

# About Wire

## Introduction

There's a mind-boggling variety of wire available nowadays, probably thousands of kinds. Wire is made by drawing ductile metal bars through ever smaller holes in a succession of dies to produce the desired size. Much wire is used for mechanical purposes: wire rope, wire-wrapped cannon barrels, picture wire, guy wires, spring wire, barbed wire, all mostly iron and steel and alloys. Practically every solid element in the periodic table is used as wire, pure or more often as an alloy, for a wide variety of purposes. Some common examples are lead wire for fuses and lead-tin alloys for solder, indium and gold for vacuum gaskets, platinum for electrodes and resistance thermometers. Most of the wire used for electrical conductors is made of copper or copper alloy, or aluminum.

Electrical wire comes in diameters from 0.0001inch (Wollaston wire, made by drawing down silver-clad platinum wire and then dissolving away the silver) up to about a half inch--larger than that and its called `cable' or `bar'. The size is described by a "gauge" number according to the "American Wire Gauge" (AWG), a scheme in which the diameter of wire of each successively higher gauge number is less than the diameter of the previous one by a constant factor, the 39th root of 92 = 1.122932197. The idea of a constant ratio between successive sizes comes naturally from the drawing process, and the particular choice of numbers, essentially arbitrary, provides enough wire sizes for many different uses, from power transmission to miniaturized electronics. (This constant ratio scheme is like the equally tempered musical scale, where each note is higher in pitch than the previous one by the 12th root of 2).

## Facts About Wire

Number 2 copper wire weighs 0.2 pounds per foot and number 10 wire with a diameter of 0.10 inch has a resistance of about 1.0 ohms per 1000 feet. You can scale from this using the fact that an increase of three gauge numbers halves the area and weight and doubles the resistance. Increases of 6 and 10 gauge numbers approximately divides the area by 4 and 10, respectively. It's often important to know the current-carrying capacity of a particular wire, which depends on what kind of insulation it has, how hot it can get safely, and of course how well it's cooled. Cooling is complicated; heat must be conducted outward through the wire insulation, and then removed, mostly by convection, a process in which heated, less-dense fluid rises and is replaced by cooler stuff.

Most electrical wire is insulated to prevent shorts, either by plastic or rubber or by a coating of "enamel", so-called because it's shiny like porcelain. Teflon, fiberglass and cotton are also used as insulation, and in the past, silk and asbestos were common.

Data from the Handbook of Chemistry and Physics (HCP, 58th edition, p F-163) will give you an idea of the current-carrying capacity of bare copper wire: #12, 30 A; #14, 20 A; #18, 6 A. Plotting the current-carrying capacity versus area for these wires (and a few more) reveals the relations:

$$I_{max} = 7.2d^2 \quad d \text{ in } mm, \quad I \text{ in } A$$

We can use this formula to compute current-carrying capacities-- not to be taken too seriously; if it smokes it's too much-- to put in the following table of wire properties.

Gauge	Material	Insulation	Diameter ( mm )	Resistance per length at 20C ( $\Omega/m$ )	Max Current ( A )	Comments
30	Cu	none	0.255	0.339	0.5	
26	Cu	enamel	0.405	0.134	1.0	
22	tinned Cu	plastic	0.644	0.053	3.0	Solid & stranded as discussed
16	alloy	none	1.29	1.02		Used as shunt
14	Cu	plastic	1.63	0.008	20	house wire

### Comments On Wire You'll Use

**Red & black insulated #22 stranded tinned copper wire**—This stranded #22 wire is made of 7 #30 wires, each covered with a thin layer of solder, ie. tinned, which makes it easy for you to solder it. Seven strands of #30 wires have the same area (within 10%), and hence about the same current carrying capacity as solid #22 wire. The plastic insulation is vinyl, a good insulator, but easily melted as you'll discover while soldering. Be careful when stripping off the insulation with wire strippers not to take along any of the wire strands; check by inspecting the removed piece of insulation. Stranded wire is more flexible and resistant to breaking than the corresponding solid wire.

**#16 resistance wire**, made of a metal called "Alloy 800" by its manufacturer (MWS Wire Industries); it has a composition (in percentages) of 75 Ni, 20 Cr, 2.5 Al, 2.5 Cu. Number 16, diameter 1.3mm, has a resistance of 1.02 $\Omega$  per meter. Contrast this with copper wire of the same gauge with a resistance of 0.013 $\Omega/m$  or with much thinner #30 with 0.34 $\Omega/m$ . In our experiments currents rarely exceed 1A and are usually much less, so voltage drops are unimportant. By putting the resistance wire in series in a circuit you can measure currents beyond the range of your multimeter simply by measuring the voltage drop across a measured length, and hence known resistance, of the wire.

## Wires Found in Various Kits:

**Lengths of bare and insulated red & black #20 or #22 solid tinned copper wire**—Wire up circuits on perfboard (LVPS, HVPS, AMP) with this wire. Wherever there is no danger of shorts use bare wire; otherwise, red wire for positive leads, black wire for ground, common or negative leads.

**#30 bare copper wire**—This is used in Experiment EF (*Electrostatic Force*) to connect to the steel washer capacitor plates. Negligible current flows, and the flexibility of this thin wire minimizes mechanical disturbances.

**#26 enamel coated copper wire**—The insulating enamel, usually a dark brown, is a kind of plastic (urethane?). Use it to wind the coils used in Experiment MF (*Magnetic Force*). Except The enamel insulation must be removed to make electrical connection by soldering. Remove the enamel by careful sanding with the emery cloth or scraping with a knife or scissor blade; be careful not to weaken the wire by nicking it. There are solvents for enamel, nasty chemicals, and some people burn the enamel off with match, kind of a mess, also anneals and therefore weakens the wire.

**#14, 2-conductor with ground, house wire**, called "NM", non-metallic sheathed—By convention in house wiring, the black insulated wire is "hot", the white wire is the return near ground potential, and the bare wire is connected to ground, a buried metal water pipe for instance. This is to ground tools or appliances for safety so that internal electrical shorts or leakage to the metal case will not electrocute an operator who touches a grounded conductor, including moist earth. This wire, with the insulation pulled off, is used for transmitting and receiving dipole antennas in Experiment MW (*Microwaves*).

**#22 speaker wire**—This has two stranded #22 wires in a single clear plastic insulating sheath that can be split at the ends so that the wires can be individually stripped. It's a handy way to connect the transmitting antenna in Experiment MW (*Microwaves*) to the HVPS.

**Single-conductor or double-conductor shielded wire**—The shield is a tubular envelope of braided wire around the insulated inner conductor. With the shield grounded, charge and current that would be induced on the inner conductor by external electric fields are greatly reduced. It's used to connect the receiving dipole antenna in Experiment MW (*Microwaves*) to the AMP (*Amplifier*). It shields out lower frequency disturbances which the spark generating microwaves in Experiment MW makes.