipe.

Exact details of how this bonding should be done is beyond the scope of this FAQ. It tends to be a 6ga wire running from the grounding terminal of the panel to a convenient copper pipe. If the water supply is used as a grounding electrode, the rules become stricter (5' rule applies in NEC etc.)

Subject: Testing grounding conductors and grounding electrodes.

Testing grounds is a tricky and somewhat dangerous process. Testing for continuity is not enough. Nor is simple resistance testing. We will outline some possible approaches, but if you're the slightest bit uncomfortable, don't even think of trying these procedures.

For a ground conductor to be good, the resistance must be "low". It must also be robust enough to withstand an overload long enough to allow the fuse or breaker to trip. The electrical code states, as a general principle, that the resistance of the grounding conductor be such that 4-5 times the current of the breaker rating will flow. For example, if your breaker is 15A, the grounding conductor's resistance should be low enough to permit 60-75A to flow - around 2 ohms maximum at 120V. For comparative purposes, 1000' of 14ga wire is 2.5 ohms.

The difficulty in older homes is that the grounding conductor's condition may be that even though the resistance is < 2 ohms, a ground connection may blow out before the fuse/breaker goes, leaving the case of the appliance that just shorted out live.

Therefore, you have to measure both the resistance and it's ability to stand up to load.

One simple way to perform a "real" test is dead short the hot to ground and see if the fuse or breaker trips. This is, unfortunately, _extremely_ dangerous. The fuse might explode. The breaker may malfunction. You may get sprayed with molten copper. You may start a fire. You may get electrocuted or blinded. So don't even think of trying this.

One moderately safe approach is to connect a 100W lightbulb between hot and the ground you wish to test. The lamp should light fully. If you have a voltmeter, test the voltage between the ground and the neutral. You should see less than 2 volts. If the voltage is much higher, or the lamp dims, disconnect it quickly - the ground may be overheating somewhere. The ground should be checked for poor connections.

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Testing a grounding electrode is a somewhat different matter.
The codes aim for a dirt-to-electrode resistance of 25 ohms or
better.  One moderately safe way is:

        - turn off the main panel
        - turn off all of the breakers
        - disconnect the grounding electrode from the rest of
          the system.  (often just a bolt in the panel)
        - connect a 5A fuse between the output of one 15A breaker
          and the grounding electrode.  (use a 5A automotive fuse
          in a pigtail holder)
        - turn on the main breaker and the single breaker connected
          to the 5A fuse.
        - if the 5A fuse blows, your ground is good.
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Subject: Why is one prong wider than the other? Polarization

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Nowadays, many two-prong devices have one prong wider than the
other.  This is so that the device could rely (not guaranteed!)
on one specific wire being neutral, and the other hot.
This is particularly advantageous in light fixtures, where the
the shell should neutral (safety), or other devices which want to
have an approximate ground reference (ie: some radios).

Most 2-prong extension cords have wide prongs too.

This requires that you wire your outlets and plugs the right
way around.  You want the wide prong to be neutral, and the
narrow one hot.  Most outlets have a darker metal for the
hot screw, and lighter coloured screw for the neutral.
If not, you can usually figure out which is which by which
prong the terminating screw connects to.
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Subject: How do I convert two prong receptacles to three prong?

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Older homes frequently have two-prong receptacles instead
of the more modern three.  These receptacles have no safety
ground, and the cabling usually has no ground wire.  Neither
the NEC or CEC permits installing new 2 prong receptacles anymore.

There are several different approaches to solving this:
    1) If the wiring is done through conduit or BX, and the
       conduit is continuous back to the panel, you can connect
       the third prong of a new receptacle to the receptacle
       box.  NEC mainly - CEC frowns on this practice.
    2) If there is a metallic cold water pipe going nearby, and
       it's electrically continuous to the main house ground
       point, you can run a conductor to it from the third
       prong.  You MUST NOT assume that the pipe is continuous,
       unless you can visually check the entire length and/or
       test it.  Testing grounds is tricky - see "Testing
       Grounds" section.
    3) Run a ground conductor back to the main panel.
    4) Easiest: install a GFCI receptacle.  The ground lug
       should not be connected to anything, but the GFCI
       protection itself will serve instead.  The GFCI
       will also protect downstream (possibly also two prong
       outlets).  If you do this to protect downstream outlets,
       the grounds must not be connected together.  Since it
       wouldn't be connected to a real ground, a wiring fault
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could energize the cases of 3 prong devices connected to other outlets. Be sure, though, that there aren't indirect ground plug connections, such as via the sheath on BX cable.

The CEC permits you to replace a two prong receptacle with a three prong if you fill the U ground with a non-conducting goop. Like caulking compound. This is not permitted in the NEC.

The NEC requires that three prong receptacles without ground that are protected by GFCI must be labelled as such.

See the next section about computers on GFCI-protected groundless outlets.

Subject: Surges, spikes, zaps, grounding and your electronics

Theoretically, the power coming into your house is a perfect AC sine wave. It is usually quite close. But occasionally, it won't be. Lightning strikes and other events will affect the power. These usually fall into two general categories: very high voltage spikes (often into 1000s of volts, but usually only a few microseconds in length) or surges (longer duration, but usually much lower voltage).

Most of your electrical equipment, motors, transformer-operated electronics, lights, etc., won't even notice these one-shot events. However, certain types of solid-state electronics, particularly computers with switching power supplies and MOS semiconductors, can be damaged by these occurances. For example, a spike can "punch a hole" through an insulating layer in a MOS device (such as that several hundred dollar 386 CPU), thereby destroying it.

The traditional approach to protecting your electronics is to use "surge suppressors" or "line filters". These are usually devices that you plug in between the outlet and your electronics.

Roughly speaking, surge suppressors work by detecting overvoltages, and shorting them out. Think of them as voltage limiters. Line filters usually use frequency-dependent circuits (inductors, capacitors etc.) to "tune out" undesirable spikes - preventing them from reaching your electronics.

So, you should consider using suppressors or filters on your sensitive equipment.

These devices come in a very wide price range. From a couple of dollars to several hundred. We believe that you can protect your equipment from the vast majority of power problems by selecting devices in the $20-50 range.

A word about grounding: most suppressors and EFI filters require real grounds. Any that don't are next to useless.

For example, most surge suppressors use MOVs (metal oxide varistors) to "clamp" overvoltages. Yes, you can have a suppressor that only has a MOV between neutral and hot to combat differential-mode voltage excursions, but that isn't enough. You need common-mode protection too. Good suppressors should have 3 MOVs, one between each pair of wires. Which means you should have a good solid ground. Eg: a solidly connected 14ga wire back to the panel. Not rusty BX armour or galvanized pipe with condensation turning the copper connection green.

Without a ground, a surge or spike is free to "lift" your entire electronics system well away from ground. Which is ideal for blowing out interface electronics for printer ports etc.

Secondly, static electricity is one of the major enemies of electronics. Having good frame grounds is one way of protecting against static zaps.

If you're in the situation of wanting to install computer equipment on two wire groundless circuits take note:

Adding a GFCI outlet to the circuit makes the circuit safe for you. But it doesn't make it safe for your equipment - you need a ground to make surge suppressors or line filters effective.

Subject: Are you sure about GFCIs and ungrounded outlets?
Should the test button work?

The NEC, section 210-7(d), and CEC, section 26-700(9), are quite explicit that GFCIs are a legal substitute for a grounded outlet in an existing installation where there is no ground available in the outlet box.

But your local codes may vary. As for the TEST button -- there's a resistor connecting the LOAD side of the hot wire to the LINE side of the neutral wire when you press the TEST button. Current through this resistor shows up as an imbalance, and trips the GFCI. This is a simple, passive, and reliable test, and doesn't require a real ground to work. If your GFCI does not trip when you press the TEST button, it is very probably defective or miswired. Again: if the test button doesn't work, something's broken, and potentially dangerous. The problem should be corrected immediately.

The instructions that come with some GFCIs specify that the ground wire must be connected. We do not know why they say this. The causes may be as mundane as an old instruction sheet, or with the formalities of UL or CSA listing -- perhaps the device was never tested without the ground wire being connected. On the other hand, UL or CSA approval should only have been granted if the device behaves properly in *all* listed applications, including ungrounded outlet replacement. (One of us called Leviton; their GFCIs are labeled for installation on grounded circuits only. The technician was surprised to see that; he agreed that the NEC does not require it, and promised to investigate.)

Part1 - Part2 - MultiPage

Related questions and answers

Send corrections/additions to the FAQ Maintainer:
clewis@ferret.ocunix.on.ca (Chris Lewis)

Last Update February 21 2007 @ 02:15 AM

Electrical Wiring FAQ (Part 2 of 2)


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From: clewis@ferret.ocunix.on.ca (Chris Lewis)
Newsgroups: alt.home.repair, misc.consumers.house, rec.woodworking,
sci.electronics.misc
Subject: Electrical Wiring FAQ (Part 2 of 2)
Date: 12 Mar 2004 20:28:01 GMT
Message-ID: <wirefaq-2-1079123277@ferret.ocunix.on.ca>
Reply-To: clewis@ferret.ocunix.on.ca (Chris Lewis)
Summary: A series of questions and answers about house wiring
Keywords: Electrical Wiring FAQ
X-Posting-Frequency: Posted every 14 days
X-Content-Currency: This FAQ hasn't been updated in a number of years,
        and is somewhat out of date with the last revision or two of the NEC
        and CEC.  We anticipate this will be changing soon.

Posted-By: auto-faq 3.3.1 (Perl 5.006)
Archive-name: electrical-wiring/part2

Updated: WARNING

This FAQ has not been updated or posted in a number of years.  It
is intended that it will be updated to bring it more into compliance
with current code.  Comments welcome at wirefaq(@)ferret.ocunix.on.ca
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The latest FAQ can always be obtained from:

ftp://rtfm.mit.edu/pub/usenet/news.answers/electrical-wiring/part[1-2]

Subject: How to wire 3-way and 4-way switches

http://homewiring.tripod.com

The above is a truly excellent site with pictures and very detailed code analysis. Warning, it's NEC-only-specific. So, if you're outside of the USA, you will need to be careful. For example, the rules for kitchens are considerably different in Canada.

Subject: What kind of outlets do I need in a kitchen?

The NEC requires at least two 20 amp ``small appliance circuits'' for kitchen counters. The CEC requires split-duplex receptacles. Outlets must be installed such that no point is more than 24" (NEC) (900 mm CEC) from an outlet. Every counter wider than 12" (NEC) or 300 mm (CEC) must have at least one outlet. The circuit these outlets are on may not feed any outlets except in the kitchen, pantry, or dining room. Furthermore, these circuits are in addition to any required for refrigerators, stoves, microwaves, lighting, etc.

New rule (1996 NEC): all counter outlets must be GFCI protected.

(Old NEC rule for historical purposes) Non-dedicated outlets within 6' of a sink *must* be protected by a GFCI.

Split duplex receptacles are fed with a 220V circuit. The tab is broken on the hot side of the outlet, and one hot goes to the upper outlet, and the other hot goes to the lower outlet. The neutral connects to both outlets through one screw. When "carrying through" to another outlet, the neutral must be pigtailed, such that removing the outlet, or having the neutral connection fall off or burn out doesn't cause the neutral to disconnect from downstream outlets ("loose neutral" problems - see "What does it mean when the lights brighten...").

Subject: Where must outlets and switches be in bathrooms?

There must be at least one outlet in each bathroom, adjacent to the sink, in addition to any outlet that may be incorporated in the light fixture. All such outlets *must* be GFCI-protected.

The NEC says that switches may not be installed inside bathtubs or showers. The CEC says that switches may not be installed "within reach" of bathtubs or showers (consult an inspector if you can't make it at least four feet).

Subject: General outlet placement rules/line capacities

We paraphrase CEC 26-702 (NEC: 210-52 through 210-63)

Note: In laying out receptacle outlets, consideration shall be given to the placement of electrical baseboards, hot air registers, hot water or steam registers, with a view of eliminating cords having to pass over hot or conductive surfaces wherever possible.

NEC: You're not allowed to put outlets over electric baseboards. That, coupled with the spacing requirements, more or less mandates the use of baseboards with integral outlets. Note that such outlets are fed by a different branch circuit than the heating elements.

2. Except as otherwise required, receptacles shall be installed in the finished walls of every room or area, other than kitchens, bathrooms, hallways, laundry rooms, utility rooms or closets, so that no point along the floor line of any usable wall space is more than 1.8m (6') horizontally from a receptacle in that or an adjoining space, such distance being measured along the floor line of the wall spaces involved.

Fixed dividers, counters, etc., are considered wall space. Floor outlets do not satisfy the requirement unless they are ``near'' the wall. Insofar as practical, outlets should be spaced equidistantly.

3. At least one duplex receptacle shall be provided in each enclosed area such as a balcony or porch that is not classified as a finished room or area.

[NEC doesn't seem to have this rule.]

4. The receptacles referred to in (2) and (3) shall be duplex receptacles or equivalent number of single receptacles.

5. "Usable wall space" is defined as any wall space 900mm (3', NEC 2') or more in width, not to include doorways, areas occupied by a door when fully opened, windows which extend to the floor, fireplaces or other permanent installations that would limit the use of the wall space.

6. See kitchen counter requirements. At least one duplex receptacle in eat-in dining area.

[We don't think the latter part is in the NEC. Also, the NEC says that the two 20-amp small appliance circuits can't go outside of the kitchen, dining room, pantry, etc., nor can they be used for anything else, except for things like clock outlets, stove accessory outlets, etc.]

7. Receptacles shall not be mounted facing up in the work surfaces or counters of the kitchen or dining area.

8. No point in a hallway within a dwelling unit shall be more than 4.5m (15', NEC 10') from a duplex receptacle as measured by the shortest path which the supply cord of an appliance connected to the receptacle would follow without passing through an openning fitted with a door. (vacuum-cleaner rule).

9. At least one duplex receptacle shall be provided: in laundry room, utility room and any unfinshed basement area

[NEC: see GFCI requirements. There must be a dedicated 20 amp laundry receptacle, with no other outlets, plus an additional unfinished basement receptacle. Any attic or crawl space with heating or air conditioning equipment must have a receptacle. (this is probably in the CEC too.)]

10, 11, 12, 13: See bathroom requirements, GFCI, washing machine outlet placement.

14, 15. Outlets shall not be placed in ironing cabinets, cupboards, wall cabinets, nor in similar enclosures except where they're for specific non-heating appliances (including microwave) in the enclosure.

[NEC: No such requirement. Are you sure Steven?]

16, 17. For each single-family dwelling, at least one duplex receptacle shall be installed outdoors to be readily available from ground level (see GFCI requirements). Appendix B (additional notes) suggests front and back outlets to be controlled by an interior switch.

[NEC: One in front, one in back. No discussion of them being switched.]

18. At least one duplex receptacle shall be provided for each car space in a garage or carport.

[NEC: For an attached garage, or detached garage with electric service -- but there is no requirement that detached garages have power. This remark is probably relevant to CEC as well.]

19. For the purposes of this rule, all receptacles shall be of the grounding type, configuration 5-15R (standard 110V/15A 3 prong).

20. Any receptacle that is part of a lighting fixture or appliance that is > 1.7m (5 feet) above the floor, or in cabinets or cupboards, is not counted in the above rules.

21. Where a switched duplex outlet is used in lieu of a light outlet and fixture, the receptacle shall be considered one of the wall mounted receptacles required here.

22. At least one duplex receptacle shall be provided for a central vacuum system if the ducting is installed.

[NEC: couldn't find an equivalent rule.]

Capacities: Knight recommends no more than 10 outlets per circuit. Some US references talk about a limit of 12. There appears to be a wattage/area/outlet count calculation somewhere in the NEC. 20A circuits may have different rules.

It is open to considerable debate whether you should mix general lighting and outlets on individual circuits. Knight recommends it. Some netters don't. I tend towards the former for load balancing reasons.

NEC: There's a new rule on outdoor outlets. If exposed to the weather, and if used for unattended equipment (pool filters, outdoor lighting, etc.), the outlet must still be weatherproof even when the device is plugged in.

Subject: What is Romex/NM/NMD? What is BX? When should I use each?

Romex is a brand name for a type of plastic insulated wire. Sometimes called non-metallic sheath. The formal name is NM. This is suitable for use in dry, protected areas (ie: inside stud walls, on the sides of joists etc.), that are not subject to mechanical damage or excessive heat. Most newer homes are wired almost exclusively with NM wire. There are several different categories of NM cable.

BX cable -- technically known as armored cable or "AC" has a flexible aluminum or steel sheath over the conductors and is fairly resistant to damage.

TECK cable is AC with an additional external thermoplastic sheath.

Protection for cable in concealed locations: where NM or AC cable is run through studs, joists or similar wooden members, the outer surface of the cable must be kept at least 32mm/1.25" (CEC & NEC) from the edges of the wooden members, or the cable should be protected from mechanical injury. This latter protection can take the form of metal plates (such as spare outlet box ends) or conduit.

[Note: inspector-permitted practice in Canada suggests that armored cable, or flexible conduit can be used as the mechanical protection, but this is technically illegal.]

Additional protection recommendations: [These are rules in the Canadian codes. The 1993 NEC has many changes that bring it close to these rules. These are reasonable answers to the vague "exposed to mechanical damage" in both the NEC and CEC.]

- NM cable should be protected against mechanical damage where it passes through floors or on the surface of walls in exposed locations under 5 feet from the floor. Ie: use AC instead, flexible conduit, wooden guards etc.
- Where cable is suspended, as in, connections to furnaces or water heaters, the wire should be protected. Canadian practice is usually to install a junction or outlet box on the wall, and use a short length of AC cable or NM cable in flexible conduit to "jump" to the appliance. Stapling NM to a piece of lumber is also sometimes used.
- Where NM cable is run in close proximity to heating ducts or pipe, heat transfer should be minimized by means of a 25mm/1" air space, or suitable insulation material (a wad of fiberglass).
- NM cable shall be supported within 300mm/1' of every box or fitting, and at intervals of no more than 1.5m/5'. Holes in joists or studs are considered "supports". Some slack in the cable should be provided adjacent to each box. [while fishing cable is technically in violation, it is permitted where "proper" support is impractical]
- 2 conductor NM cable should never be stapled on edge. [Knight also insists on only one cable per staple, referring to the "workmanship" clause, but this seems more honoured in the breach...]
- cable should never be buried in plaster, cement or similar finish, except were required by code [Ie: cable burial with shallow bedrock.].
- cable should be protected where it runs behind baseboards.
- Cable may not be run on the upper edge of ceiling joists or the lower edges of rafters where the headroom is more than 1m (39").

Whenever BX cable is terminated at a box with a clamp, small plastic bushings must be inserted in the end of the cable to prevent the clamps forcing the sharp ends of the armor through the insulation.

Whenever BX cable is buried in thermal insulation, 90C wire should be selected, but derated in current carrying capacity to 60C.

BX is sometimes a good idea in a work shop unless covered by solid wall coverings.

In places where damage is more likely (like on the back wall of a garage ;-), you may be required to use conduit, a UL- (or CSA-) approved metal pipe. You use various types of fittings to join the pipe or provide entrance/exit for the wire.

Service entrances frequently use a plastic conduit.

In damp places (eg: buried wiring to outdoor lighting) you will need special wire (eg: CEC NMW90, NEC UF). NMW90 looks like very heavy-duty NMD90. You will usually need short lengths of conduit where the wire enters/exits the ground. [See underground wiring section.]

Thermoplastic sheath wire (such as NM, NMW etc.) should not be exposed to direct sunlight unless explicitly approved for that purpose.

Many electrical codes do not permit the routing of wire through furnace ducts, including cold air return plenums constructed by metal sheeting enclosing joist spaces. The reason for this is that if there's a fire, the ducting will spread toxic gasses from burning insulation very rapidly through the building. Teflon insulated wire is permitted in plenums in many areas.

Canada appears to use similar wire designations to the US, except that Canadian wire designations usually include the temperature rating in Celsius. Eg: "AC90" versus "AC". In the US, NM-B is 90 degrees celcius.

NOTE: local codes vary. This is one of the items that changes most often. Eg: Chicago codes require conduit *everywhere*. There are very different requirements for mobile homes. Check your local codes, *especially* if you're doing anything that's the slightest out of the ordinary.

Wire selection table (incomplete - the real tables are enormous, uncommon wire types or applications omitted)

Condition	Type	CEC	NEC
Exposed/Concealed dry	plastic	NMD90	NM
	armor	AC90	AC
		TECK90	
Exposed/Concealed damp	plastic	NMD90	NMC
	armor	ACWU90	
		TECK90	
Exposed/Concealed wet	plastic	NMWU90	
	armor	ACWU90	
		TECK90	
Exposed to weather	plastic	NMWU	
		TW etc.	
	armor	TECK90	
Direct earth burial/	plastic	NMWU*	UF
Service entrance		RWU	
		TWU	
	armor	RA90	
		TECK90	
		ACWU90	

[* NMWU not for service entrance]

Subject: Should I use plastic or metal boxes?

The NEC permits use of plastic boxes with non-metallic cable only. The reasoning is simple -- with armored cable, the box itself provides ground conductor continuity. U.S. plastic boxes don't use metal cable clamps.

The CEC is slightly different. The CEC never permits cable armor as a grounding conductor. However, you must still provide ground continuity for metallic sheath. The CEC also requires grounding of any metal cable clamps on plastic boxes.

The advantage of plastic boxes is comparatively minor even for non-metallic sheathed cable -- you can avoid making one ground connection and they sometimes cost a little less. On the other hand, plastic boxes are more vulnerable to impacts. For exposed or shop wiring, metal boxes are probably better.

Metal receptacle covers must be grounded, even on plastic boxes. This may be achieved by use of a switch with ground connection.

Subject: Junction box positioning?

A junction box is a box used only for connecting wires together.

Junction boxes must be located in such a way that they're accessible later. Ie: not buried under plaster. Excessive use of junction boxes is often a sign of sloppy installation, and inspectors may get nasty.

Subject: Can I install a replacement light fixture?

In general, one can replace fixtures freely, subject to a few caveats. First, of course, one should check the amperage rating of the circuit. If your heart is set on installing half a dozen 500 watt floodlights, you may need to run a new wire back to the panel box. But there are some more subtle constraints as well. For example, older house wiring doesn't have high-temperature insulation. The excess heat generated by a ceiling-mounted lamp can and will cause the insulation to deteriorate and crack, with obvious bad results. Some newer fixtures are specifically marked for high temperature wire only. (You may find, in fact, that your ceiling wiring already has this problem, in which case replacing any devices is a real adventure.)

Other concerns include providing a suitable ground for some fluorescent fixtures, and making sure that the ceiling box and its mounting are strong enough to support the weight of a heavy chandelier or ceiling fan. You may need to install a new box specifically listed for this purpose. A 2x4 across the ceiling joists makes a good support. Metal brackets are also available that can be fished into ceilings thru the junction box hole and mounted between the joists.

There are special rules for recessed light fixtures such as "pot" lamps or heat lamps. When these are installed in insulated ceilings, they can present a very substantial fire hazard. The CEC provides for the installation of pot lamps in insulated ceilings, provided that the fixture is boxed in a "coffin" (usually 8'x16"x12" - made by making a pair of joists 12" high, and covering with plywood) that doesn't have any insulation. (Yes, that's 8 *feet* long)

NEC rules are somewhat less stringent. They require at least 3" clearance between the fixture and any sort of thermal insulation. The rules also say that one should not obstruct free air movement, which means that a CEC-style ``coffin'' might be worthwhile. Presumably, that's up to the local inspector. [The CEC doesn't actually mandate the coffin per-se, this seems to be an inspector requirement to make absolutely certain that the fixture can't get accidentally buried in insulation. Ie: if you have insulation blown in later.]

There are now fixtures that contain integral thermal cutouts and fairly large cases that can be buried directly in insulation. They are usually limited to 75 watt bulbs, and are unfortunately, somewhat more expensive than the older types. Before you use them, you should ensure that they have explicit UL or CSA approval for such uses. Follow the installation instructions carefully; the prescribed location for the sensor can vary.

There does not yet appear to be a heat lamp fixture that is approved for use in insulation. The "coffin" appears the only legal approach.

Subject: Noisy fluorescent fixtures, what do I do?

Many fluorescent fixtures tend to buzz, objectionably so when used in residential (rather than warehouse or industrial) situations. This tends to be the result of magnetic/physical resonances at the (low) frequencies that standard fixture ballasts operate. You can eliminate this problem by switching to electronic ballasts, which operate at a higher (inaudible) frequency. Unfortunately, these are quite expensive.

Subject: Noisy lights with dimmer switches, what do I do?

Often, after installing a dimmer switch, or replacing bulbs controlled by a dimmer, you'll start hearing objectionable buzzing or humming from the bulb. Sometimes it even interferes with televisions or radios.

A little theory first. The voltage on the wiring in your house looks like this - a sine wave (forgive the lousy ASCII graphics ;-):

```
          ...             ...             ~ +160V
         .   .           .   .
        .     .         .     .
      ------------------------------------ 0V
               .     .         .     .
                .   .           .   .
                 ...             ...      ~ -160V
```

Most dimmers work by having a solid-state switch called a triac in series with the light bulb. Whenever the voltage passes through zero (it does this 120 times per second), the triac turns itself off. The control circuitry in the dimmer provides an adjustable delay before the triac turns back on. So, the resulting wave form looks like this:

```
          ...             ...             ~ +160V
```

```
          |  .            |  .
          |   .           |   .
      ------------------------------------ 0V
                  |   .           |   .
                  |  .            |  .
                  ...             ...      ~ -160V
```

As you can see, by varying the turn-on point, the amount of power getting to the bulb is adjustable, and hence the light output can be controlled. Voila, a dimmer!

This is where it gets interesting. Note the sharp corners. According to the Nyquist theorem, those corners effectively consist of 60Hz plus varying amounts of other frequencies that are multiples of 60Hz. In some cases up to 1Mhz and more. The wiring in your house acts as an antenna and essentially broadcasts it into the air. Hence TVs and radios can be effected. This is called EMI (Electromagnetic Interference).

As far as the bulbs are concerned, a bulb consists of a series of supports and, essentially, fine coils of wire. When you run current through a coil, it becomes a magnet right? If there's any other metal nearby, it'll move. Just like a solenoid. Further, when the amount of current flow abruptly changes the magnetism change can be much stronger than it is on a simple sine wave. Hence, the filaments of the bulb will tend to vibrate more with a dimmer chopping up the wave form, and when the filaments vibrate against their support posts, you will get a buzz.

Worse, some dimmers only do half-wave switching, such that the one half of the chopped wave form will be absent. Which means that the current flow during the present half will have to be much stronger to produce the same amount of light - more EMI and more tendency to buzz.

Solving buzzing problems: If you have buzzing, it's always worth trying to replace the bulb with a different brand. Some cheap bulb brands have inadequate filament support, and simply changing to a different brand may help. Try "rough service" or "farm service" bulbs. They're usually much stronger and better supported.

Chance are, however, that switching bulbs won't make that much of a difference. Perhaps the buzzing will go away at some dimmer settings, but not at all.

Buzzing bulbs are usually a sign of a "cheap" dimmer. Dimmers are supposed to have filters in them. The filter's job is to "round off" the sharp corners in the chopped waveform, thereby reducing EMI, and the abrupt current jumps that can cause buzzing. In cheap dimmers, they've economized on the manufacturing costs by cost-reducing the filtering, making it less effective. Perhaps the dimmer will be okay at some settings, but not others. Or be very picky about what bulbs to use.

It is our belief that most buzzing problems can be traced down to cheap (<$15 dimmers), and most effectively solved by going to mid-range ($25-$35) dimmers from respected companies, such as Leviton. One of the authors of this FAQ, after learning this lesson, will still use $.89 outlets, but insists on better dimmers. By all means, try a different bulb first. You may get lucky. If not, it's time to swap dimmers.

If you have EMI problems, it's almost certain to be a cheap dimmer.

Subject: What does it mean when the lights brighten when a motor starts?

This usually means that the neutral wire in the panel is loose. Depending on the load balance, one hot wire may end up being more than 110V, and the other less than 110V, with respect to ground. This is a very hazardous situation - it can destroy your electronic equipment, possibly start fires, and in some situations electrocute you (ie: some US jurisdictions require the stove frame connected to neutral).

If this happens, contact your electrical authority immediately and have them come and check out the problem. If you say "loose neutral", they will come.

Note: a brief (< 1 second) brightening is sometimes normal with lighting and motors on the same 220V with neutral circuit. A loose main panel neutral will usually show increased brightness far longer than one second. In case of doubt, get help.

Subject: What is 3 phase power? Should I use it? Can I get it in my house?

Three phase power has three "hot" wires, 120 degrees out of phase with each other. These are usually used for large motors because it is more "efficient", provides a bit more starting torque, and because the motors are simpler and hence cheaper.

You're most likely to encounter a 3 phase circuit that shows 110 volts between any hot and ground, and 208 volts between any two hots. The latter shows the difference between a normal 220V/110V common neutral circuit, which is 240 volts between the two hots. There are 3 phase circuits with different voltages.

Bringing in a 3 phase feed to your house is usually ridiculously expensive, or impossible. If the equipment you want to run has a standard motor mount, it is *MUCH* cheaper to buy a new 110V or 220V motor for it. In some cases it is possible to run 3 phase equipment on ordinary power if you have a "capacitor start" unit, or use a larger motor as a (auto-)generator. These are tricky, but are a good solution if the motor is non-standard size, or too expensive or too big to replace. The Taunton Press book ``The Small Shop'' has an article on how to do this if you must.

Note that you lose any possible electrical efficiency by using such a converter. The laws of thermodynamics guarantee that.

Subject: Is it better to run motors at 110 or 220?

Theoretically, it doesn't make any difference. However, there is a difference is the amount of power lost in the supply wiring. All things being equal, a 110V motor will lose 4 times more power in the house wiring than a 220V motor. This also means that the startup surge loss will be less, and the motor will get to speed quicker with 220V. And in some circumstances, the smaller power loss will lead to longer motor life.

This is usually irrelevant unless the supply wires are more than 50 feet long.

Subject: What is this nonsense about 3HP on 110V 15A circuits?

It is a universal physical law that 1 HP is equal to 746 watts. Given heating loss, power factor and other inefficiencies, it is usually best to consider 1 HP is going to need 1000-1200 watts. A 110V 15A circuit can only deliver 1850 watts to a motor, so it cannot possibly be more than approximately 2 HP. Given rational efficiency factors, 1.5HP is more like it.

Some equipment manufacturers (Sears in particular, most router manufacturers in general ;-) advertise a HP rating that is far in excess of what is possible. They are giving you a "stall horsepower" or similar. That means the power is measured when the motor is just about to stop turning because of the load. What they don't mention is that if you kept it in that condition for more than a few seconds your motor will melt - the motor is drawing far more current than its continuous rating.

When comparing motors, compare the continuous horsepower. This should be on the motor nameplate. If you can't find that figure, check the amperage rating, which is always present.

Subject: How should I wire my shop?

As with any other kind of wiring, you need enough power for all devices that will be on simultaneously. The code specifies that you should stay under 80% of the nominal capacity of the circuit. For typical home shop use, this means one circuit for the major power tools, and possibly one for a dust collector or shop vac. Use at least 12 gauge wire -- many power tools have big motors, with a big start-up surge. If you can, use 20 amp breakers (NEC), though CEC requires standard 20A receptacles which means you'd have to "replug" all your equipment. Lights should either be on a circuit of their own -- and not shared with circuits in the rest of the house -- or be on at least two separate circuits. The idea is that you want to avoid a situation where a blade is still spinning at several thousand RPM, while you're groping in the dark for the OFF switch.

Do install lots of outlets. It's easier to install them in the beginning, when you don't have to cut into an existing cable. It's useful if at least two circuits are accessible at each point, so you can run a shop vac or a compressor at the same time as the tool you really want. But use metal boxes and plates, and maybe even metal-sheathed cable; you may have objects flying around at high speeds if something goes a bit wrong.

Note that some jurisdictions have a "no horizontal wiring" rule in workshops or other unfinished areas that are used for working. What this means is that all wiring must be run along structural members. Ie: stapled to studs.

Other possible shop circuits include heater circuits, 220V circuits for some large tools, and air compressor circuits. Don't overload circuits, and don't use extension cords if you can help it, unless they're rated for high currents. (A coiled extension cord is not as safe as a straight length of wire of the same gauge. Also, the insulation won't withstand as much heat, and heat dissipation is the critical issue.)

If your shop is located at some remove from your main panel, you should probably install a subpanel, and derive your shop wiring from it. If you have young children, you may want to equip this panel with a cut-off switch, and possibly a lock. If you want to install individual switches to ``safe'' particular circuits, make sure you get ones rated high enough. For example, ordinary light switches are not safely able to handle the start-up surge generated by a table saw. Buy ``horsepower-rated'' switches instead.

Finally, note that most home shops are in garages or unfinished basements; hence the NEC requirements for GFCIs apply. And even if you ``know'' that you'd never use one of your shop outlets to run a lawn mower, the next owner of your house might have a different idea.

Note: Fine Woodworking magazine often carries articles on shop wiring. April 1992 is one place to start.

Subject: Doorbell/telephone/cable other service wiring hints.

Auxiliary services, such as cable, telephone, doorbell, furnace control circuits etc. are generally considered to be "class 2" wiring by both the CEC and NEC.

What this generally means is:

1) class 2 and house power should not share conduit or termination boxes.
2) class 2 and house power should be 12" apart in walls except where necessary.
3) cross-over should be at 90 degrees.

While the above may not be strictly necessary to the code, it is advantageous anyways - paralleling house power beside telephone lines tends to induce hum into the telephone. Or could interfere with fancier furnace control systems.

With telephone wiring, twisted pair can alleviate these problems, and there are new cable types that combine multiple services into one sheath. Consult your inspector if you really want to violate the above recommendations.

Subject: Underground Wiring

You will need to prepare a trench to specifications, use special wire, protect the wire with conduit or special plastic tubing and possibly lumber (don't use creosoted lumber, it rots thermoplastic insulation and acts as a catalyst in the corrosion of lead). The transition from in-house to underground wire is generally via conduit. All outdoor boxes must be specifically listed for the purpose, and contain the appropriate gaskets, fittings, etc. If the location of the box is subject to immersion in water, a more serious style of water-proof box is needed. And of course, don't forget the GFCIs.

The required depths and other details vary from jurisdiction to jurisdiction, so we suggest you consult your inspector about your specific situation.

A hint: buy a roll of bright yellow tape that says "buried power line" and bury it a few inches above where the wire has been placed.

Subject: Aluminum wiring

During the 1970's, aluminum (instead of copper) wiring became quite popular and was extensively used. Since that time, aluminum wiring has been implicated in a number of house fires, and most jurisdictions no longer permit it in new installations. We recommend, even if you're allowed to, that do not use it for new wiring.

But don't panic if your house has aluminum wiring. Aluminum wiring, when properly installed, can be just as safe as copper. Aluminum wiring is, however, very unforgiving of improper installation. We will cover a bit of the theory behind potential problems, and what you can do to make your wiring safe.

The main problem with aluminum wiring is a phenomenon known as "cold creep". When aluminum wiring warms up, it expands. When it cools down, it contracts. Unlike copper, when aluminum goes through a number of warm/cool cycles it loses a bit of tightness each time. To make the problem worse, aluminum oxidises, or corrodes when in contact with certain types of metal, so the resistance of the connection goes up. Which causes it to heat up and corrode/oxidize still more. Eventually the wire may start getting very hot, melt the insulation or fixture it's attached to, and possibly even cause a fire.

Since people usually encounter aluminum wiring when they move into a house built during the 70's, we will cover basic points of safe aluminum wiring. We suggest that, if you're considering purchasing a home with aluminum wiring, or have discovered it later, that you hire a licensed electrician or inspector to check over the wiring for the following things:

1) Fixtures (eg: outlets and switches) directly attached to aluminum wiring should be rated for it. The device will be stamped with "Al/Cu" or "CO/ALR". The latter supersedes the former, but both are safe. These fixtures are somewhat more expensive than the ordinary ones.

2) Wires should be properly connected (at least 3/4 way around the screw in a clockwise direction). Connections should be tight. While repeated tightening of the screws can make the problem worse, during the inspection it would pay off to snug up each connection.

   Note that aluminum wiring is still often used for the main service entrance cable. It should be inspected.

3) "push-in" terminals are an extreme hazard with aluminum wire. Any connections using push-in terminals should be redone with the proper screw connections immediately.

4) There should be no signs of overheating: darkened connections, melted insulation, or "baked" fixtures. Any such damage should be repaired.

5) Connections between aluminum and copper wire need to be handled specially. Current Canadian codes require that the connectors used must be specially marked for connecting aluminum to copper. The NEC requires that the wire be connected together using special crimp devices, with an anti-oxidant grease. The tools and materials for the latter are quite expensive - not practical to do it yourself unless you can rent the tool.

   [Note that regulations are changing rapidly in this area. Suggest that you discuss any work with an inspector if you're going to do more than one or two connections.]

6) Any non-rated receptacle can be connected to aluminum wiring by means of a short copper "pigtail". See (5) above.

7) Shows reasonable workmanship: neat wiring, properly stripped (not nicked) wire etc.

If, when considering purchasing a home, an inspection of the wiring shows no problems or only one or two, we believe that you can consider the wiring safe. If there are signs of problems in many places, we suggest you look elsewhere. If the wrong receptacles are used, you can replace them with the proper type, or use pigtails - having this professionally done can range from $3 to $10 per receptacle/switch. You can do this yourself too.

There's a useful article at http://inspect-ny.com/aluminum.htm

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Subject: I'm buying a house! What should I do?

Congratulations. But... It's generally a good idea to hire an inspector to look through the house for hidden gotchas. Not just for wiring, but plumbing and structural as well. If an inspection of the wiring shows no problems or only one or two minor ones, we believe that you can consider the wiring safe (after any minor problems are fixed). If there are signs of problems in many places, we suggest you look elsewhere.

Here's some hints on what to look for:

Obvious non-code wiring can include:

- Zip cord wiring, either concealed or nailed to walls
- Hot wiring on the identified (neutral) conductor without proper marking.
- Ungrounded grounding outlets (except when downstream of a GFCI)
- Splices hanging in mid-air (other than proper knob-and-tube)
- Switched neutrals
- Unsecured Romex swinging about like grapevines

Certain wiring practices that are actually to code (or were at one time) sometimes reveal DIY wiring that may have hidden violations:

- Switches that seem to control nothing (abandoned, perhaps not properly terminated wiring)
- A wall switch that controls things that you think it shouldn't, for instance mysteriously removing power from lights or outlets in other rooms.
- Switches and outlets in bizarre locations

- Great numbers of junction boxes without outlets or lamps
- Junction boxes with great numbers of wires going into them
- Wiring that passes through a closet instead of a wall or ceiling
- Backwrapped grounding wires (ground wire wrapped around the incoming cable insulation outside the box).
- A breaker or fuse for outside wiring that is near the bottom of the breaker panel or in an add-on fusebox. The outdoor wiring may have been homeowner-installed after the house was built, and was not buried deep enough or was done with the wrong kind of wire - if the wire is visible, check for "UF" or "NMW" markings.

Subject: What is this weird stuff? Old style wiring

In the years since Edison "invented" electricity, several different wiring "styles" have come and gone. When you buy an older home you may encounter some of this stuff. This section describes the old methods, and some of their idiosyncrasies.

The oldest wiring system you're likely to encounter is called "knob and tube" (K&T). It is made up of individual conductors with a cloth insulation. The wires are run along side structural members (eg: joists or studs) using ceramic stand-offs (knobs). Wire is run through structural members using ceramic tubes. Connections were made by twisting the wire together, soldering, and wrapping with tape. Since the hot and neutral were run separately, the wiring tends to be rather confusing. A neutral often runs down the centre of each room, with "taps" off to each fixture. The hot wire tended to run from one fixture to the next. In some cases K&T isn't colour-coded, so the neutral is often the same colour as the hot wires.

You'll see K&T in homes built as late as the 40's.

Comments on K&T:

- the people installing K&T were pretty paranoid about electricity, so the workmanship tends to be pretty good.
- The wire, insulation and insulators tend to stand up very well. Most K&T I've seen, for example, is in quite good condition.
- No grounding. Grounding is usually difficult to install.
- boxes are small. Receptacle replacement (particularly with GFCI) can be difficult. No bushing on boxes either, so wiring changes need special attention to box entry.
- Sometimes the neutral isn't balanced very well between separately hot circuits, so it is sometimes possible to overload the neutral without exceeding the fusing on any circuit.
- In DC days it was common to fuse both sides, and no harm was done. In fact, it was probably a Good Thing. The practise apparently carried over to K&T where you may find fused neutrals. This is a very bad thing.
- Building code does not usually permit insulation in walls or ceilings that contains K&T. Some jurisdictions will allow it under some circumstances (eg: engineer's certificate).
- Connection to existing K&T from new circuits can be tricky. Consult your inspector.
- Modern wiring practice requires considerably more

outlets to be installed than K&T systems did.

Since K&T tends to be in pretty decent condition it generally isn't necessary to replace it simply because it's K&T. What you should watch out for is renovations that have interfered with it and be cautious about circuit loading. In many cases it's perfectly reasonable to leave existing K&T alone, and add new fixtures on new circuits using modern techniques.

After K&T, they invented multi-conductor cable. The first type you will see is roughly a cloth and varnish insulation. It looks much like the romex cable of the last decade or two. This stuff was used in the 40's and 50's. Again, no grounding conductor. It was installed much like modern wiring. Its major drawback is that this type of insulation embrittles. We've seen whole systems where the insulation would fracture and fall off at a touch. BX cable of the same vintage has similar problems. It is possible for the hot conductor to short out to the cable jacket. Since the jacket is rusted, it no longer presents a low resistance return path for the current flow, but rather more acts like a resistance heater. In extreme cases the cable jacket will become red hot without blowing the fuse or circuit breaker. The best thing to do with old style BX is to replace it with modern cable whenever it's encountered and there's any hint of the sheath rusting.

This stuff is very fragile, and becomes rather hazardous if the wires become bare. This wiring should be left untouched as much as possible - whenever an opportunity arises, replace it. A simple receptacle or switch replacement can turn into a several hour long frustrating fight with electrical tape or heat-shrink tubing.

After this wiring technique, the more modern romex was invented. It's almost a asphalt impregnated cloth. Often a bit sticky. This stuff stands up reasonably well and doesn't present a hazard and is reasonably easy to work with. It does not need to be replaced - it should be considered as safe as the "modern" stuff - thermoplastic insulation wire. Just don't abuse it too much.

Subject: Where do I buy stuff?

Try to find a proper electrical supply outlet near you. Their prices will often be considerably better than chain hardware stores or DIY centres, have better quality materials, have wider variety including the "odd" stuff, and have people behind the counter that know what you're talking about. Cultivate friendly knowledgeable sales people. They'll give you much valuable information.

Subject: Copper wire characteristics table

These are taken from the Amateur Radio Relay Handbook, 1985.

AWG	dia mils	circ mils	open air A	cable Amp	ft/lb bare	ohms/ 1000'
10	101.9	10380	55	33	31.82	1.018
12	80.8	6530	41	23	50.59	1.619
14	64.1	4107	32	17	80.44	2.575

We don't show specs for 8ga or larger because they're usually stranded.

Mils are .001". "open air A" is a continuous rating for a single conductor with insulation in open air. "cable amp" is for in multiple conductor cables. Disregard the amperage ratings for household use.

To calculate voltage drop, plug in the values:

V = DIR/1000'

Where I is the amperage, R is from the ohms/1000' column above, and D is the total distance the current travels (don't forget to add the length of the neutral and hot together - ie: usually double cable length). Design rules in the CEC call for a maximum voltage drop of 6% (7V on 120V circuit)

Subject: Smoke detector guidelines

Many (most?) building codes now require the installation of smoke detectors in homes. In fact, this has been made retroactive in many municipalities.

There are many different types of smoke detectors. Ionization, photo-cell, battery-powered, AC-powered etc. The only thing we're concerned with here, is AC versus battery powered, other than to comment that most building codes are based around ionization detectors, photocell units being usually for somewhat more specialized purposes. All things being equal, in a residential setting with the "ordinary fire", an ionization detector will detect smoke before a photo-cell will - indeed, in some fires, the smoke is almost invisible, and less likely to trip a photo-cell.

There is another type of fire detectors - "heat detectors". These work usually by a small piece of special metal melting at 110F or so. These are much better at avoiding false trips. But they usually take much longer to trip than a smoke detector, and should usually only be considered for triggering sprinkler devices (where the consequences of a false trip are quite severe). Heat detectors should not be used as primary fire detection.

Most building codes that mandate detectors mandated AC-powered ones for new construction. This is because the statistics show that, in houses equipped with smoke detectors, a lot more people were getting killed in houses with battery-only detectors that had dead batteries than were getting killed in houses where the breakers tripped and killed an AC-only detector. It's also worth noting that some battery detectors are quite sensitive about battery condition. Some even refuse to work if the battery is zinc-carbon (standard cheap battery) instead of alkaline (more expensive).

Our building code discourages the installation of smoke detectors on circuits used for other purposes. This means that only a main-panel breaker trip can kill the detectors. A main-panel trip is unlikely even in a fire started by an electrical fault until well after the fire has really engulfed the home.

These codes also usually require that the AC detectors be interconnected so that if one triggers, they all sound the alarm. This is usually done by an additional wire between the units.

The above suggests that the best way of doing things is to have one circuit dedicated for smoke detectors, and you run 14-3 between each of the detectors - the red wire being the "gang trip" control.

If you're still concerned about losing power and thereby losing your detectors, we suggest either the use of detectors that run off AC power with battery backup, OR, adding battery detectors into a system that's already adequately covered with AC detectors.

Battery-only detectors should only be considered a stopgap measure in putting detectors into a house that doesn't have any detectors at all, or adding redundancy into a system that already has AC detectors.

We also suggest that, if you have battery detectors, you make changing the battery a yearly (or semi-yearly) scheduled event. Some people change the batteries on their birthdays. Others change the batteries during a "daylight/standard time change" maintenance pass.

In Canada, the day before the standard/daylight time change (a Saturday) now seems to be officially called "smoke detector battery day" ;-)

We don't recommend waiting for the detector to tell you that the battery is dead, unless you manually test the detector monthly.

Subject: Other links

http://www.epanorama.net/wire_mains.html
http://www.fatti.com/guests/engdahl/wiring.html

Send corrections/additions to the FAQ Maintainer:
clewis@ferret.ocunix.on.ca (Chris Lewis)

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