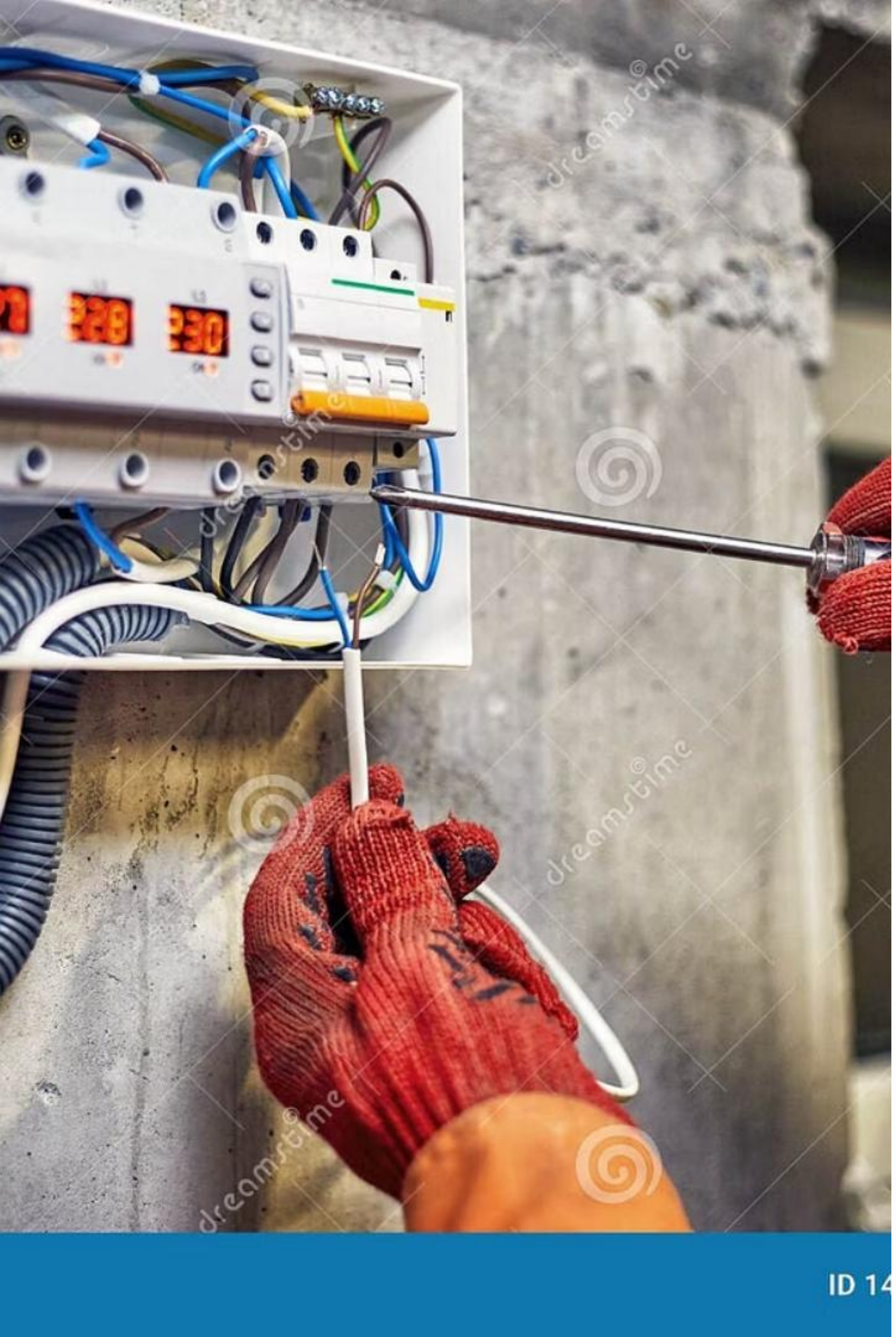


CSA Unit 12 Basic Electricity

Chapter 1

Power Supply for Gas Appliances

Most gas appliances are designed with some electrical components to aid in their operation. It is important for gas technicians and fitters to understand how power is supplied and accessed, as well as the various methods and devices used to ensure that electricity is distributed safely.

Created

MK by Mike Kapin

Electrical Service Overview

Purpose

Understanding electrical components in gas appliances and how power is safely distributed

Objectives

Describe electrical services, ground fault circuit interrupters, electrical bonding to gas piping, single and three-phase power, types and ratings of fuses and breakers, and types and gauges of wire

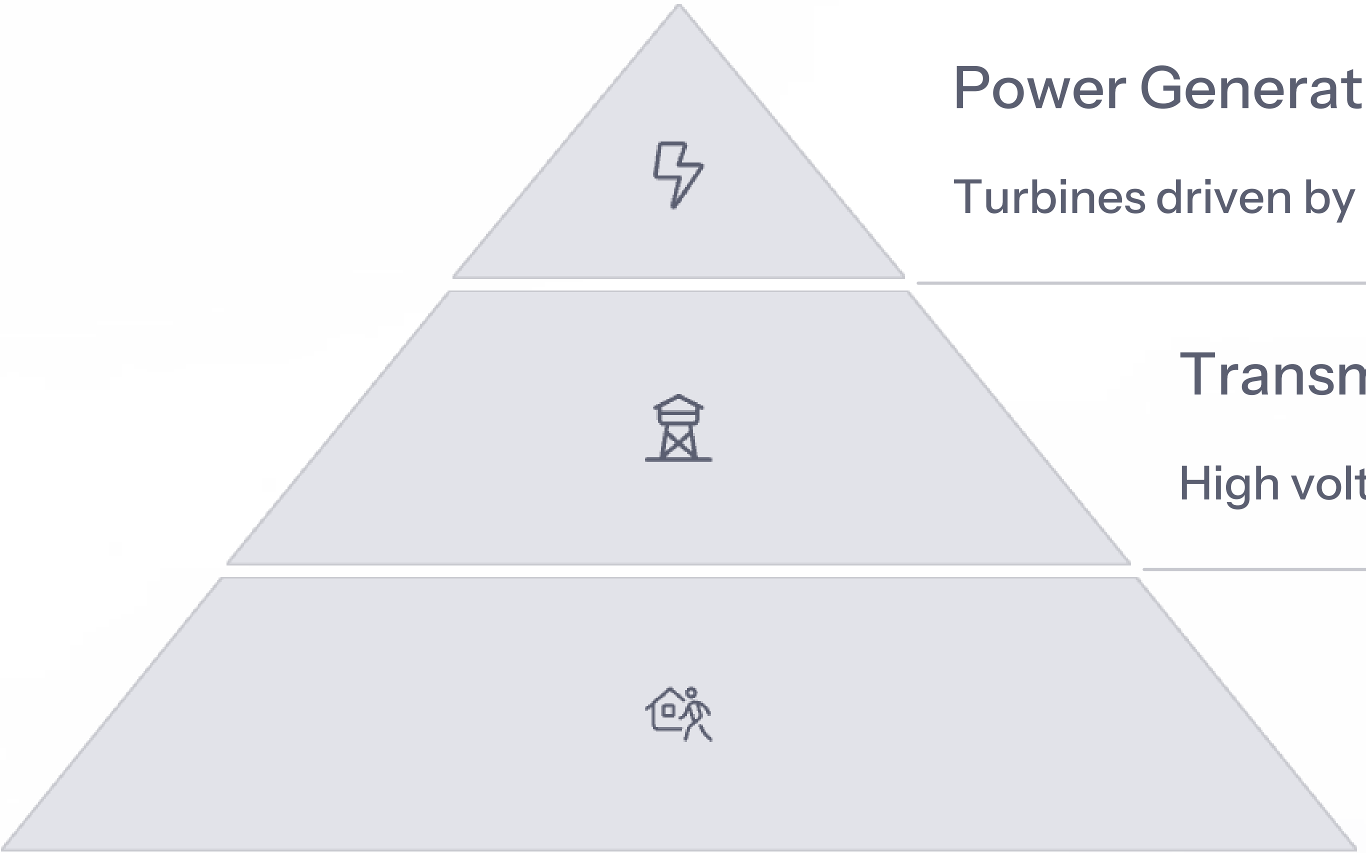
Key Terminology

Term	Definition
Ampacity	The amount of current a conductor is rated to safely handle
Bonding	Permanent joining of all non-current-carrying metal parts to ensure electrical continuity and establish a low-impedance path
Conductor	A material that allows electrical current to flow through it with relative ease
Electrolysis	Chemical breakdown of two metals in contact reacting with one another
Ground fault circuit interrupter (GFCI)	A specially designed receptacle or distribution panel circuit breaker used to protect users from electric shock

More Key Terminology

Term	Definition
Grounding	Connection of all exposed non-current-carrying metal parts to the earth that provides a direct path for unwanted current
Non-metallic-sheathed cable (dry) - NMD	For exposed wiring in dry or damp locations and for concealed wiring in dry or damp locations
Non-metallic-sheathed cable (wet) - NMW	For exposed wiring in dry locations, wet locations, and for concealed wiring in dry locations
Overcurrent device	Main circuit breaker or a pair of fuses that protect the line wires and transfer power to the two hot bus bars
Overload	Moderate increase in current beyond the rated current value

Electrical Generation and Distribution



Power Generation

Turbines driven by wind, water, steam, or gas

Transmission

High voltage lines carry power from sources

Distribution

Lines connect to individual customers

Almost all commercial electrical power on Earth is generated with a turbine, which drives a generator, transforming mechanical energy into electrical energy through electromagnetic induction. The electrical grid is an interconnected network for delivering electricity from producers to consumers.

Power Distribution Network

Generating Stations

Produce electrical power

Step-Up Transformers

Change voltage to a level suitable for transmission

Transmission Lines

Carry power long distances

Substations

Step down voltage from transmission to distribution level

Service Location

Final step down to required service voltage

Three-Phase Power Applications

Uses

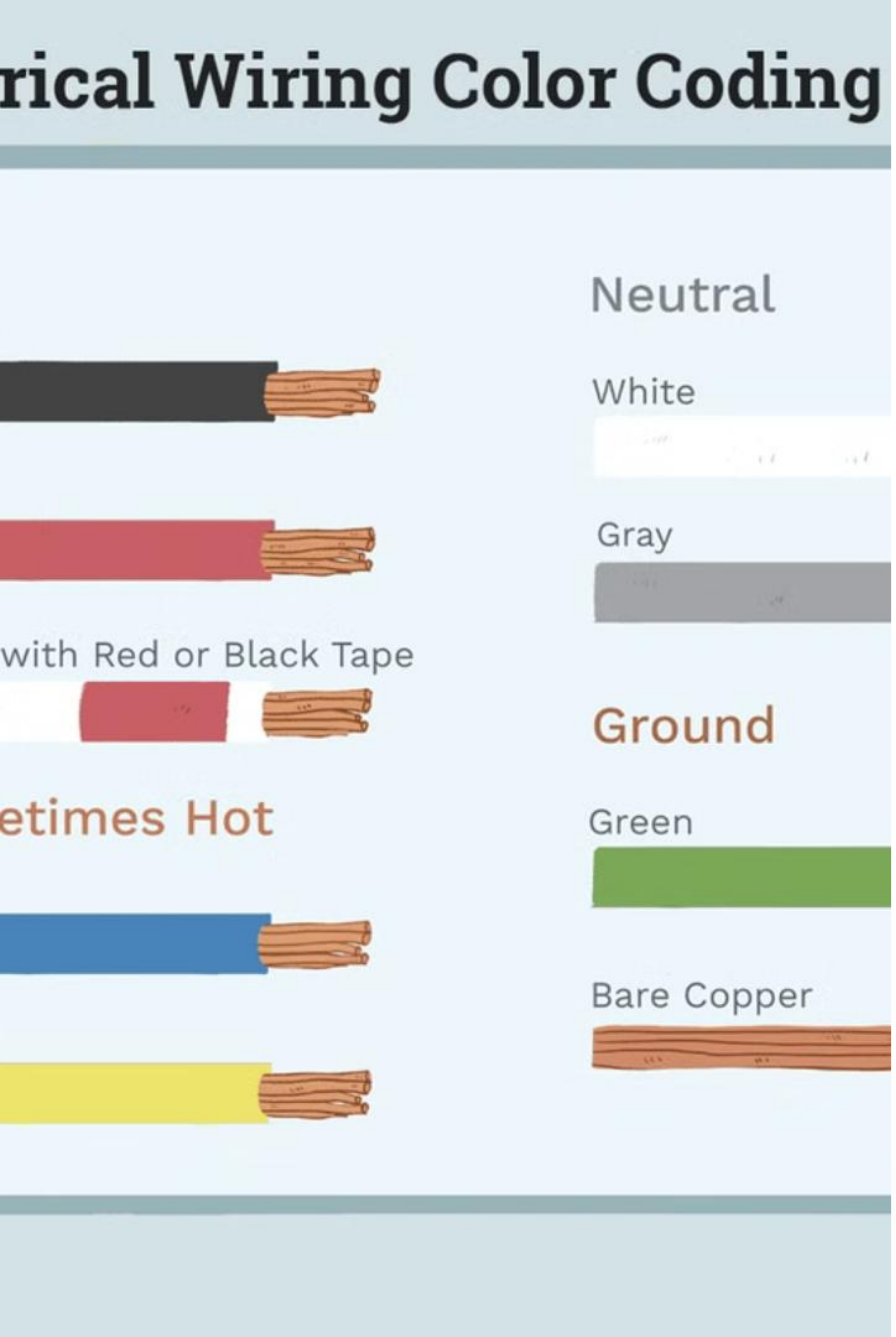
Three-phase power supply is used to power large motors and other heavy loads. A three-phase system is generally more economical than equivalent single-phase or two-phase systems at the same voltage.

Three-phase, three- and four-wire systems are used for industrial and commercial applications.

Four-Wire System Components

- Three hot line wires
- A ground wire
- A neutral may also be included, at times

Four commonly supplied voltages are: 120/208 V, 240/416 V, 347/600 V, and 600 V.



Three-Phase Wire Color Coding

Wire	Colour
Neutral (when present)	White or natural grey
Phase A (phase wire A)	Red
Phase B (phase wire B)	Black
Phase C (phase wire C)	Blue

The neutral wire (the identified circuit conductor) must have the same colour throughout the whole length of the circuit it services, for conductor sizes up to No. 2 AWG. Identified circuit conductors larger than No. 2 AWG must be identified at both ends with white tape, unless the conductor is white.

Residential Service Requirements

Minimum Requirements

The minimum requirement in most new residential construction is 100-amp service

Older Homes

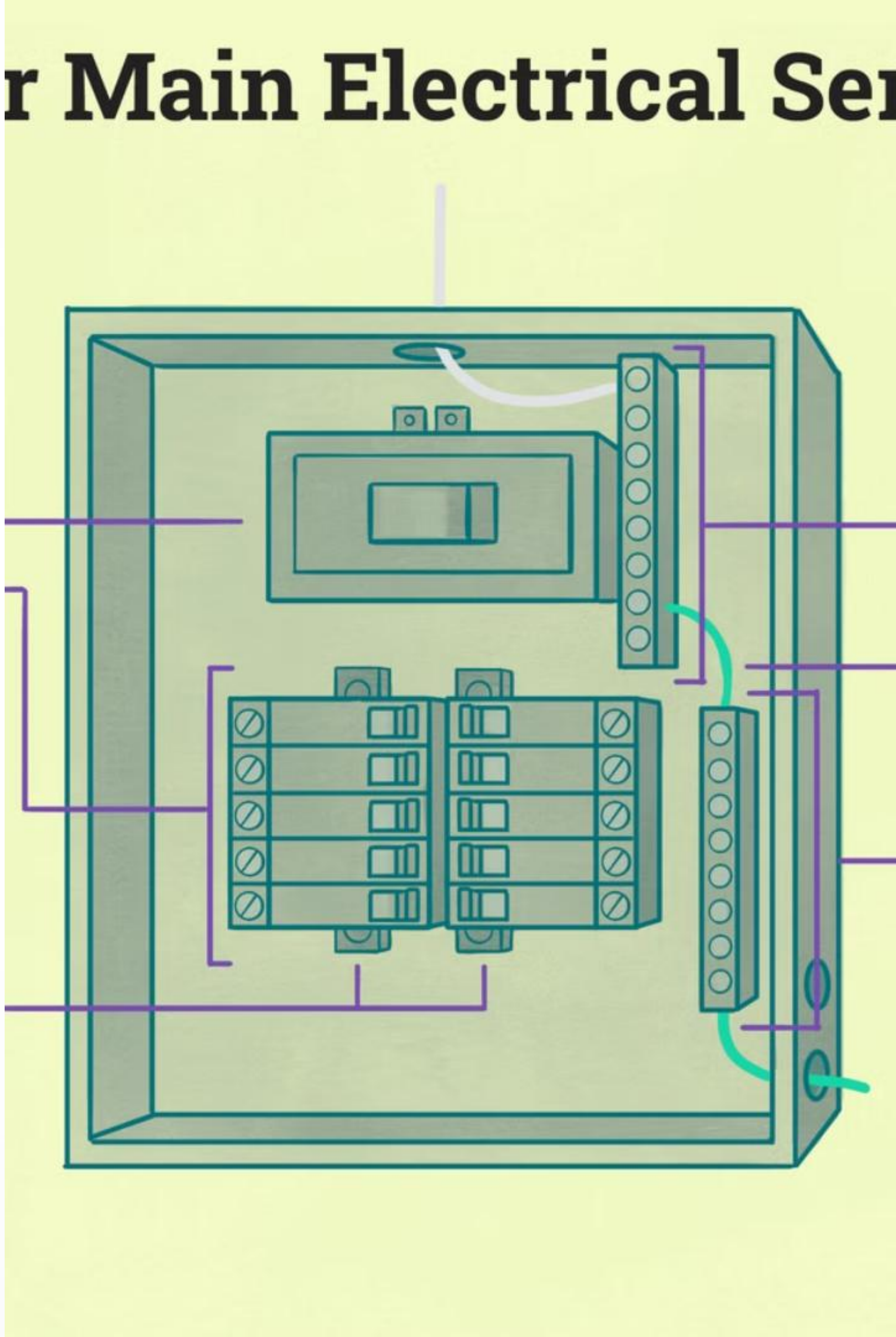
Many older homes have 60-amp services

Electric Heating

Homes heated by electricity require a 200-amp service

Service Upgrades

As more appliances are added, the electrical service may need to be upgraded to a higher amperage rating



Electrical Distribution System Components

Electric Meter

Records the amount of electrical energy in kilowatt-hours consumed over a certain period

Main Switch

Used to shut off the supply of electricity to the building

Distribution Panel

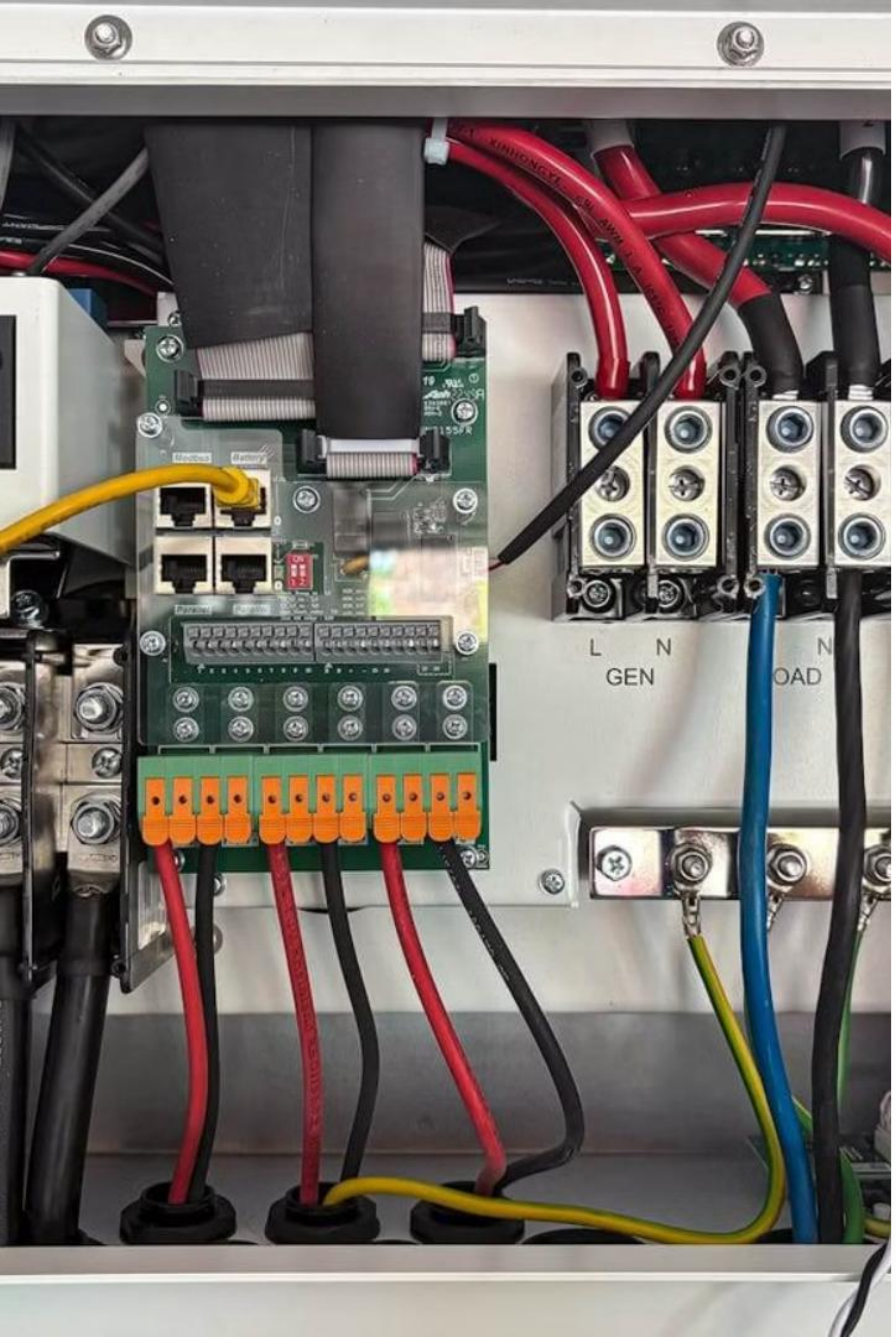
Contains fuses or circuit breakers that connect the electrical supply to various loads

Fuses/Circuit Breakers

Protect conductors from overloads and short circuits

Wire Conductors

Carry electricity to various circuits throughout the building



Fuses and Circuit Breakers

Sizing

Fuses and circuit breakers are sized according to the wire they protect, and the wire is sized according to the load of the individual branch circuits.

Circuit Limitations

120 V branch circuits are limited to a maximum number of receptacles and fixtures to avoid overloading. Some 120 V appliances, such as refrigerators and freezers, require separate circuits and breakers.

Heating Circuits

Individual heating circuits are limited to a maximum wattage rating and have separate fuses or breakers.

High-Load Appliances

Electric ranges, dryers, and hot waters are on separate circuits, protected by high-amperage fuses or breakers.

Wire Conductors

Branch Circuit Sizing

Individual branch circuits are sized according to the size of wire used in the circuit: as more circuits are added, the total current increases.

Most residential lighting and receptacle circuits and other 120 V circuits are supplied by 14-2 AWG (14-gauge, 2-wire, plus bond) conductors. Heating circuits, including most hot water heaters, generally use 12-2 AWG conductors, while ranges and dryers require much heavier gauge conductors.

Appliance Wiring

Wire used in the internal wiring of gas-fired appliances will frequently be a lighter (smaller) gauge and is generally of the multi-stranded type of design. Appliances are manufactured in accordance with a particular standard and are certified for use with specific wiring. Any repairs to this wiring must conform to the same standard.

External wiring must conform to the electrical code adopted in the province where the work is being performed.

Wire Size and Ratings

Wire size	Rating (amperage)	Breaker size (amps)
#14	15 A	15 A
#12	20 A	20 A
#10	30 A	30 A
#8	45 A	40 A
#6	65 A	60 A
#3	105 A	100 A

Always refer to the Canadian Electrical Code, Part I (CE Code) and the manufacturer for the correct application of wire and ratings.

Gas Piping System Hazards

Fire and Shock Hazards

The gas piping system in a building can create fire and shock hazards throughout the building if it is not properly bonded to ground

Fault Current Path

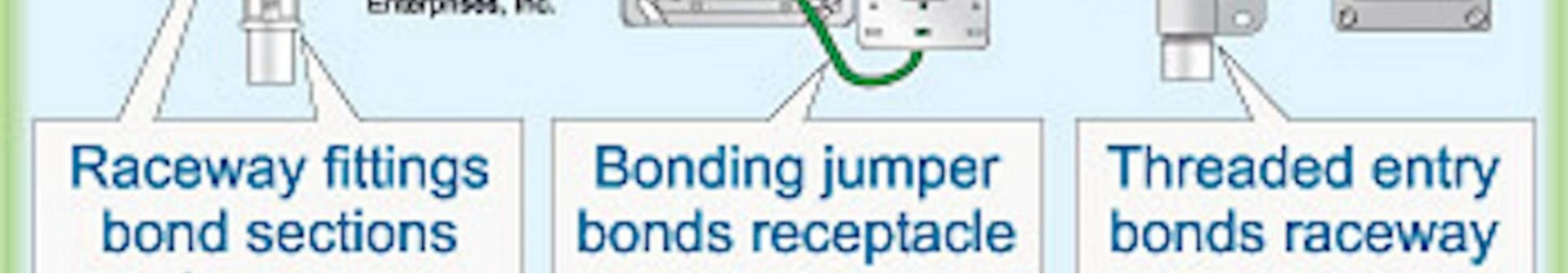
The piping system can become a path for a fault current event from the electrical system

Equipotential Bonding

Bonding of conductive pipes and systems is provided to prevent them from carrying a voltage different from the electrical system

Metal Gas Tubing

The requirement to provide equipotential bonding to a metal gas piping system is not intended to apply to metal gas tubing



Benefits of Bonding and Grounding

Shock Protection

Protect persons from electric shock hazards

Short Circuit Path

Provides a path for short circuit current

Property Protection

Protect property from damage caused by short circuits and lightning

Circuit Protection

Open fuses and circuit breakers when short circuits occur

Interior gas piping systems are electrically bonded to ground at the electrical panel to prevent possible hazards. Bonding the gas piping system to ground prevents arcing (sparking) due to electrical potential difference between the piping and ground, reducing the risk of accidental ignition.

Purpose of Fuses and Breakers

Protection Devices

The fuse and the circuit breaker are the two most commonly used devices for the protection of electrical systems. The purpose of a protective device is to open the electrical circuit, stopping current flow, before damage can be done to the conductors and equipment connected to the circuit.

Key Differences

The difference between fuses and circuit breakers is that:

- Fuses are one-time-use only devices and must be replaced when they activate and open
- Circuit breakers can be reset if they trip

All fuses and breakers are sized to protect the circuit conductors, not the appliances connected to the circuit. Fuses and breakers must not be oversized.

Fuse and Breaker Applications

Time-Delay Fuses

Time-delay fuses should be used to protect inductive type circuits (motors) and where intermittent, momentarily high loads will be encountered, such as motor and air conditioning circuits.

Code Specifications

The CE Code specifies maximum ampacity values for fuses, breakers, and other protective devices.

Manufacturer Details

Each fuse or breaker manufacturer has specific details of the use and application of electrical circuit protectors. Electrical safety and protective devices are matched to the application to ensure the right overcurrent protection.

Replacement Guidelines

When changing a circuit protector, replace it with the same type as originally provided by the manufacturer or consult the manufacturer for the correct replacement.

Safety Warnings for Circuit Protection

Never change a fuse with the power on!

Always disconnect power before replacing fuses to prevent electrical shock

Never work live unless you are authorized and supervised!

Working on energized circuits requires special training and authorization

Understanding Overloads

An overload is a moderate increase in current beyond the rated current value and exposes conductors and equipment to more current than their design allows.

A circuit becomes overloaded when the equipment connected to it draws more current than that for which the circuit is designed or rated. The heat produced by an overload often causes electrical insulation deterioration and failure. During an overload, the protective device must open before damage occurs.

Causes of Overload

Too Much Equipment

Too much equipment connected to a circuit (the octopus effect)

Insufficient Capacity

Using equipment with insufficient capacity for the work to be done

Worn Components

Worn-out or seized motor bearings and other electrical components

Excessive Load

Excessive mechanical load

Faulty Wiring

Faulty or damaged wiring causing short circuits

Overload current values may range as high as six times normal current value.

Understanding Overcurrent

What is Overcurrent?

An overcurrent may range from six times to many hundreds of times the normal rated currents and, unlike an overload, happens very quickly. Two situations can cause an overcurrent:

- Current surge when a motor starts up
- Short circuit

Current Surge

When an electric motor starts up, it momentarily draws a current much greater than its normal full-load current. The overcurrent that results from this inrush current surge lasts a very short time, but the protective device must be capable of withstanding it.

Short Circuits

Rapid Development

Within a few thousandths of a second, the overcurrent that results from a short circuit can increase to hundreds of times larger than the normal operating current.

Insulation Failure

Failure of a conductor's insulation, causing the conductor to touch a metal casing and create a line-to-ground short.

Foreign Object Contact

A foreign object making accidental contact with a conductor, causing a line-to-line short.

Abnormal Path

A short-circuit current is different from an overload because it flows outside its normal path. The thermal and magnetic arcing associated with short circuits can cause extensive damage.

Types of Fuses

Fuses are simple current-limiting devices that protect circuit and conductors. A fuse consists of an insulated tube containing a strip of heat-sensitive metal that has a lower melting point than copper or aluminum. This metal strip (link) will heat up before the circuit conductors do when excessive current passes through the conductors.

The heat generated by the excess current melts the link, automatically opening the circuit before the conductors are overheated and damaged. A short circuit then causes the fuse element to melt in just a fraction of a second.

Common Categories of Fuses

Plug Fuses

Plug fuses are also known as screw-base or Edison-base fuses. These were quite common in wiring installations in homes at one time, but they have pretty much been replaced by circuit breakers, although they are still used in domestic ranges and seen in many older installations.

Cartridge Fuses

There are three basic types of cartridge fuse:

- Ferrule-contact
- Knife
- Bolt-on

Standard fuses and high-rupturing capacity fuses are manufactured in all three designs.

CE Code Plug Fuse Requirements

Rule 14-208 1)

States that the maximum rating of any plug fuse is 30 A. Commonly available ratings are 15 A, 20 A, 25 A, and 30 A. Plug fuses with lower ratings are available for special applications (1 A, 2 A, 3 A, 5 A, 6 A, 8 A, and 10 A).

Rule 14-202

States that a plug fuse shall not be used in a circuit with more than 125 V between conductors, except where the circuit is supplied from a system with a grounded neutral and there is no conductor operating at more than 150 V to ground.

Rule 14-204

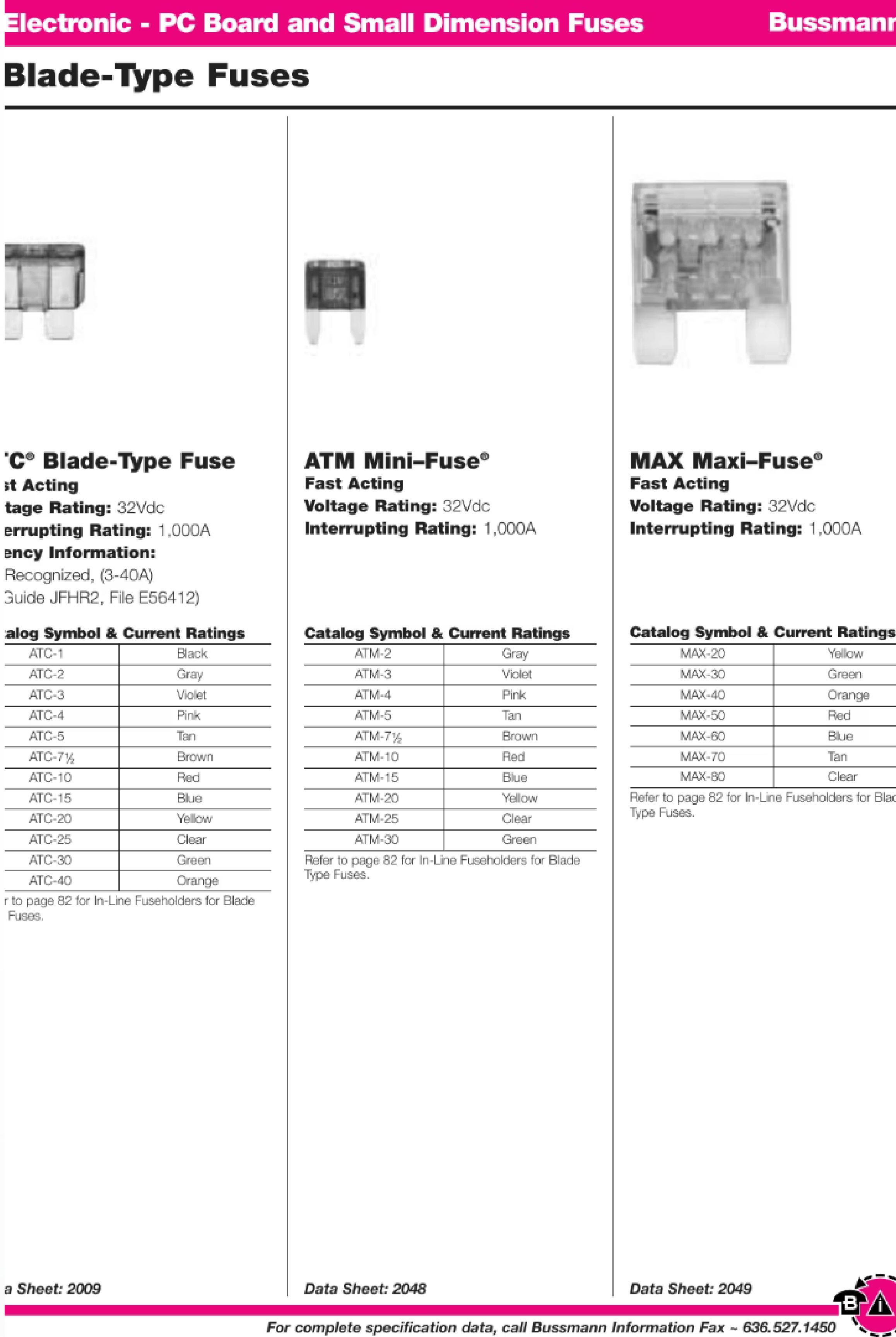
States that plug fuses with different ratings must not be interchangeable. Where an alteration or addition is made to an existing fusible panel, all the plug fuses in the panel shall comply with CE Code Rule 14-204.

A Type C plug fuse with the correct rejection washer or a Type S plug fuse with the correct nonremovable socket adapter can be used to comply with Rule 14-204.

Rejection Washers for Type C Fuses

Before a Type C plug fuse can be inserted into the panel, a properly sized rejection washer must be placed in the fuse holder. The thickness of the washer and the diameter of the hole prevent fuses with different ratings from making contact.

Colour	For
Blue	15 A or less
Red	20 A or less
Green	30 A or less


lectronic - PC Board and Small Dimension Fuses Bussmann

Blade-Type Fuses

'C® Blade-Type Fuse
t Acting
tage Rating: 32Vdc
errupting Rating: 1,000A
ency Information:
Recognized, (3-40A)
Guide JFHR2, File E56412)

alog Symbol & Current Ratings	
ATC-1	Black
ATC-2	Gray
ATC-3	Violet
ATC-4	Pink
ATC-5	Tan
ATC-7½	Brown
ATC-10	Red
ATC-15	Blue
ATC-20	Yellow
ATC-25	Clear
ATC-30	Green
ATC-40	Orange

r to page 82 for In-Line Fuseholders for Blade Fuses.

a Sheet: 2009

ATM Mini-Fuse®
Fast Acting
Voltage Rating: 32Vdc
Interrupting Rating: 1,000A

Catalog Symbol & Current Ratings	
ATM-2	Gray
ATM-3	Violet
ATM-4	Pink
ATM-5	Tan
ATM-7½	Brown
ATM-10	Red
ATM-15	Blue
ATM-20	Yellow
ATM-25	Clear
ATM-30	Green

Refer to page 82 for In-Line Fuseholders for Blade Type Fuses.

Data Sheet: 2048

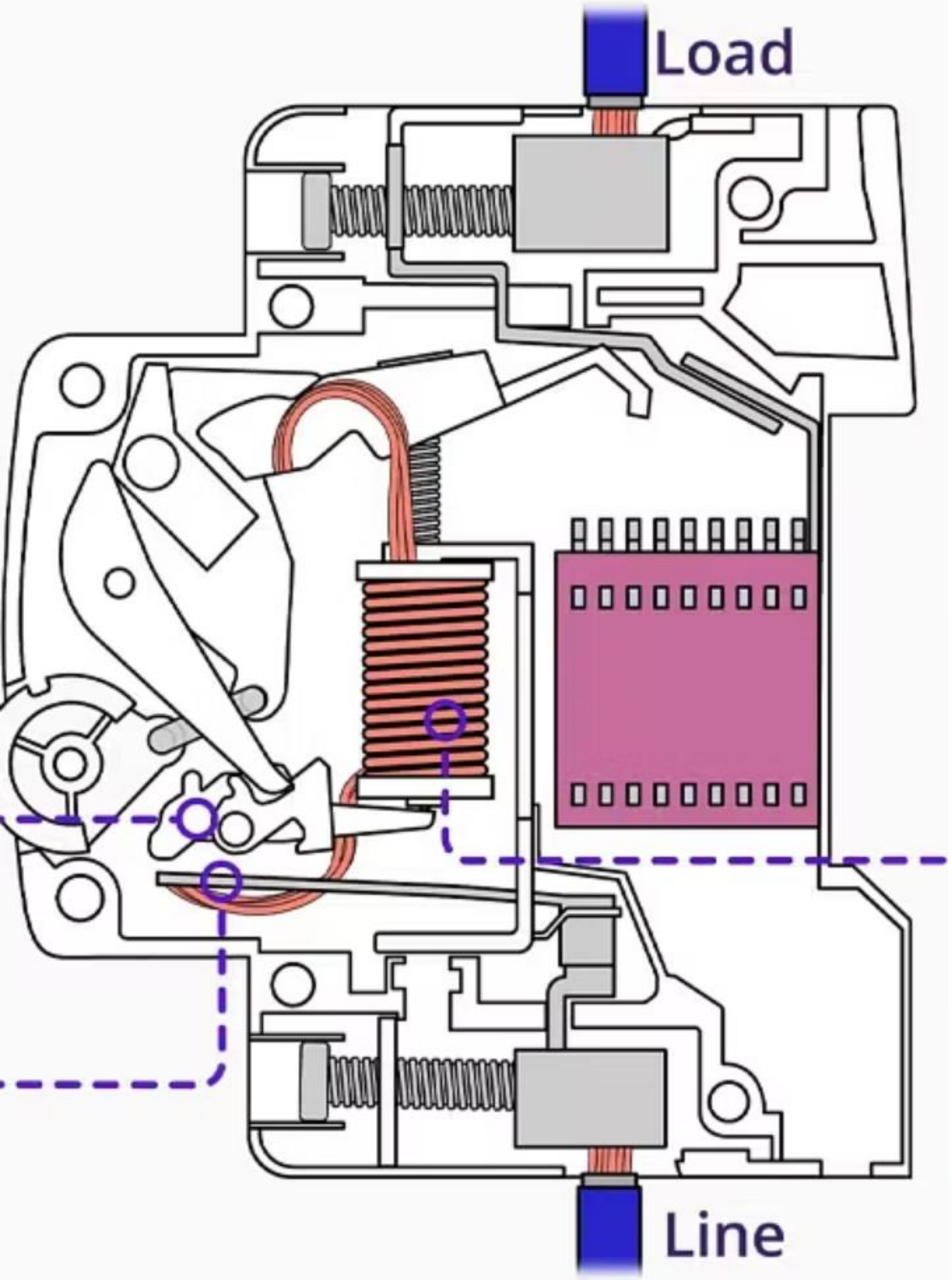
MAX Maxi-Fuse®
Fast Acting
Voltage Rating: 32Vdc
Interrupting Rating: 1,000A

Catalog Symbol & Current Ratings	
MAX-20	Yellow
MAX-30	Green
MAX-40	Orange
MAX-50	Red
MAX-60	Blue
MAX-70	Tan
MAX-80	Clear

Refer to page 82 for In-Line Fuseholders for Blac Type Fuses.

Data Sheet: 2049

For complete specification data, call Bussmann Information Fax ~ 636.527.1450



Circuit Breaker Advantages

Resettable

When a circuit breaker trips to open a circuit, it can be reset by hand without the need to replace any parts

Weakening Over Time

A breaker that has tripped several times will become weaker and cause the breaker to trip sooner than it is rated (i.e., a 15 amp breaker may start to trip at 12 amp)

Replacement

In cases of weakening, the breaker will have to be replaced

Circuit Breaker Components

Frame (or Case)

The outer housing that contains all components

Operating Mechanism

Controls the opening and closing of contacts

Trip Elements

Triggers the operating mechanism under fault conditions

Contacts

The points that connect or disconnect the circuit

Terminal Connection

Where the circuit wires connect to the breaker

Circuit Breaker Operation

Quick-Make, Quick-Break

A quick-make, quick-break type handle is used to turn the breaker on and off. This means that the speed at which the contacts snap open or closed is independent of how fast the handle is moved.

Trip-Free Design

The breaker is trip-free, which means it cannot be prevented from tripping by holding the handle in the ON position. When the breaker trips, the handle moves midway between the ON and OFF positions. To reset the breaker, the handle must be moved from the centre position to OFF, then back to ON.

Magnetic Trip Element

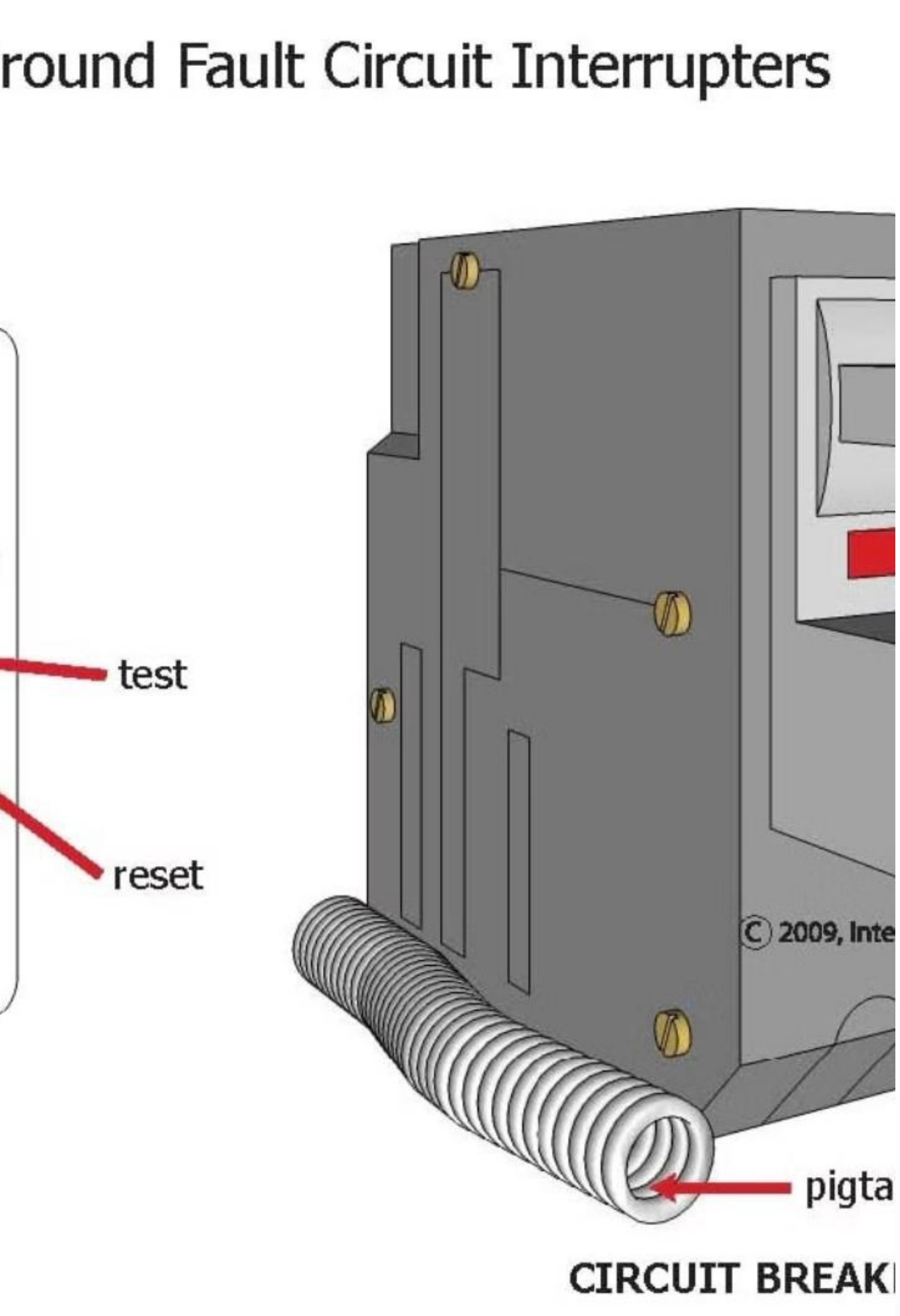
This short-circuit and ground-fault protection element is an electro-magnetic device wired in series with the load.

When a short circuit occurs, the fault current passing through the circuit causes the electromagnet to attract an armature mounted on the trip bar. This action opens the contacts.

High-Interrupting-Capacity Breaker

When a large electric current is interrupted, an arc forms, and if the interrupting (breaking) capacity of a fuse or circuit breaker is exceeded, it does not extinguish the arc. Current then continues, resulting in damage to equipment, fire, or explosion. If you look closely at the standard low-voltage breakers in previous images, you can see a breaking capacity of 10 kA (10,000 amps).

In many low-voltage distribution systems, the available short-circuit current from the supply system often exceeds the interrupting capacity of standard breakers. This situation requires a special high-interrupting-capacity (HIC) breaker is similar to and has the same size as the standard thermal-magnetic breaker, except that it provides a higher interrupting capacity.



GFCI Operation

High Sensitivity

The GFCI trips when it senses a change in current flow as small as 5 milliamps (mA)

Quick Response

The tripping action occurs quickly enough to prevent serious or fatal electrical shock

Reset Mechanism

A GFCI receptacle has an internal circuit breaker that can be reset by means of a pushbutton when the ground fault is corrected

Panel Type

A GFCI distribution panel breaker must be reset at the panel

GFCI Limitations

Not for Overload Protection

A GFCI does not protect a circuit or electrical device from current overload-that is the purpose of the circuit breaker.

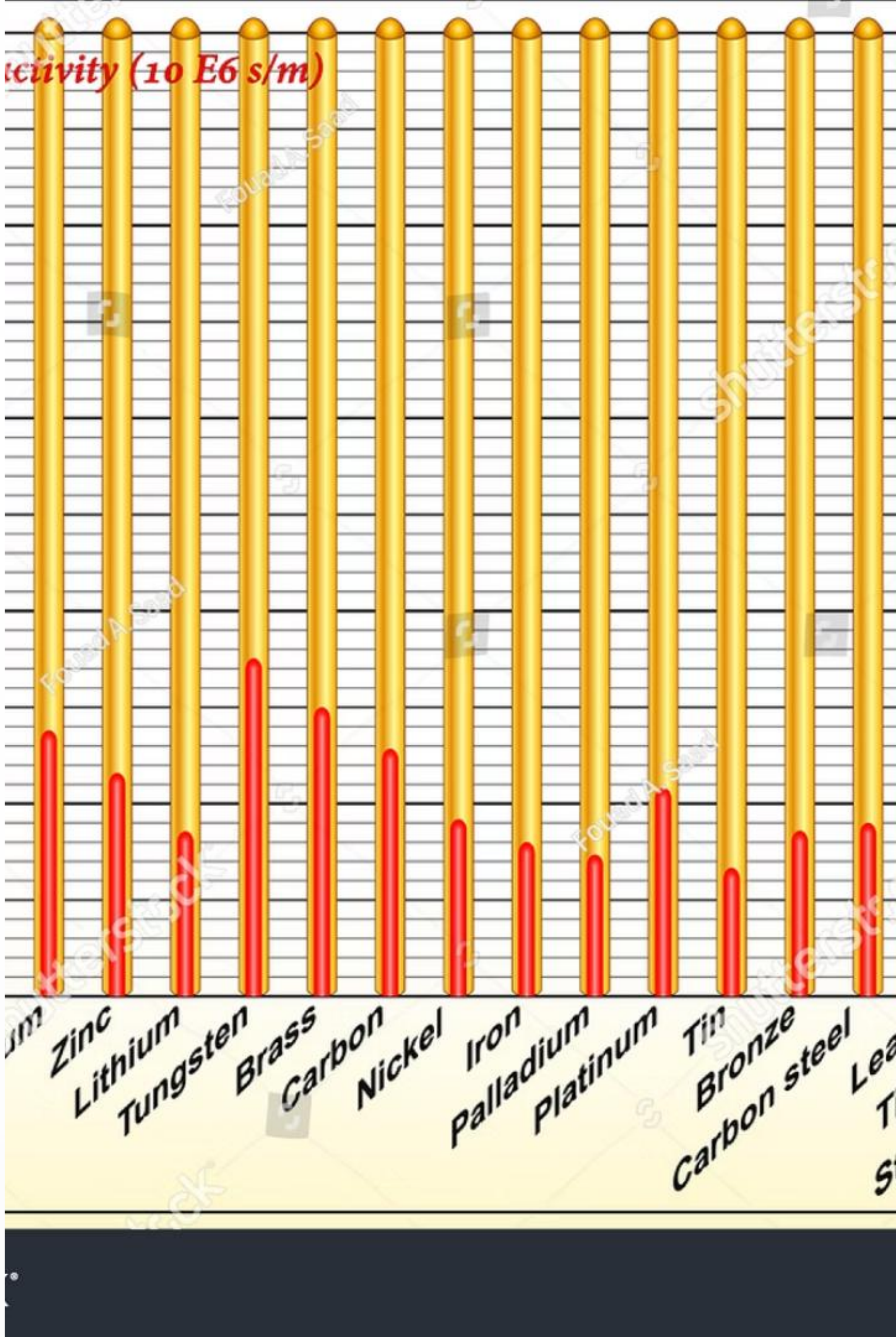
Limited Shock Protection

It does not provide protection from electric shock if a person touches both conductors of the GFCI-protected circuit or a live conductor from another circuit.

Conductors

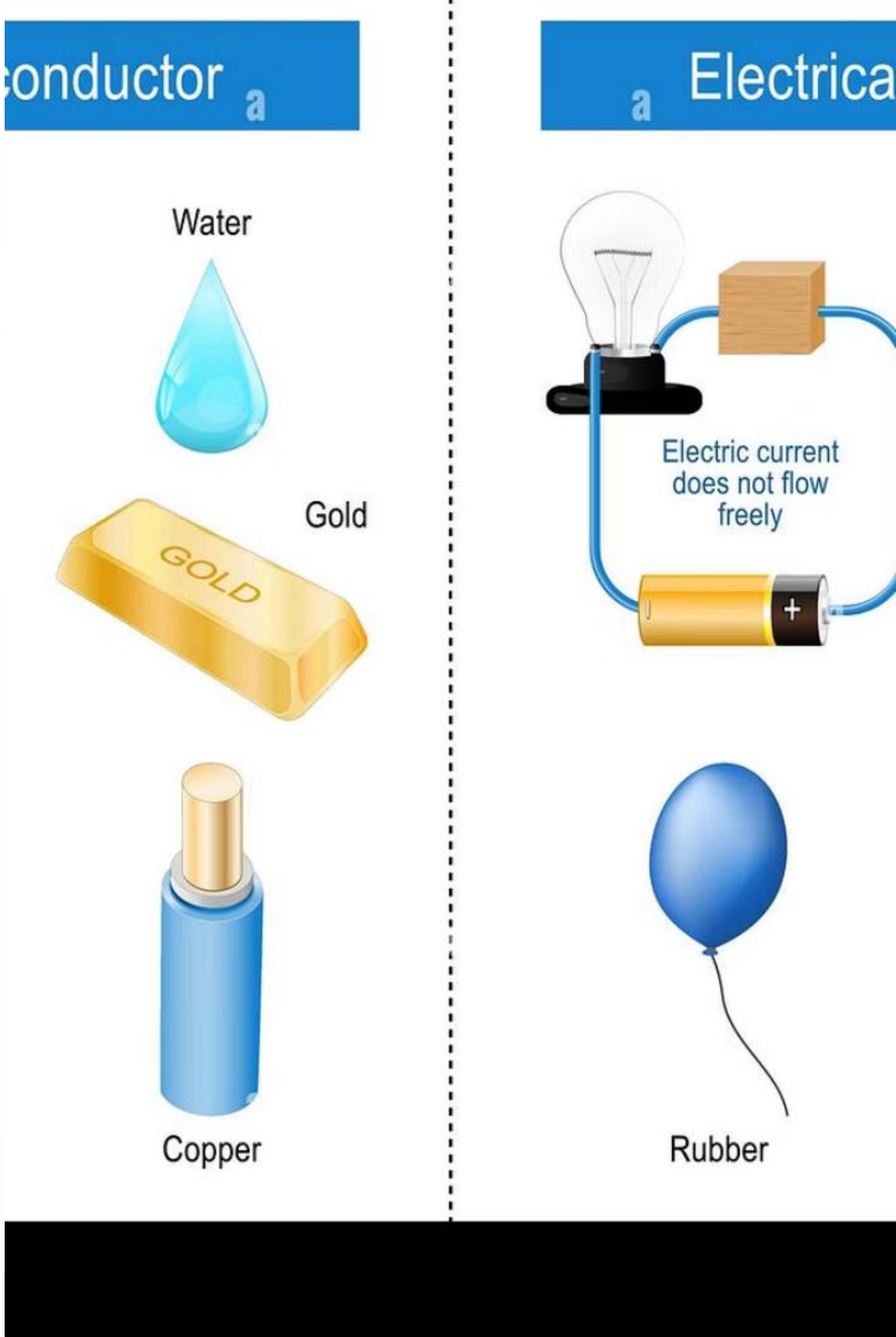
A conductor is a conductive material that is constructed for the purpose of carrying electric current. The best conductor is one that carries the greatest amount of current with the lowest rise in temperature.

The selection of a conductor for specific purposes is based on factors such as cost, weight, oxidation, ductility, malleability, ultimate strength, oxide resistance, contact resistance, and conductance.



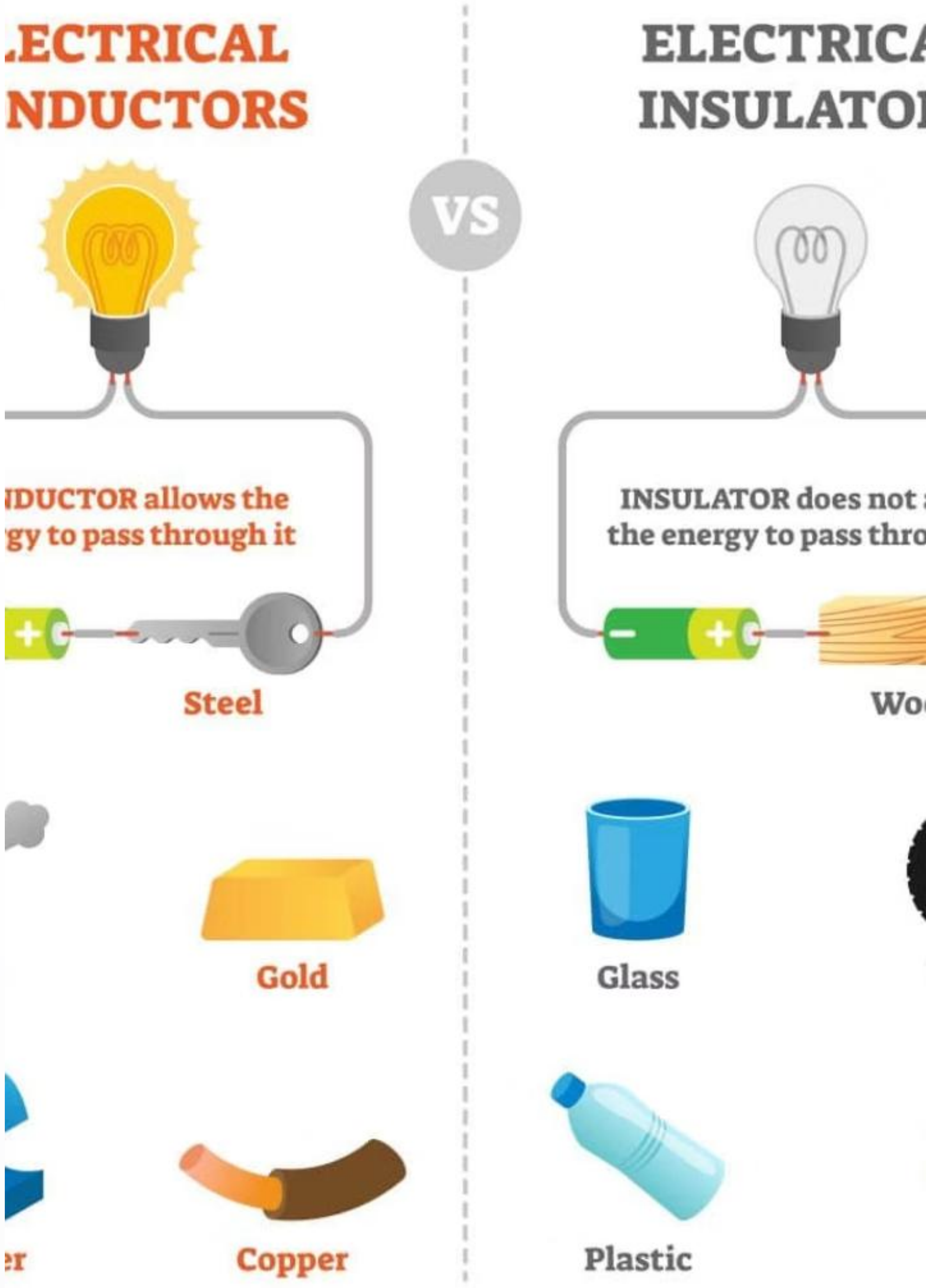
Conductor Selection Factors

Factor	Consideration
Cost	Gold and silver are excellent conductors, but very expensive
Weight	Aluminum does not conduct as well as copper but is used in many applications because it is 30% lighter than copper
Oxidation	Aluminum oxidizes faster than copper, but this is offset by aluminum's lower cost
Ductility	The ability of a material to be drawn into wire form. The finer the wire, the more ductility the material must have
Malleability	The ability of a material to be formed in thin sheets. Thin conductive foil is used in some resistors and other electronic components



More Conductor Selection Factors

Factor	Consideration
Ultimate strength	The amount of mechanical stress a material can withstand before breaking. Aluminum does not have sufficient ultimate strength to support its own weight when strung over long distances
Oxide resistance	When the surface of a conductor oxidizes, the oxide can negatively affect connections and terminations
Contact resistance	The resistance per area of contact between two conductors at a given pressure varies with the conductor material
Conductance	The opposite of resistance. A good conductor has high conductance and low resistance



Copper Conductors

Excellent Conductor

Copper is an excellent conductor, used extensively in wire form and in electronic circuits

Easy to Solder

It solders easily and provides secure electrical connections

Workability

Copper is easily worked and more resistant to oxidation than steel or aluminum

Cost Factor

It is more expensive than some alternatives

Aluminum Conductors

Characteristics

Aluminum is lighter than copper but less conductive. An aluminum conductor must be slightly larger in diameter than a copper conductor of the same current-carrying capacity.

Disadvantages

Aluminum has three major disadvantages when used as an electrical conductor:

- It oxidizes rapidly
- It is subject to electrolysis
- It is prone to cold flow

Other Conductor Materials

Silver and Gold

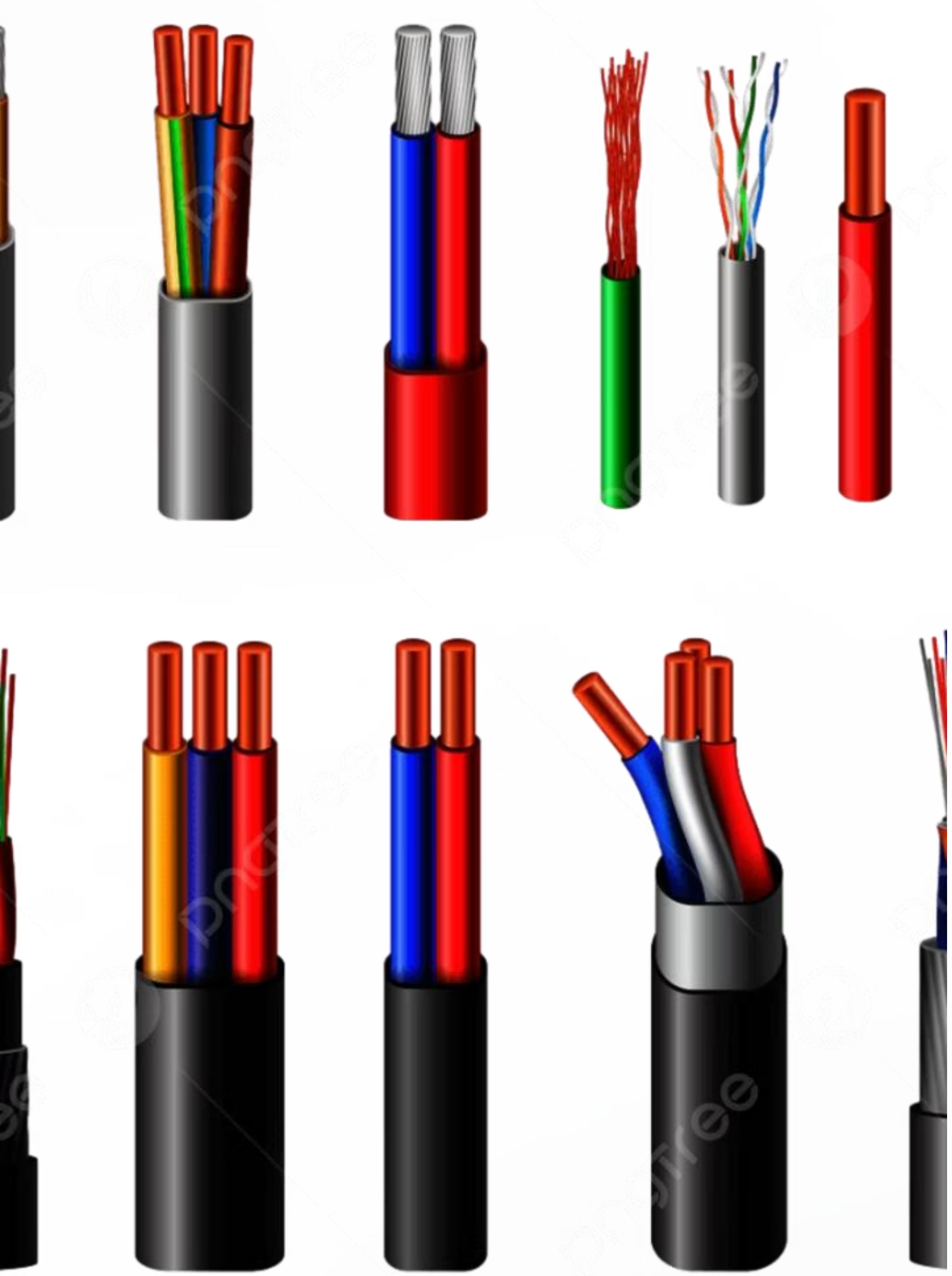
Silver and gold are very expensive and rarely used in wire form as conductors. However, they are used in thin layers on electronic contacts and in other similar applications due to their:

- Slow rate of oxidation
- High conductivity
- High malleability

Steel

Steel is stronger and cheaper than the other conductors and is used in the following applications:

- As a supporting core for aluminum and copper conductors used outdoors
- Conducting rails for electric railway and subway systems
- As a conductor when metal conduit and receptacle boxes are used to complete a grounding circuit



Electrical Conductors and Wiring

Electrical conductors and wiring are essential components in electrical systems, providing pathways for electrical current to flow safely and efficiently. This presentation explores the various types of conductors, their properties, applications, and safety considerations according to electrical codes.

Wire Conductors

Most Common Form

Wire is the most common form of electrical conductor. Most electrical wiring is copper or aluminum, solid or stranded in form.

Solid Wire Conductors

Manufacturing Process

Solid copper wire is usually formed by drawing a soft copper rod through a series of doughnutshaped metal blocks called dies. Each successive die has a smaller diameter hole than the previous one. As the copper rod passes through the dies, it is reduced in diameter and becomes longer.

Applications

Solid wire is commonly used in residential wiring and applications where flexibility is not a primary concern. The solid construction provides durability and consistent electrical properties.

Stranded-Wire Conductors

Construction

A stranded-wire conductor consists of a group of wires that are twisted or braided together, often around a central core. A stranded wire acts as a single conductor, with nearly the same currentcarrying capacity as a single solid wire of the same gauge.

Size Specifications

Stranded-wire conductors are usually No. 8 AWG and larger. The wires making up a stranded conductor normally have the same size.

Flexibility Factors

The size of the wires depends on the flexibility required - the smaller the diameter of the wire strands, the more flexible the conductor.

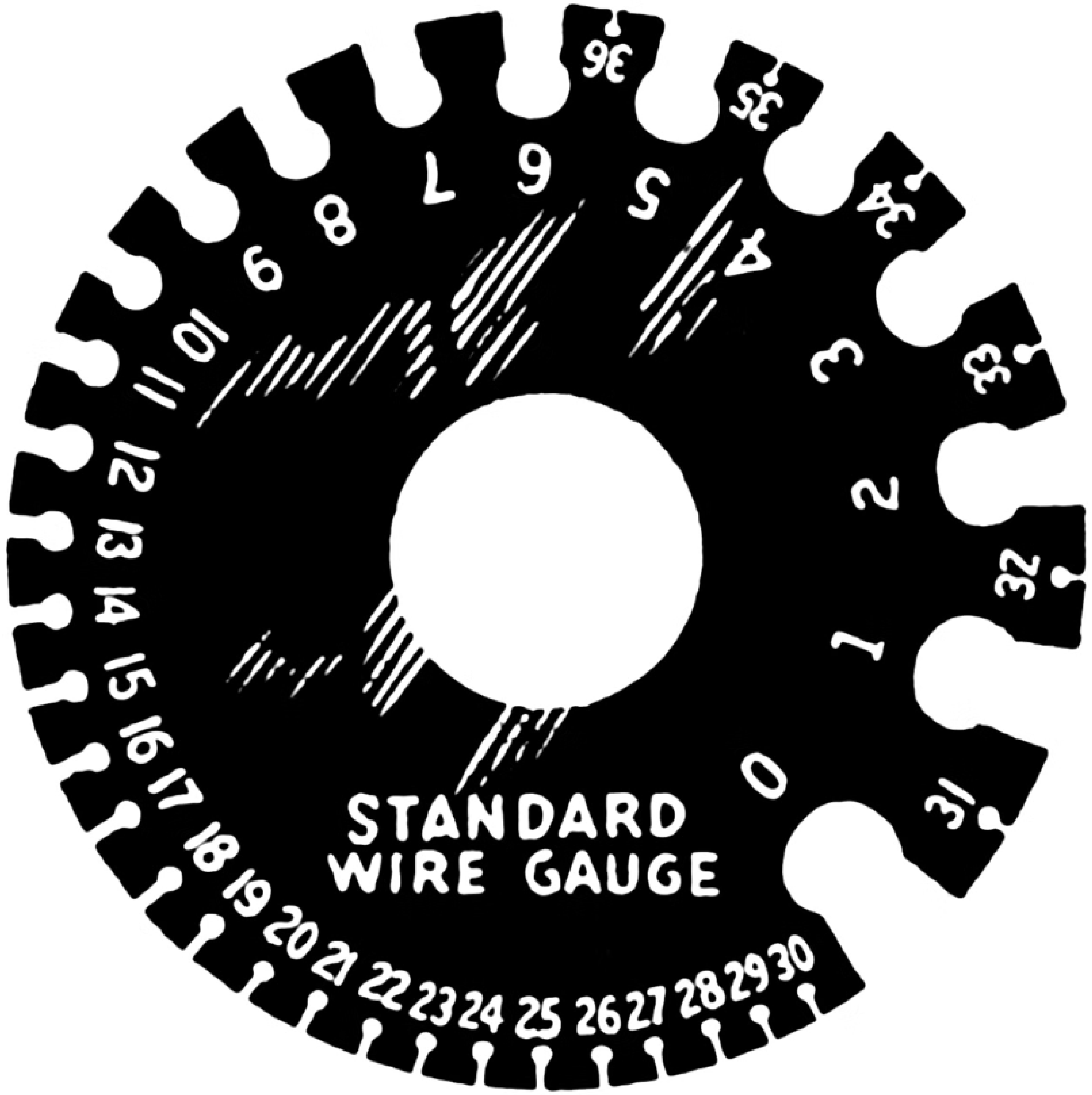
Conductor Size (Gauge)

American Wire Gauge (AWG)

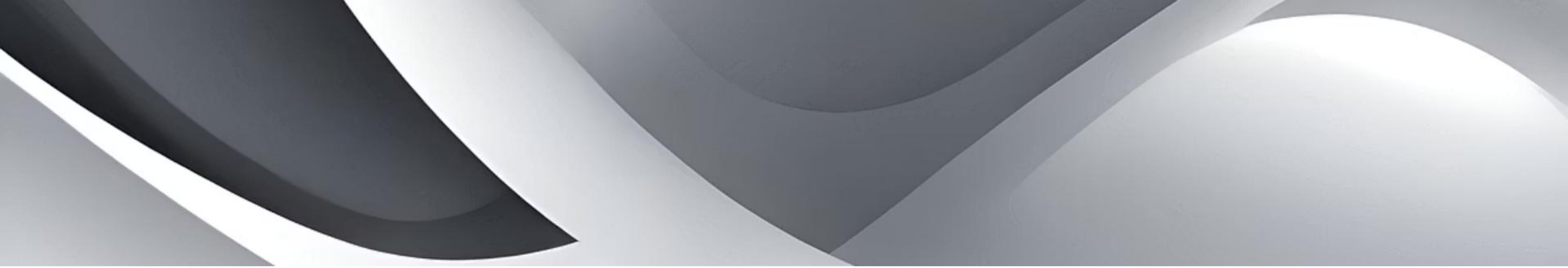
Wire conductors are sized according to the American Wire Gauge (AWG) standard.

Sizes range from No. 44 AWG to No. 4/0 AWG (0000), as shown in Table 1-3.

The smaller the AWG number, the greater the diameter and cross-sectional area of the conductor.



Visual representation of different wire gauges showing the inverse relationship



AWG Wire Conductor Sizes

AWG No.	Dia. (mils)	Area (circular mils)	AWG No.	Dia. (mils)	Area (circular mils)
0000	460	211,600	21	28.5	810
000	410	167,800	22	25.4	642
00	365	133,100	23	22.6	510
0	325	105,500	24	20.1	404

This table shows the relationship between AWG numbers, wire diameter in mils, and cross-sectional area in circular mils.

AWG Wire Conductor Sizes (Continued)

AWG No.	Dia. (mils)	Area (circular mils)	AWG No.	Dia. (mils)	Area (circular mils)
1	289	83,690	25	17.9	320
2	258	66,370	26	15.9	254
3	229	52,640	27	14.2	202
4	204	41,740	28	12.6	160
5	182	33,100	29	11.3	126.7

AWG Wire Conductor Sizes (Continued)

AWG No.	Dia. (mils)	Area (circular mils)	AWG No.	Dia. (mils)	Area (circular mils)
6	162	26,250	30	10.0	100.5
7	144	20,820	31	8.93	79.7
8	128	16,510	32	7.95	63.2
9	114	13,090	33	7.08	50.1
10	102	10,380	34	6.31	39.8

AWG Wire Conductor Sizes (Continued)

AWG No.	Dia. (mils)	Area (circular mils)	AWG No.	Dia. (mils)	Area (circular mils)
11	91	8,234	35	5.62	31.5
12	81	6,530	36	5.00	25.0
13	72	5,178	37	4.45	19.8
14	64	4,107	38	3.96	15.7
15	51	3,257	39	3.53	12.5

AWG Wire Conductor Sizes (Concluded)

AWG No.	Dia. (mils)	Area (circular mils)	AWG No.	Dia. (mils)	Area (circular mils)
16	51	2,583	40	3.15	9.9
17	45.3	2,048			
18	40.3	1,624	42	2.50	6.3
19	35.9	1,288			
20	32.0	1,022	44	1.97	3.9

*Area is in circular mills. **Diameter is in mils.

Conductor Ampacity

Definition

Ampacity is the current-carrying capacity of electric conductors expressed in amperes.

Resistance Factors

The larger the AWG number of a conductor, the greater the electrical resistance per unit length.

The resistance of a conductor increases with temperature and, as resistance increases, the voltage drop increases.

Length Considerations

Long wiring runs may require the use of larger-gauge conductors in order to maintain required circuit voltage values and remain within ampacity limits - the same reason for properly sizing gas pipe. Longer runs and larger pipe are required to maintain volume and pressure at the point of use within the allowable pressure drop.

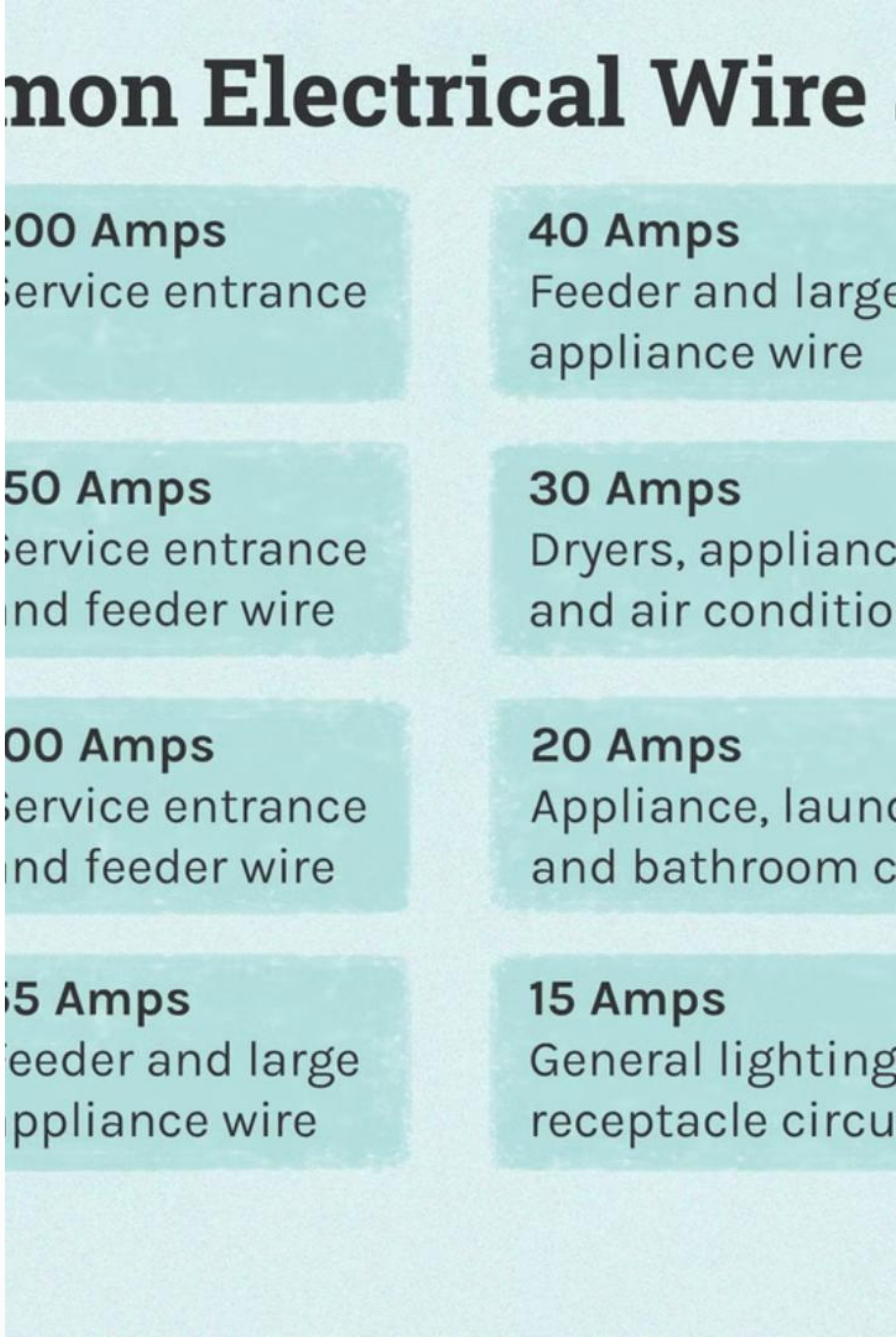
Ampacity Ratings

CE Code Specifications

The ampacity rating of wire conductor cables is specified in the CE Code.

Rating Factors

Ampacity rating depends on the type of cable, its insulation, and the maximum temperature to which the cable will be exposed.



Conductor Insulation

Protection

Prevents electric shock and undesirable current flow

Common Materials

Rubber compounds, PVC, and polyethylene plastic

Performance Requirements

Suitable voltage and temperature ratings for application

Conductor insulation is used to prevent the undesirable flow of electric current, such as ground faults and short circuits, and to protect against electric shock.

Insulation Performance Requirements

1. **Voltage Rating**

   Must have a voltage rating suitable for the intended application

2. **Temperature Rating**

   Must have a temperature rating suitable for the intended application

3. **Environmental Suitability**

   Must be appropriate for the environment in which it is to be used

4. **Mechanical Protection**

   Must be protected against possible mechanical damage

Conductor Sizing for Current Capacity

No.14 AWG copper

15 A maximum overcurrent protection

No.12 AWG aluminum

15 A maximum overcurrent protection

No.12 AWG copper

20 A maximum overcurrent protection

No.10 AWG copper

30 A maximum overcurrent protection

No.10 AWG aluminum

25 A maximum overcurrent protection

If a circuit is fused higher than allowed, the conductor can overheat and start a fire.

Allowable Ampacities for Copper Conductors

AWG size	60°C Type TW	75°C Types RW75, TW75	85-90°C Types R90, TW90, T90 Nylon	200°C Mineral insulated cable
14	15	15	15	30
12	20	20	20	40
10	30	30	30	55

Allowable ampacities for not more than 3 copper conductors in raceway or cable, based on ambient temperature of 30°C

Allowable Ampacities (Continued)

AWG size	60°C Type TW	75°C Types RW75, TW75	85-90°C Types R90, TW90, T90 Nylon	200°C Mineral insulated cable
8	40	45	45	70
6	55	65	65	95
4	70	85	85	120
3	80	100	105	145

Allowable Ampacities (Continued)

AWG size	60°C Type TW	75°C Types RW75, TW75	85-90°C Types R90, TW90, T90 Nylon	200°C Mineral insulated cable
2	100	115	120	165
1	110	130	140	190
0	125	150	155	225
00	145	175	185	250

Allowable Ampacities (Concluded)

AWG size	60°C Type TW	75°C Types RW75, TW75	85-90°C Types R90, TW90, T90 Nylon	200°C Mineral insulated cable
000	165	200	210	285
0000	195	230	235	340

*The ampacity of aluminum-sheathed cable is based on the type of insulation used on the copper conductors. Consult the CE Code for correction factors to be used where there are more than 3 conductors in a cable or raceway

**Maximum allowable conductor temperatures for 1, 2, or 3 conductors run in a raceway or 2 or 3 conductors run in a cable.

***These ratings are based on the use of 90°C insulation on the emerging conductors and for sealing.

Voltage Rating

Identification

A conductor's voltage rating is printed on the insulation.

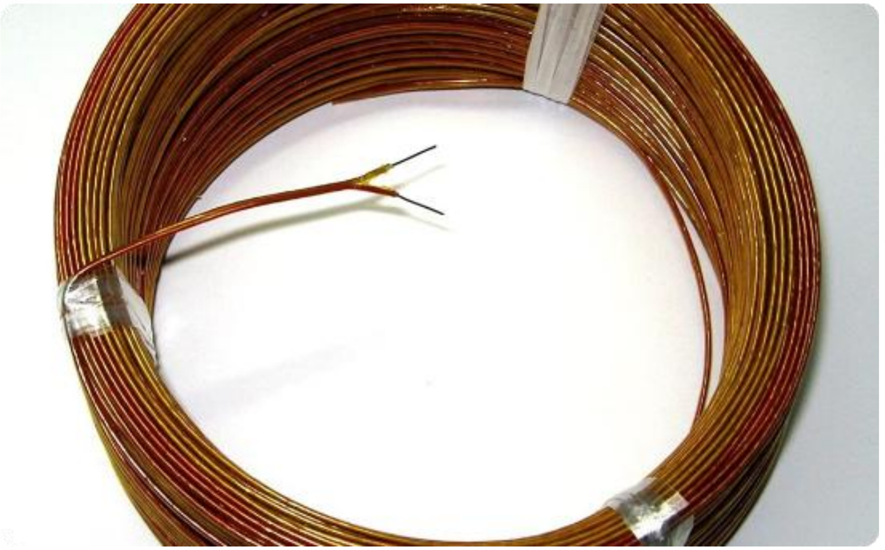
Dielectric Strength

Electrical conductor insulation subjected to excessive voltage may break down and lose its insulating ability. The ability of a conductor's insulation to resist breakdown due to voltage stress is its dielectric strength.

Wire size	Continuous duty current (amp) wires in bundles, groups, or harnesses or conduits		Max. resistance ohms/1000 feet
	Wire conductor temperature rating		
	@ 105 °C	@ 150 °C	@ 20 °C
#8	30	45	1.093
#6	40	61	0.641
#4	54	82	0.427
#2	76	113	0.268
#1	90	133	0.214
#0	102	153	0.169
#00	117	178	0.133
#000	138	209	0.109
#0000	163	248	0.085

Voltage ratings are clearly marked on conductor insulation to ensure proper application and safety.

Temperature Rating



Identification

A conductor's temperature rating is printed on its outer surface.

Excessive Heat Risks

If an electrical conductor is used in an application where it is exposed to excessive heat:

- Its insulation may melt or burn, leaving the wire conductors bare
- The life expectancy of the insulation may be greatly reduced

Special Applications

Stove wire, for example, has a high-temperature-resistant fibre wrapping over the top of its rubber or thermoplastic insulation to protect it from the heat of the appliance it services.

Environmental Considerations

Environmental Assessment

Evaluate the installation environment

Moisture Concerns

Presence of moisture can reduce dielectric strength

Chemical Exposure

Corrosive vapors can damage insulating materials

An electrical conductor used in harmful environments must have insulation that will protect it adequately under those conditions.

Cable Location Usage

NMD (non-metallic dry)

- For exposed wiring in dry or damp locations
- For concealed wiring in dry or damp locations

NMW (non-metallic wet)

- For exposed wiring in dry locations and in Category 1 and 2 locations, where not exposed to mechanical damage
- For exposed wiring in wet locations
- For concealed wiring in dry locations and in Category 1 and 2 locations where not exposed to mechanical damage

Unsheathed conductors

- Run outdoors must be enclosed in a code-compliant raceway

Mechanical Protection

Protection Requirements

The insulation of electrical conductors used in applications where they are exposed to possible physical damage must provide adequate protection.

Some conductors have an outer layer of flexible metallic sheathing to protect the conductor and its insulation from damage.

Protection for Concealed Installations

1

Location Requirements

Where the cable is run through or along metal studs, joists, sheathing, or cladding, it shall be located so as to be effectively protected from mechanical damage both during and after installation

2

Passage Protection

Where the cable passes through a member, it shall be protected by an insert adequately secured in place

Conductor Applications

Power Circuit Wiring

Electrical distribution conductors and cabling for buildings

Fixture Wiring

Special wiring for lighting fixtures and equipment

Data Cabling

Infrastructure for telecommunications and networks

Low-Voltage Control Circuits

Wiring for thermostats, gas valves, and zone valves

Section 4 of the CE Code provides general rules and reference tables governing the installation and use of electrical conductors for lighting, appliances, and power supply circuits.

Power Circuit Wiring

Definition

Power circuit wiring is the electrical distribution conductors and cabling for residential, commercial, and industrial building's electrical distribution system consists of:

- Service equipment
- Branch circuits

Power circuit wiring forms the backbone of a building's electrical system, distributing electricity from the main service to various branch circuits throughout the structure.

Service Equipment

Main Power Source

The service equipment, which uses the largest conductors, is the main power source for all other circuit wiring in the building.

Protection Requirements

Service equipment conductors usually require special mechanical protection, in accordance with Section 6 of the CE Code, and any local bulletins.

Branch Circuits

Power Supply

Branch circuits supply power to receptacle outlets, lighting, heater units, dryers, ranges, and motorized equipment.

Non-metallic Sheathed Cable

Common type used in residential applications

Armoured Cable

Used where mechanical protection is needed

Mineral-insulated Cable

For high-temperature or fire-resistant applications

Conductors in Conduit

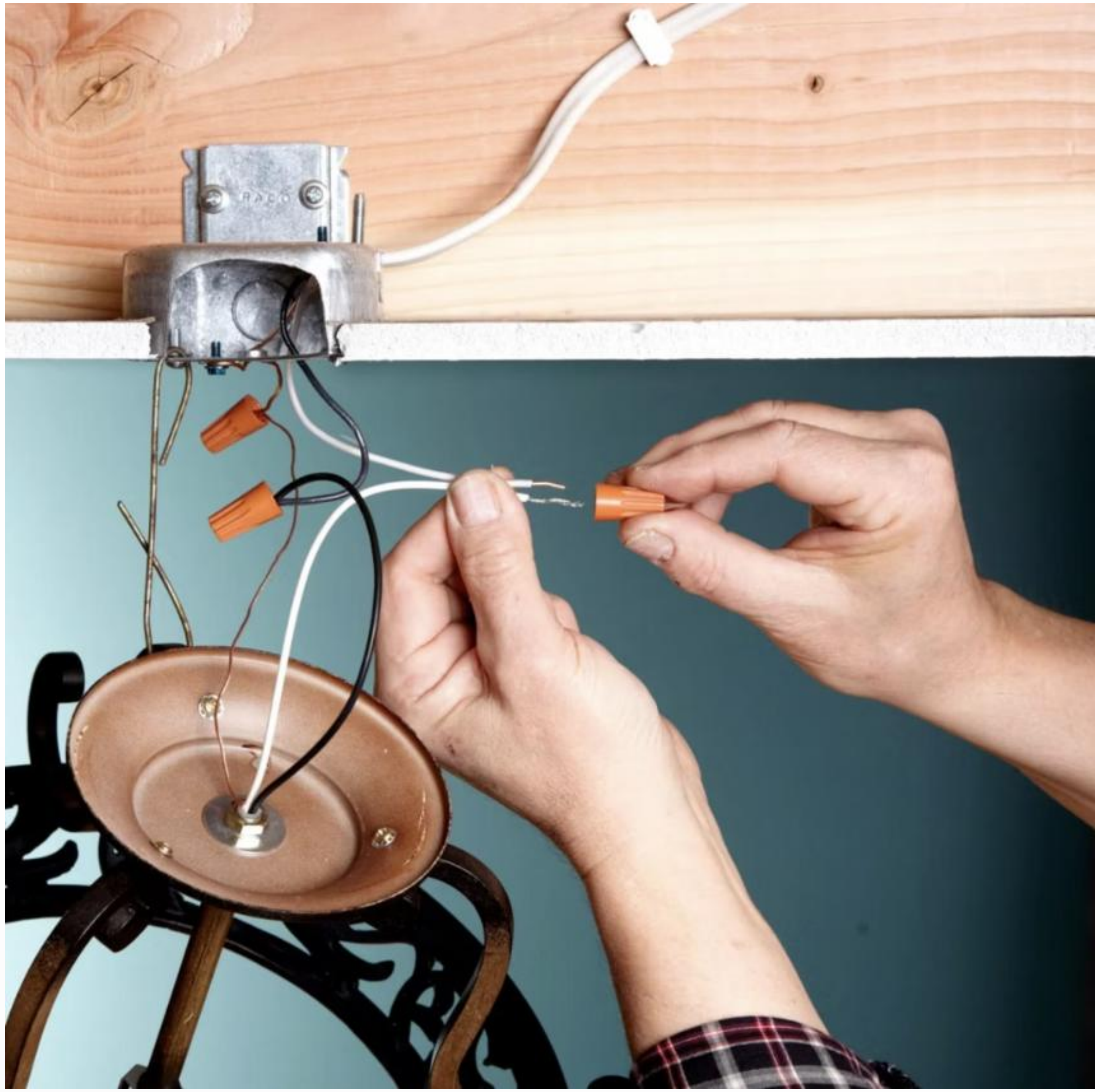
For commercial and industrial applications

Fixture Wiring

Definition and Use

Fixture wire is a special type of wire approved for use within electrical equipment such as lighting fixtures. It is usually a stranded, flexible conductor with high-temperature rated insulation.

This wire, also known as equipment wire, is used to connect internal fixtures to branch circuit conductors.



Low Voltage Control Circuits

Low Voltage Circuits

The CE Code defines low voltage circuits as those operating from 31 V to 750 V inclusive. Some motor control circuits operate at 600 V. Conductors used for these types of applications must be rated accordingly.

Extra-low Voltage Circuits

Extra-low voltage circuits operate at 30 V or less. Residential thermostat, gas valve, and zone valve control circuits fall into this category. These circuits generally use cable, No. 16 AWG, or smaller.

Data Cabling

Purpose

Data cables and associated hardware provide sites telecommunication infrastructure. Modern gas equipment is often equipped network interface device (NID) to enable them to be connected to connect to local area networks (LAN).

Twisted Pair

Most common for short to medium connections

Cost-effective solution

Coaxial

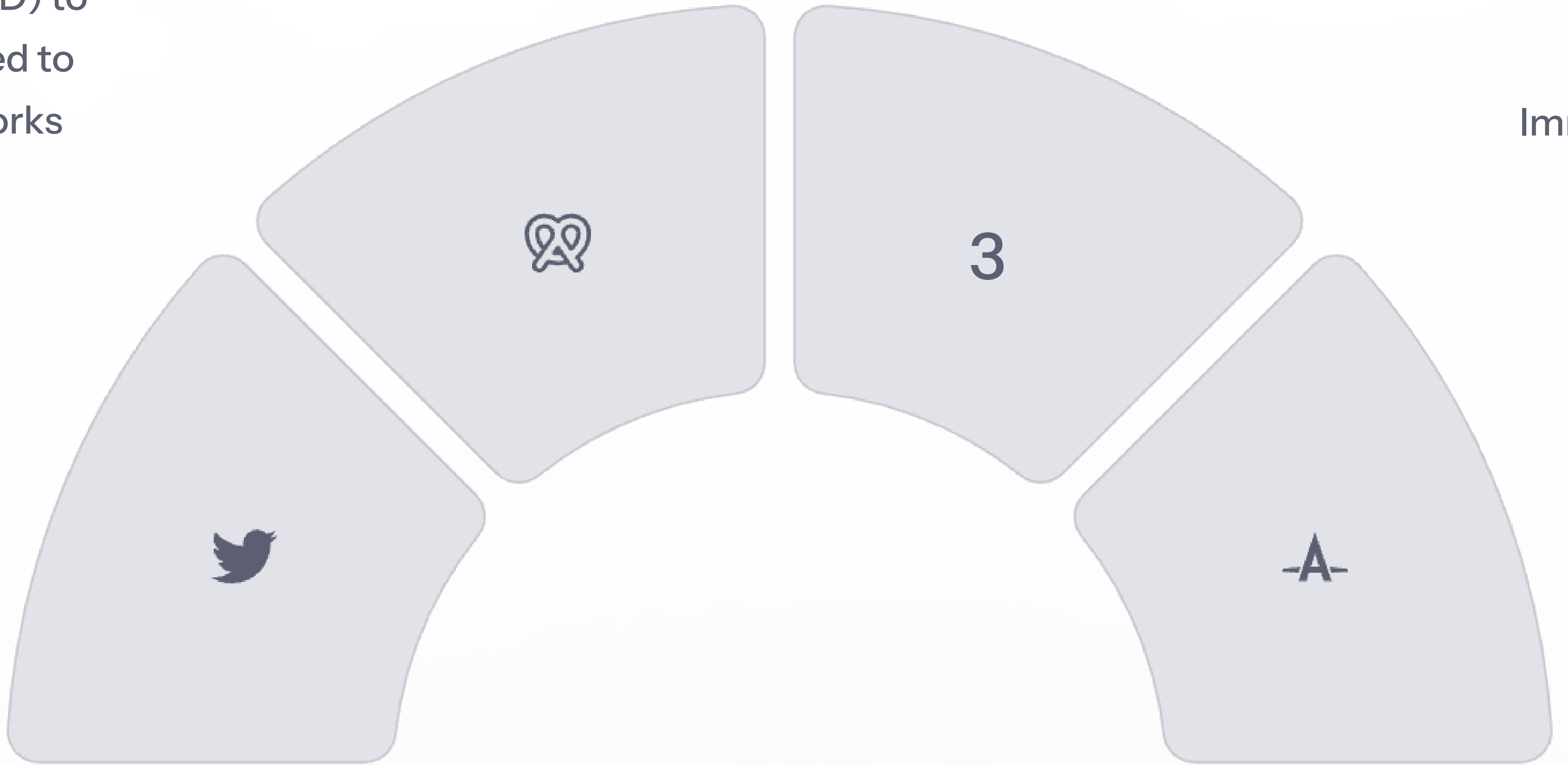
Used for cable television and some network applications

Better shielding than twisted pair

Fiber-optic

Used for high-speed, long-distance connections

Immune to electromagnetic interference

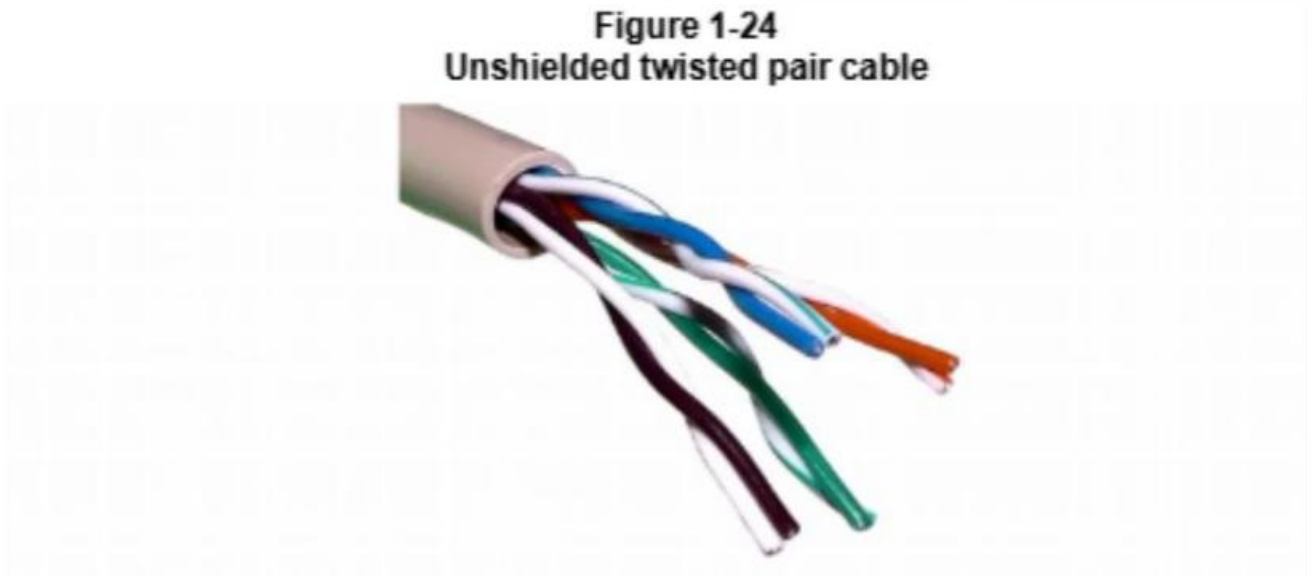


Twisted Pair Cabling

Advantages

Twisted pair cabling is often used in data networks for short and medium length connections because of its relatively lower costs compared to optical fibre and coaxial cable.

Unshielded twisted pair (UTP) cable is the most common cable used in computer networking as the twisting of pair of conductors in the cable provide shielding from electromagnetic interference.



Unshielded twisted pair (UTP) cable structure showing the twisted pairs of conductors that help reduce electromagnetic interference.

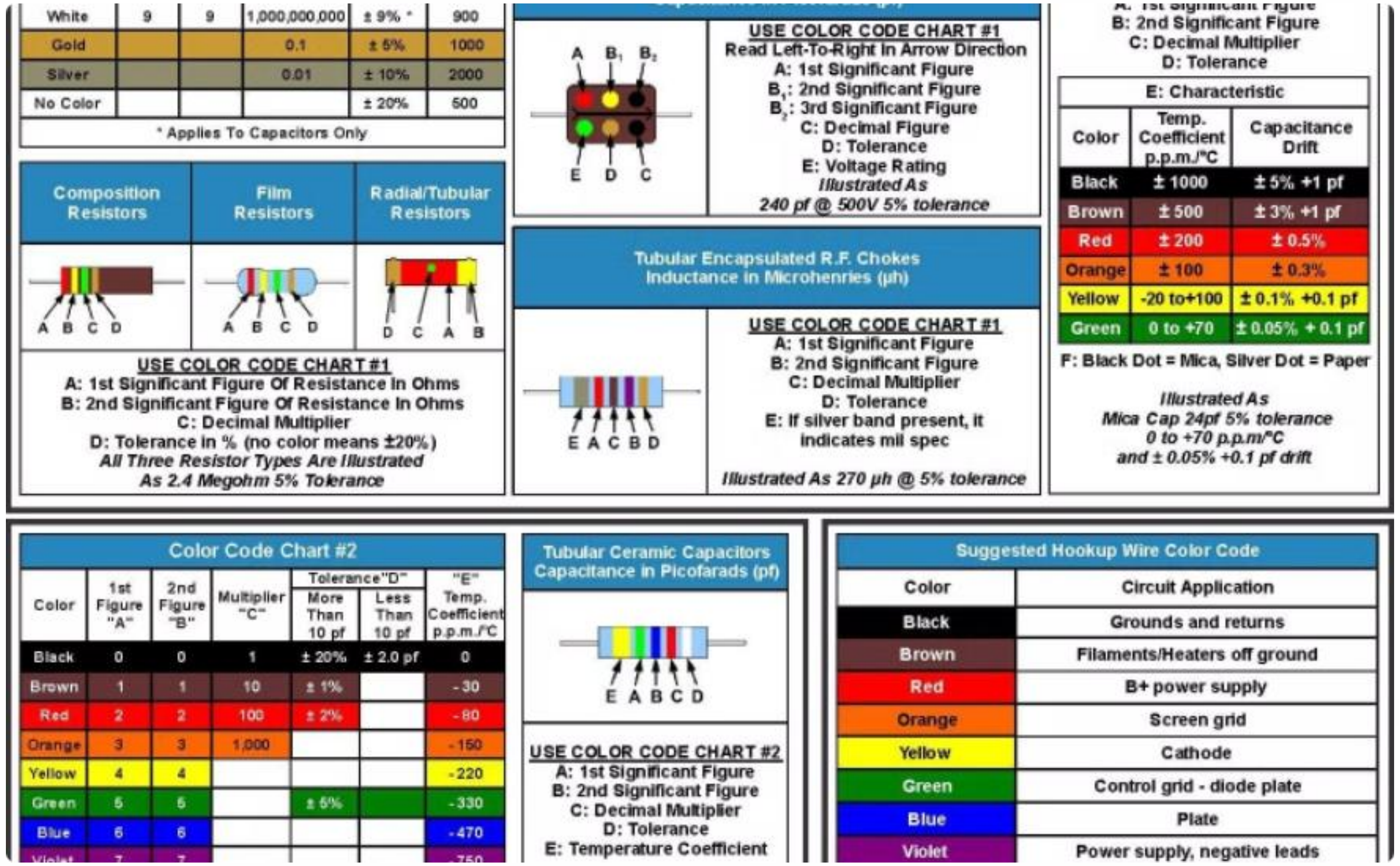
Shielded Twisted Pair Cables

Types of Shielded Cables

Two other types of twisted pair cables have additional shielding from high-frequency signals. Such shielding is done with foil and/or braided metal fibre. The shield can be applied to individual pair's referred to as shielded twisted-pair (STP) cable or to a collection of pairs called screened twisted-pair (ScTP).

Shielded twisted pair cables provide additional protection against electromagnetic interference through metal shielding around the wire pairs.

Conductor Colour Codes



Identification Methods

The wires of electrical conductors must be marked for easy identification so they can be correctly connected in circuits. There are several different methods used to differentiate wiring and two common methods used to mark wires:

- The insulation of each wire is a different colour.
- The insulation of each conductor may have an attached label marker or wire number (larger cables have a coloured strip).

Standard Color Codes

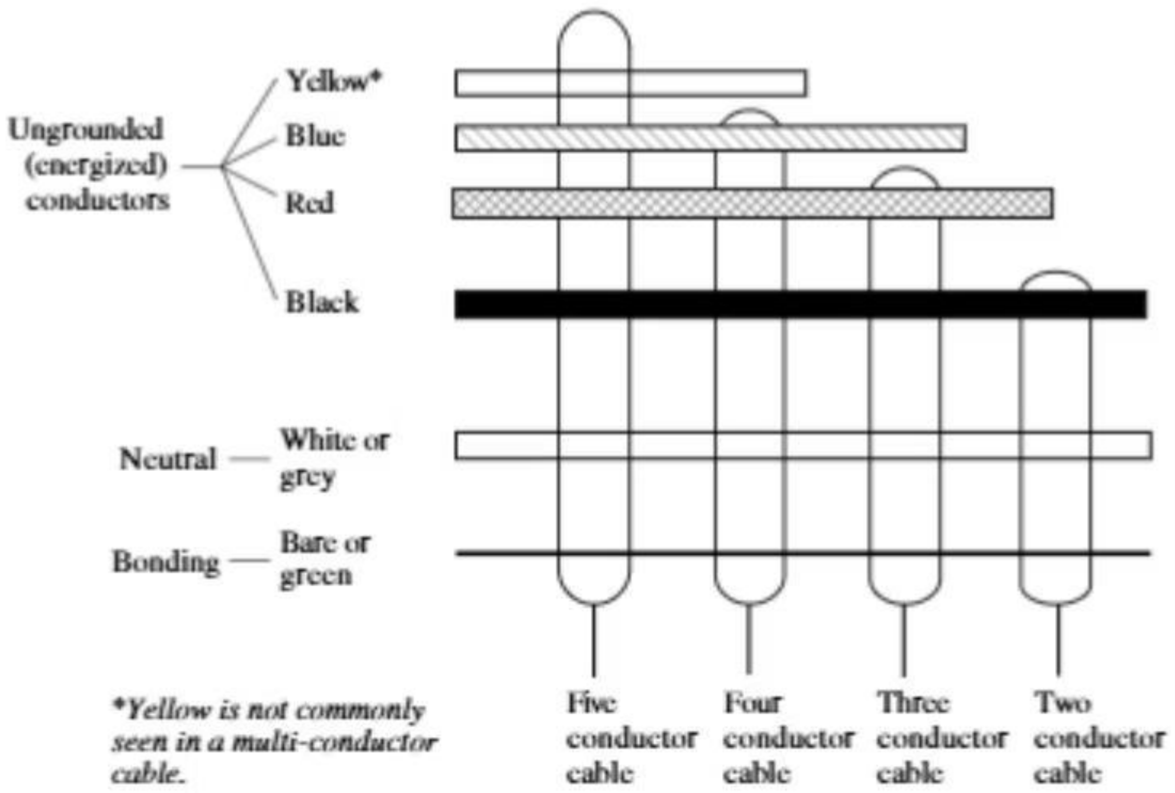
Colour	Use
White or grey	Only for insulated, neutral conductors or identified conductors
Green	Only for insulated grounding or bonding conductors
Red, black, and blue	Typically identifies live (ungrounded) conductors

Non-metallic Sheathed Cable (NMSC and NMD)

Construction and Use

Non-metallic sheathed cable usually has PVC or polyethylene plastic insulation, which also serves as the outer covering of the cable. This type of cable is most commonly used for wiring branch circuits.

Figure 1-26
Insulation colour codes



Non-metallic sheathed cable showing the outer jacket and internal conductors.

Cautions for NMSC and NMD Cable

Fire Hazards

The non-metallic covering of electric cables can burn and may transmit fire when ignited.

Toxic Emissions

Burning non-metallic coverings may emit highly toxic gases that generate dense smoke.

Corrosion Risk

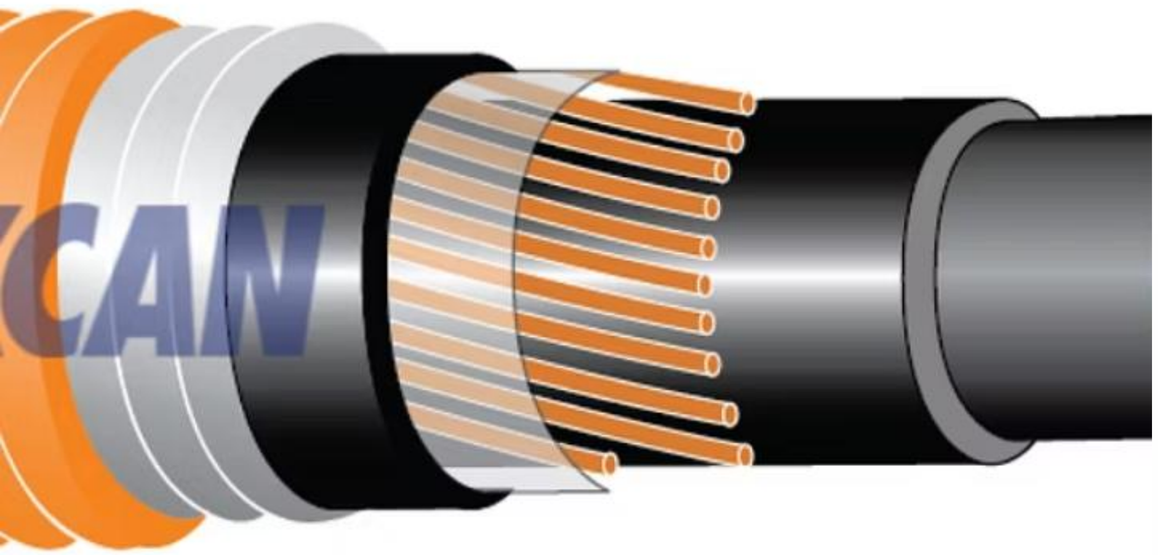
Acidic gas emissions may corrode metals in the vicinity of the cables.

Armoured Cable

Description and Use

Armoured cable, also called BX, has a flexible outer metal sheath to protect the insulated conductors. BX is commonly used in residential, commercial, and industrial applications where wiring may be exposed to mechanical damage.

CE Code Rules 12-600 to 12-618 cover the requirements for the installation of armoured cable.



Types of Armoured Cable

Cable	Use
Type AC	Use only in dry locations
Type ACL	Use where moisture resistance is required Has an additional lead covering
Type ACWU	Use in wet locations and for underground installations Has a thermoplastic outer covering
TECK	Use in exposed wiring locations and for adverse service conditions Is a special type of armoured cable Is manufactured in single- and multi-conductor form, with voltage ratings of 600 V, 1 kV, or 5 kV

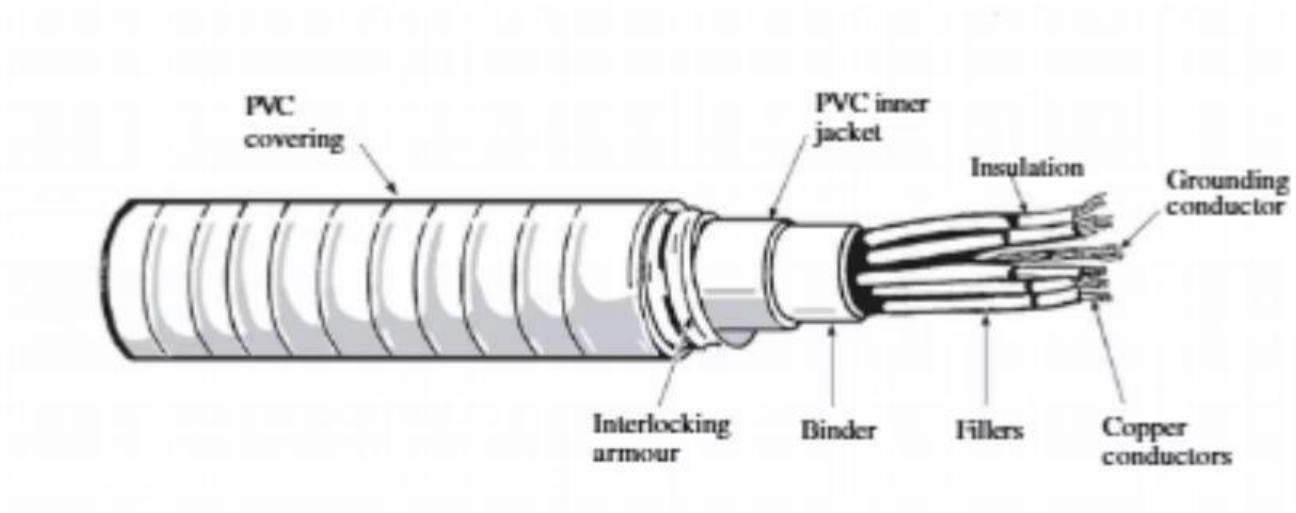
TECK Cable

Special Armoured Cable

TECK is a special type of armoured cable used in exposed wiring locations and for adverse service conditions.

It is manufactured in single- and multi-conductor form, with voltage ratings of 600 V, 1 kV, or 5 kV.

Figure 1-27
TECK90 cable



TECK cable showing the armored construction that provides excellent protection in harsh environments.

Aluminum-Sheathed Cable (ASC)

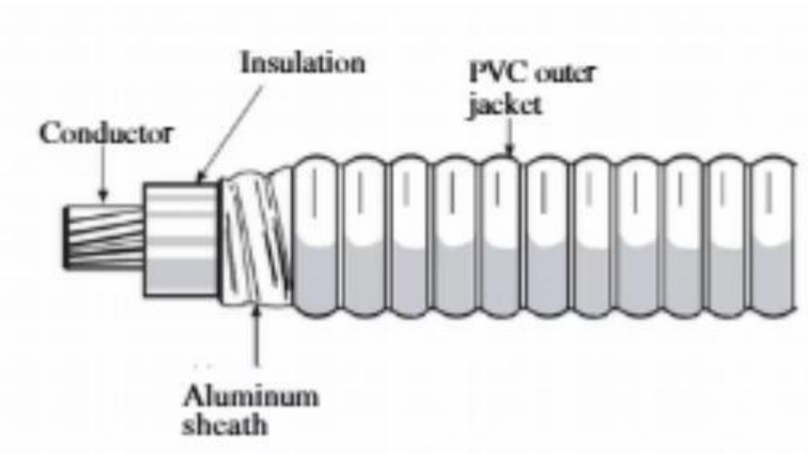
Construction and Types

Aluminum-sheathed cable (ASC) has a seamless aluminum protective sheath with either a smooth or corrugated finish.

The corrugated type is called RA90 or trade name Corflex. A PVC outer covering allows the use of ASC in adverse conditions. ASC is commonly used in industrial applications requiring voltages of 600 V to 5000 V.

CE Code Table D1 specifies ASC voltage ratings, while CE Code Rules 12-700 to 12-716 cover the requirements for the installation of aluminum-sheathed cable, MI cable and copper-sheathed cable.

Figure 1-28
RA90 "Corflex" ASC



Aluminum-sheathed cable with corrugated finish (Corflex) providing excellent protection and flexibility.

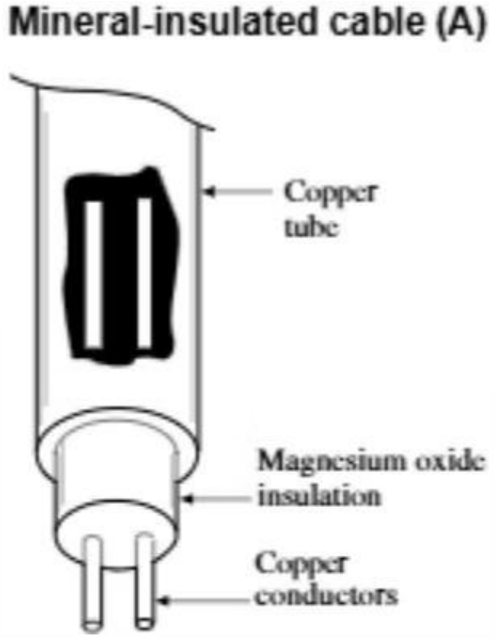
Mineral-Insulated Cable (MI)

Construction

Mineral-insulated cable has a magnesium oxide filler between its uninsulated internal conductors and outer metallic sheath, making it fire-resistant. The outer sheath is usually copper tubing. This type of cable, often referred to as Pyrotenax, can withstand severe physical abuse without failing.

Applications

MI cable is used in applications where conductors may be exposed to mechanical damage, moisture, or high temperatures. Special termination kits are required for connecting MI cable because of its uninsulated conductors. Standard MI cable is certified for circuits up to 600 V. LWMI, a light-weight cable is used for circuits up to 300 V.



Mineral-insulated cable showing the copper sheath and internal conductors separated by mineral insulation.

Flexible Cord and Cable

Usage Limitations

The use of flexible cords and cables is not generally allowed to be used for permanent wiring installations. They are used to connect appliances and equipment that have attachment plugs.

Common Types

Three common types of flexible cord and cable include:

- Heater cords
- General-service cords
- Power-supply cables

Code Requirements

CE Code Table 11 and Rules 12-400 to 12-406 specify allowable uses of various types of flexible cords and cables. Ampacity ratings for these types of conductors are indicated in CE Code Table 12.

Heater Cord

Characteristics

Heater cord is used to connect portable electric heating units to outlet receptacles.

It is available with two, three, or four conductors and is usually insulated with high temperature rated outer jacket.

Maximum voltage rating is 300 V, while conductor sizes range from No. 18 to No. 14 AWG.

Heater cords must withstand the high temperatures associated with heating appliances while maintaining their insulating properties.

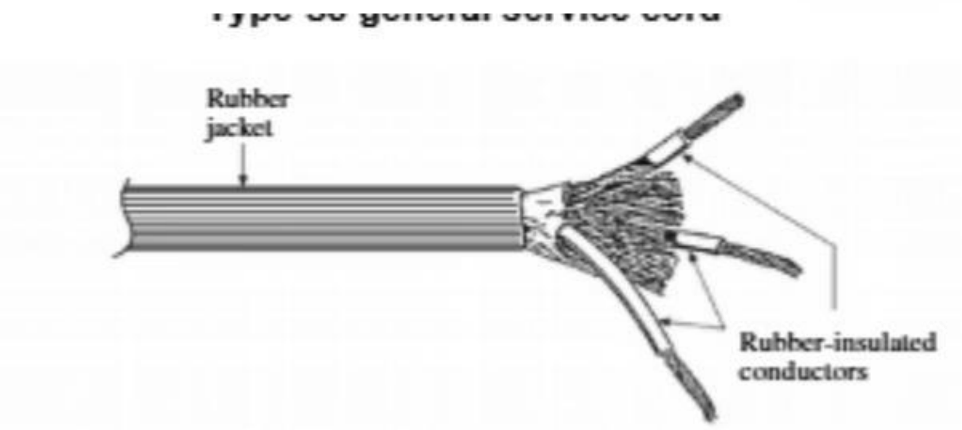
General-Service Cord

Construction and Use

General-service cord (also called cab tire) is used to connect portable appliances and equipment that is subject to hard usage. This type of cord consists of rubber-insulated conductors twisted together and is enclosed in a high-grade rubber outer jacket.

General-service cord is available with two, three, or four conductors.

Conductor sizes range from No. 18 to No. 10 AWG.



General-service cord showing the durable rubber jacket that provides protection in demanding environments.

Types of General-Service Cord

Service cord	Use
T	Rated at 300 V
S	Rated at 600 V
SJOW	300 V for outdoor use
SOW	600 V for outdoor use

Power-Supply Cables

Construction and Use

Power-supply cable is similar in construction to general service cord.

It is used for connecting equipment drawing higher currents at up to 600 V.

It is available with two, three, or four conductors, and in sizes from No. 8 to No. 2 AWG.

Figure 1-30
Type SJ general service cord

Power-supply cable designed to handle higher current loads while maintaining flexibility.

Conductor Selection Factors

4

Key Factors

Critical considerations when selecting electrical conductors

30A

Current Rating

Maximum current the conductor can safely carry

600V

Voltage Rating

Maximum voltage the insulation can withstand

90°C

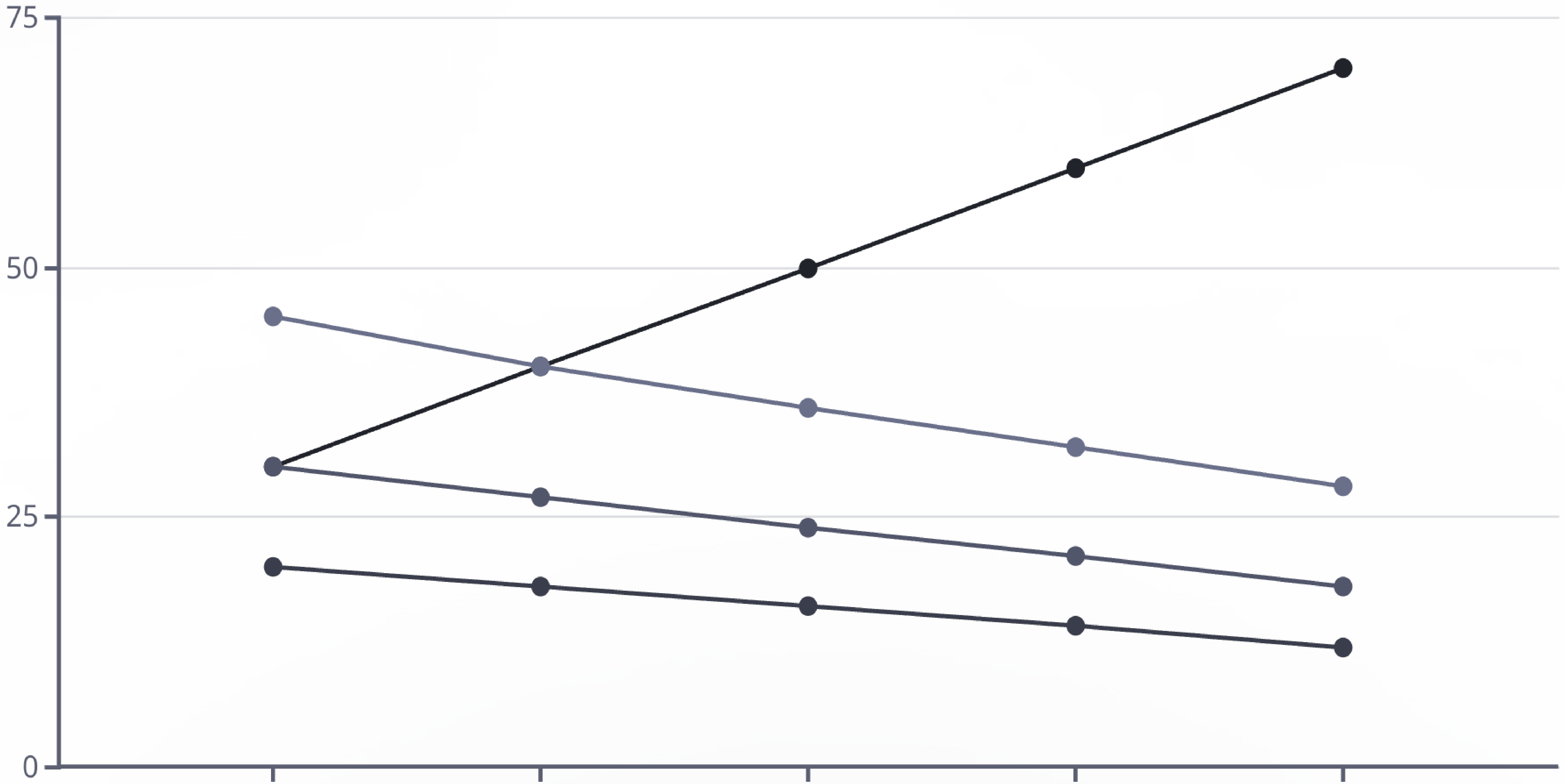
Temperature Rating

Maximum operating temperature for the insulation

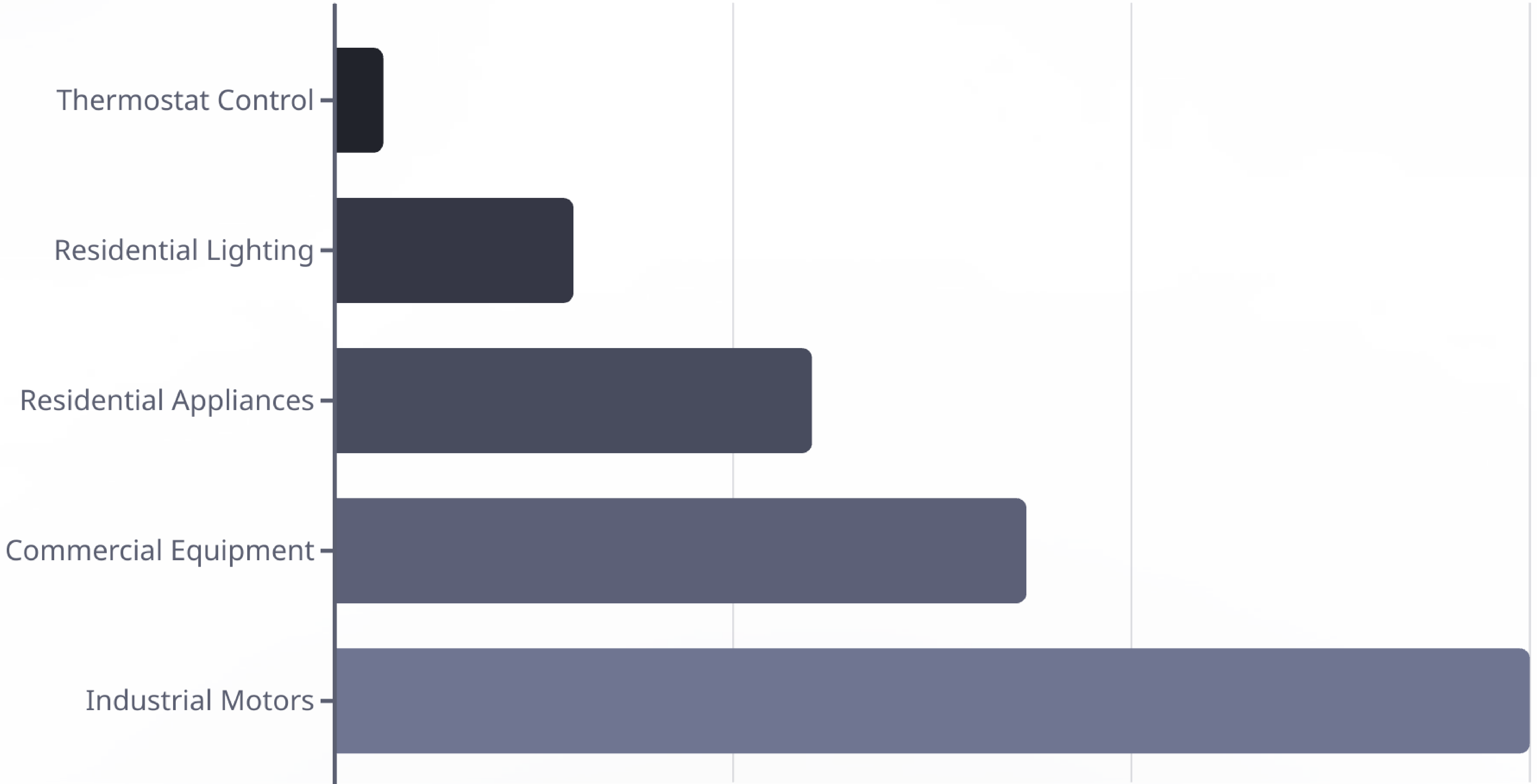
Selecting the appropriate conductor involves balancing these factors with the specific requirements of the application and compliance with electrical codes.

Conductor Installation Best Practices

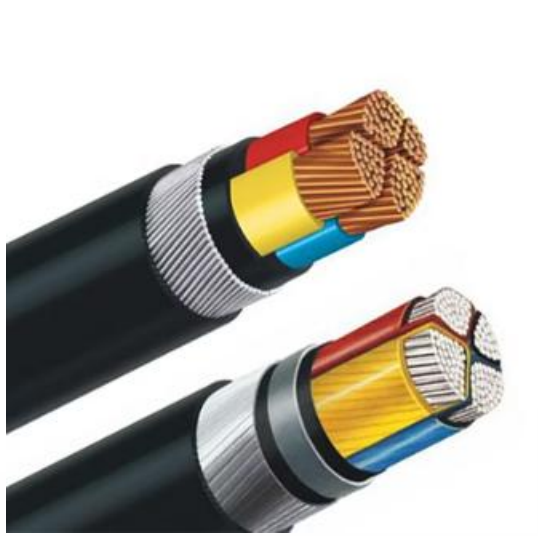
Conductor Ampacity vs. Temperature



Conductor Applications by Voltage



Conductor Selection Guide

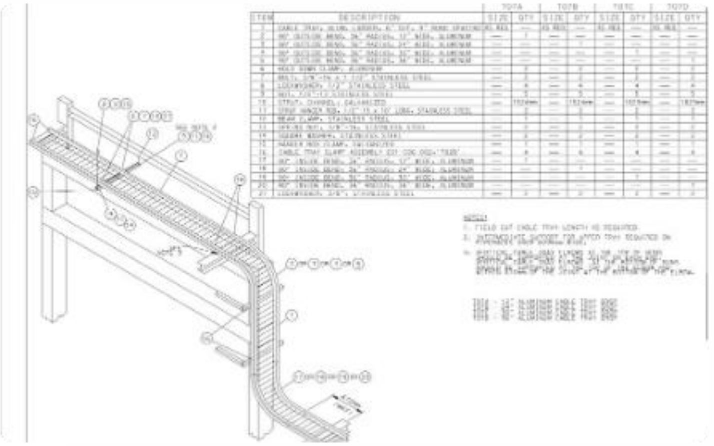


A visual guide to the various types of electrical conductors available for different applications. Proper selection depends on factors such as current requirements, environmental conditions, mechanical protection needs, and code compliance.

Conductor Installation Methods

Conduit Installation

Conductors installed in rigid or flexible conduit provide excellent mechanical protection and allow for future wire replacement. This method is common in commercial and industrial applications where exposure to physical damage is likely.



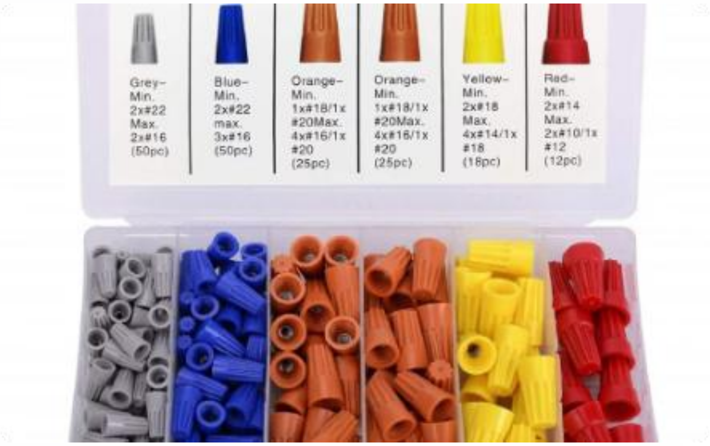
Cable Tray Systems

Cable trays provide support and organization for multiple cables in industrial and commercial settings. They offer good accessibility for maintenance while protecting cables from physical damage.

Concealed Wiring

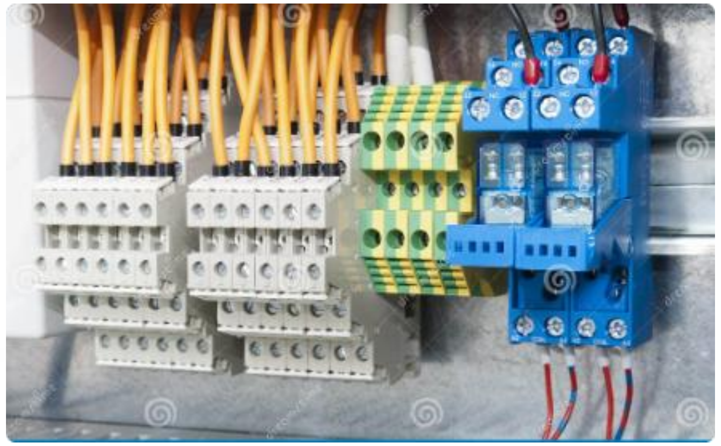
Non-metallic sheathed cable or armored cable installed within building cavities is the most common method for residential applications. Protection is required when passing through framing members.

Conductor Termination Methods



Wire Connectors

Wire nuts and push-in connectors provide a simple method for joining conductors in junction boxes and fixture connections. These are commonly used in residential and light commercial applications.

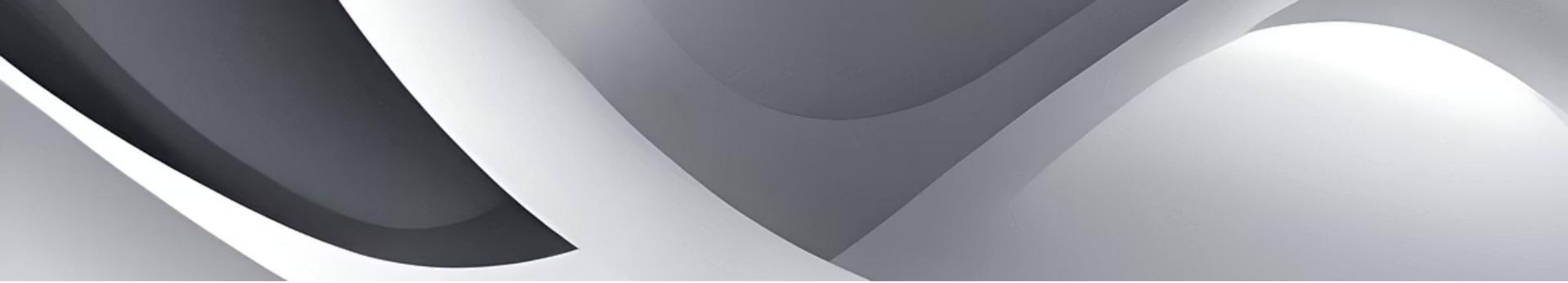


Terminal Blocks

Terminal blocks provide secure connection points for multiple conductors, often used in control panels and equipment connections. They offer excellent organization and accessibility for maintenance.

Lugs and Crimps

For larger conductors, mechanical lugs and crimped connections provide the necessary mechanical strength and electrical continuity. These are common in service equipment and distribution panels.



Conductor Protection Devices

Fuses

Sacrificial devices that melt when current exceeds rating

Circuit Breakers

Resettable protection devices that trip on overload

Ground Fault Circuit Interrupters

Detect current leakage to ground and disconnect circuit

Surge Protectors

Limit voltage spikes that could damage insulation

Proper overcurrent protection is essential to prevent conductor overheating and potential fire hazards. The protection device must be sized according to the conductor's ampacity rating.

Conductor Identification Systems

Color Coding

Standard colors identify conductor function: white/gray for neutral, green for ground, and red/black/blue for ungrounded (hot) conductors. This system provides visual identification for safe connections.

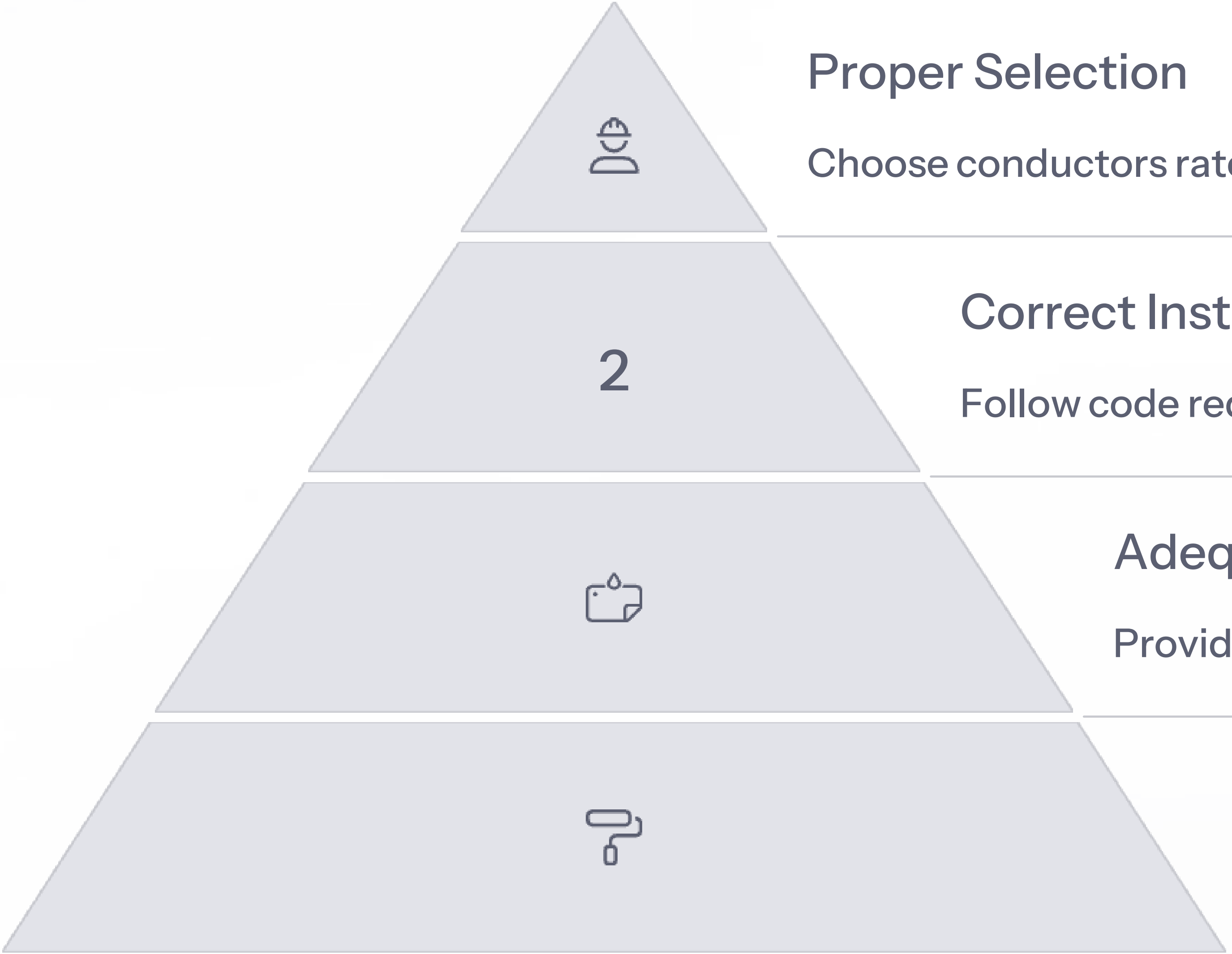
Wire Markers

Numbered or lettered tags provide unique identification for each conductor in complex systems. These are particularly important in control circuits and industrial applications with many similar conductors.

Electronic Tracing

Signal generators and receivers allow technicians to identify and trace conductors within walls or underground. This technology is invaluable for troubleshooting and maintenance in existing installations.

Conductor Safety Considerations



Proper Selection

Choose conductors rated for the application

Correct Installation

Follow code requirements and manufacturer specifications

Adequate Protection

Provide mechanical protection and overcurrent devices

Regular Inspection

Check for damage, overheating, or deterioration

Safety is the primary concern when working with electrical conductors. Proper selection, installation, protection, and maintenance are essential to prevent electrical hazards such as shock, arc flash, and fire.

Common Conductor Issues

Overheating

Caused by excessive current, poor connections, or inadequate ventilation. Can lead to insulation breakdown and fire hazards. Proper sizing and installation practices prevent this issue.

Insulation Damage

Physical damage, UV exposure, or chemical contact can compromise insulation. Regular inspection and appropriate environmental protection are essential preventive measures.

Voltage Drop

Long conductor runs can experience significant voltage drop, especially under load. Upsizing conductors for long runs ensures proper voltage at the point of use.

Corrosion

Moisture and certain environmental conditions can cause conductor corrosion, increasing resistance and heat generation. Proper selection of conductor materials and insulation types for the environment is critical.

Conductor Testing and Maintenance

1

Continuity Testing

Verify unbroken electrical path through conductor

Insulation Resistance Testing

Measure resistance between conductor and ground

Voltage Drop Testing

Measure voltage difference under load conditions

4

Thermal Imaging

Identify hot spots indicating potential problems

Visual Inspection

Check for physical damage or discoloration

Conductor Selection Summary

Determine Application Requirements

Consider voltage, current, environment, and mechanical protection needs for the specific application. Reference the appropriate sections of the CE Code for minimum requirements.

Select Appropriate Conductor Type

Choose between copper or aluminum, solid or stranded, and the appropriate insulation type based on the application requirements. Consider factors such as flexibility, temperature rating, and environmental exposure.

Size Conductor Properly

Determine the correct AWG size based on ampacity requirements, voltage drop considerations, and overcurrent protection. Remember that longer runs may require larger conductors to maintain proper voltage.

Ensure Code Compliance

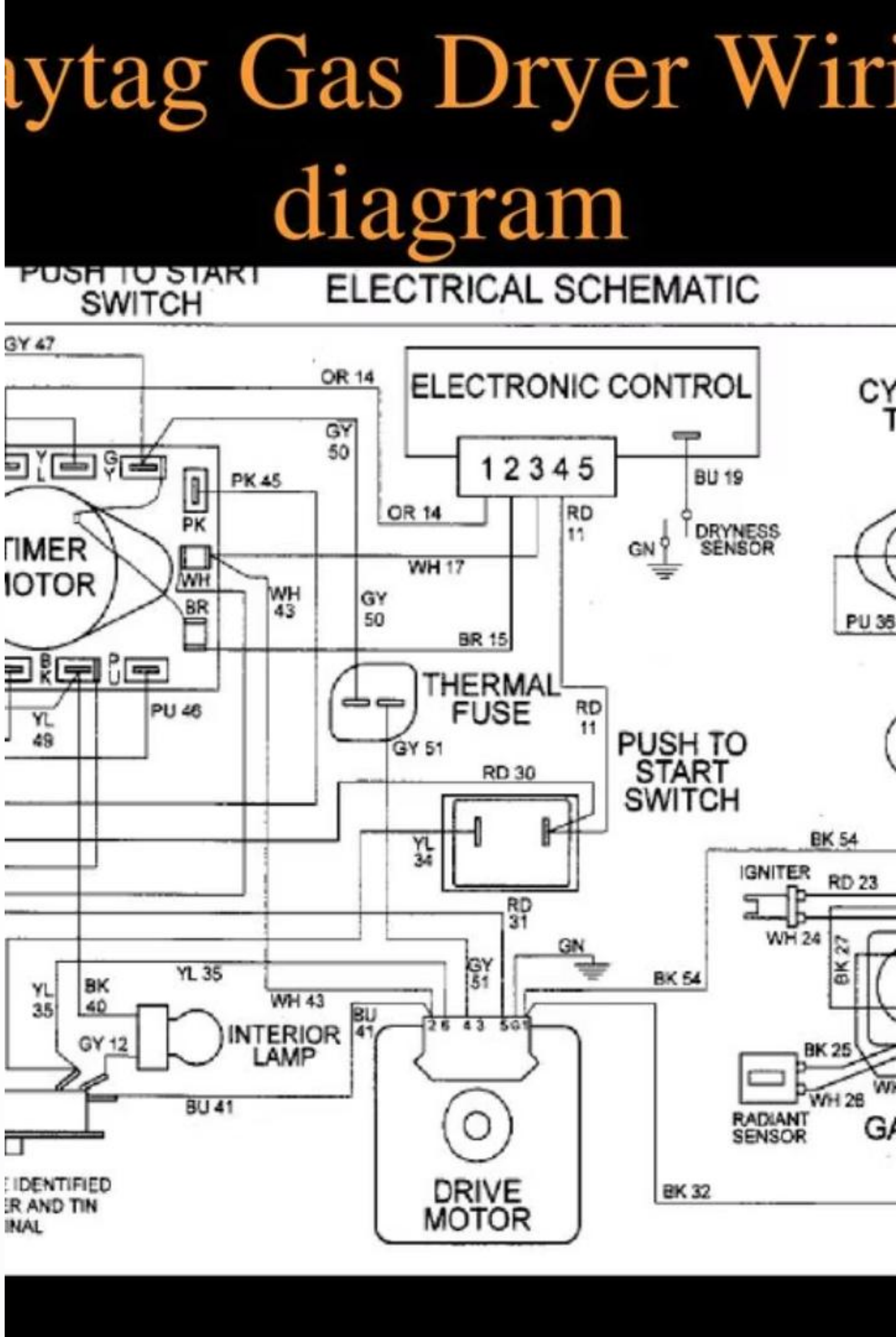
Verify that all selections comply with the Canadian Electrical Code and any local amendments or bulletins. Pay particular attention to installation methods, protection requirements, and identification standards.

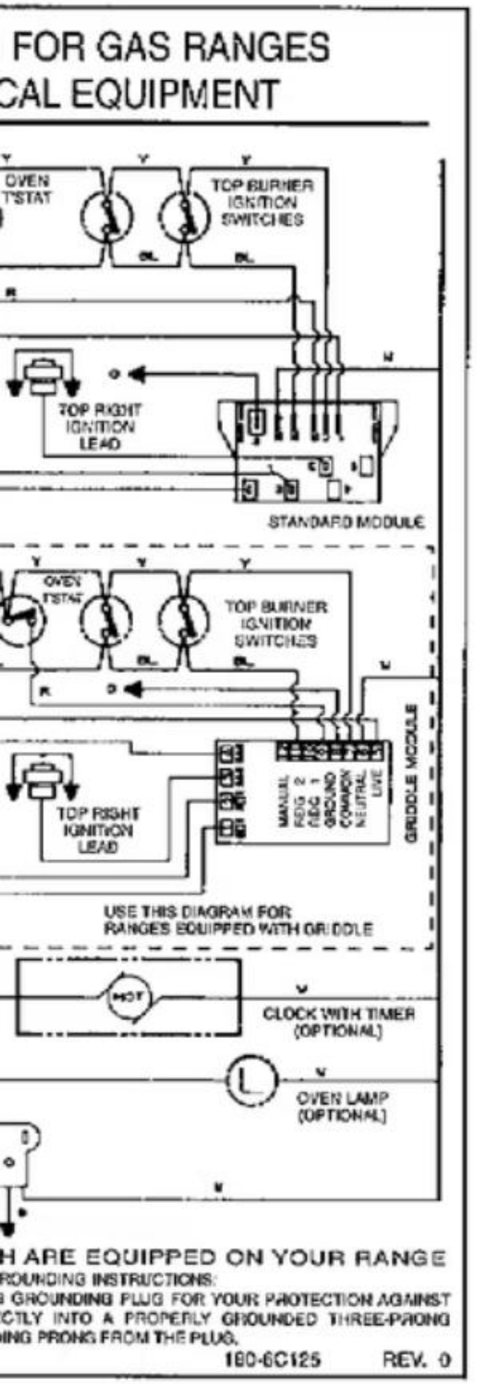
CSA Unit 12 - Electricity for Gas Fired Appliances

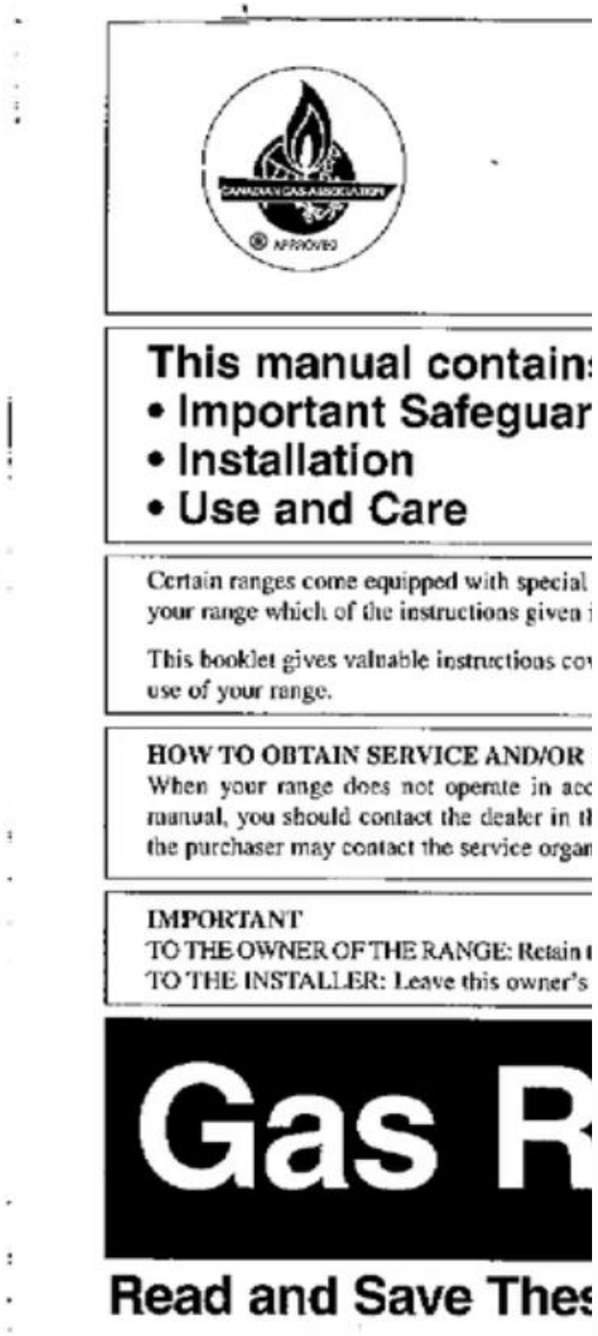
Chapter 2

Interpret Electrical Drawings

Just as piping drawings provide the gas technician/fitter with a layout of the piping system, so do electrical drawings provide the gas technician/fitter with the layout of the electrical system. Having a working knowledge of the various types of electrical drawings and electrical symbols is very important as this enables the gas technician/fitter to understand the entire sequence of operation of the gas equipment.







This manual contain
• Important Safeguar
• Installation
• Use and Care

Certain ranges come equipped with special
your range which of the instructions given i

This booklet gives valuable instructions co
use of your range.

HOW TO OBTAIN SERVICE AND/OR
When your range does not operate in acc
manual, you should contact the dealer in th
the purchaser may contact the service organ

IMPORTANT
TO THE OWNER OF THE RANGE: Retain t
TO THE INSTALLER: Leave this owner's

Gas R

Read and Save Thes

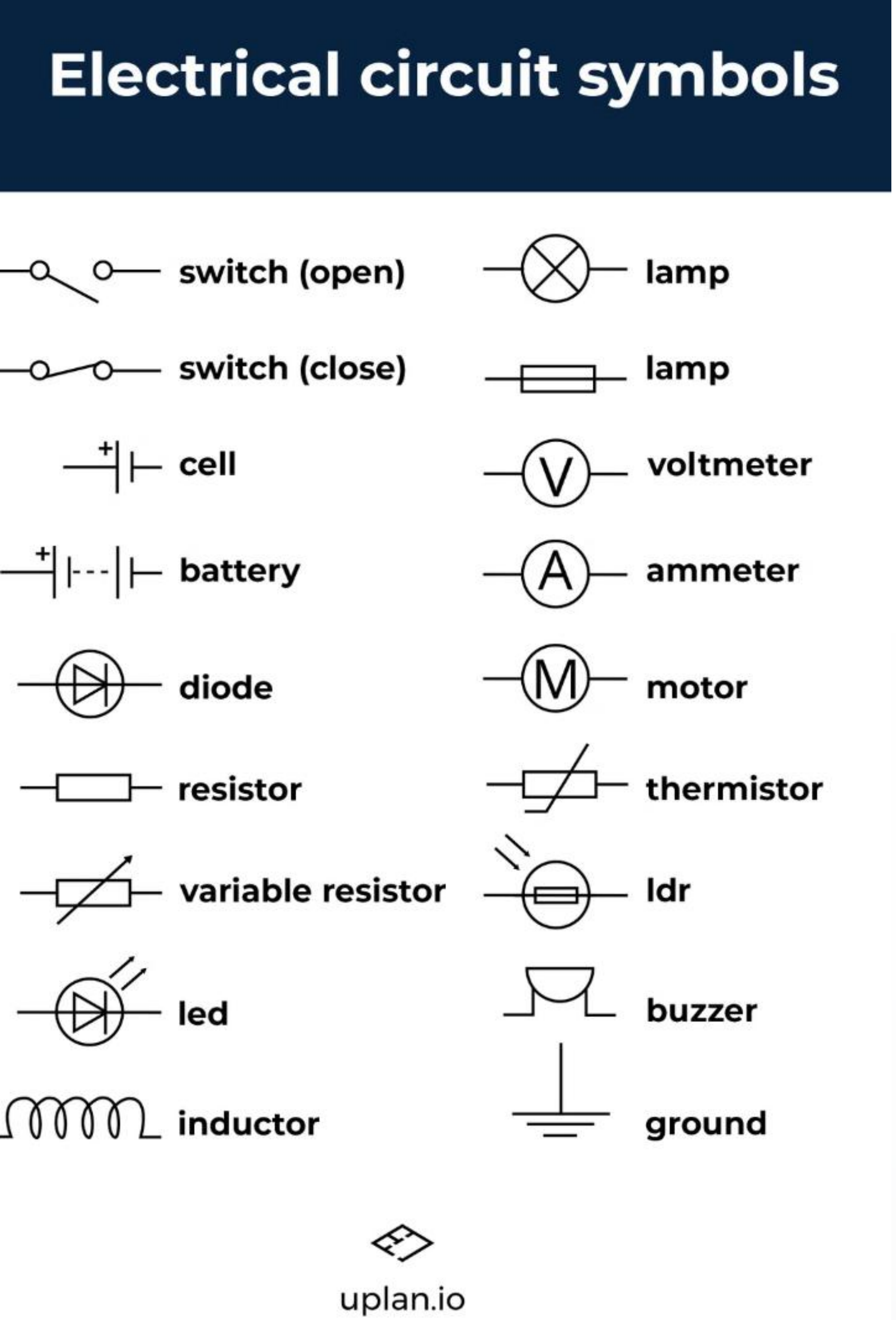
Purpose and Objectives

Purpose

Electrical drawings provide the gas technician/fitter with the layout of the electrical system, enabling them to understand the entire sequence of operation of the gas equipment.

Objectives

- Identify different types of electrical drawings
- Describe the standard electrical symbols
- Explain wiring diagrams



Key Terminology

Term	Abbreviation (Symbol)	Definition
At rest state		De-energized state

Understanding the terminology used in electrical drawings is essential for gas technicians/fitters to properly interpret diagrams and schematics.

Standard Electrical Symbols

Purpose of Symbols

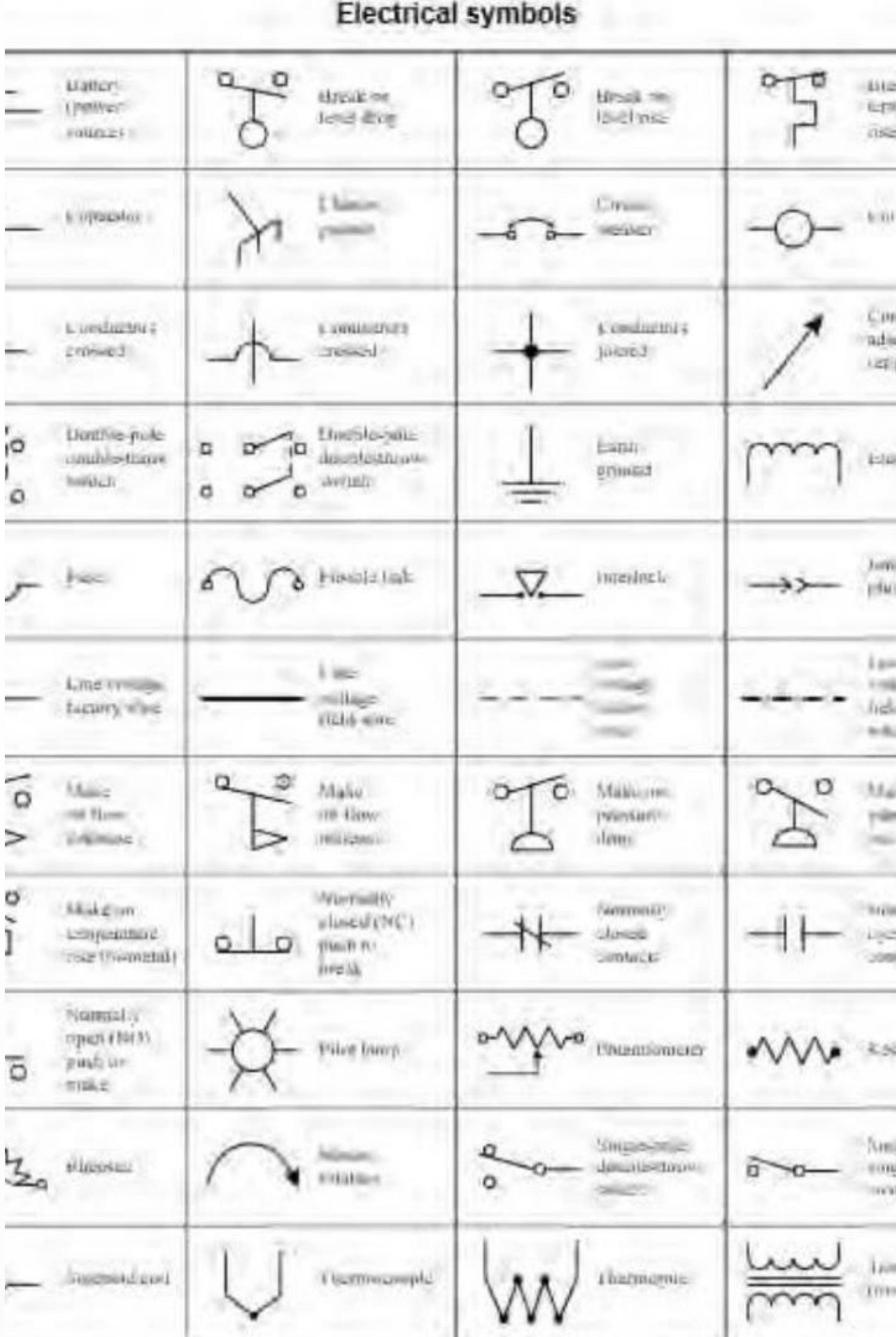
Standard electrical symbols represent components on drawings and diagrams

Importance for Technicians

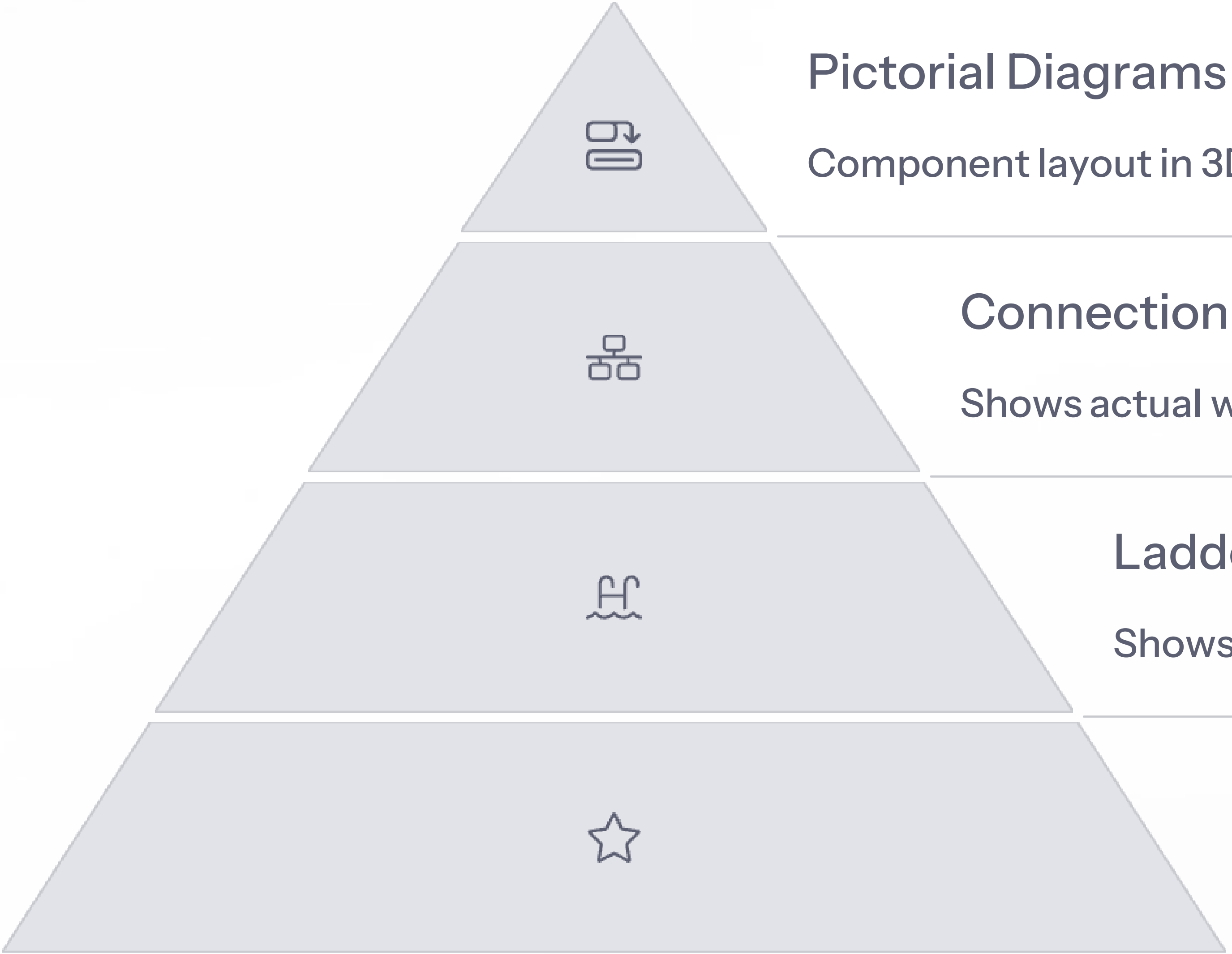
Gas technicians/fitters must be able to recognize and interpret these symbols in order to install and service equipment properly

Common Symbols

Gas technicians/fitters encounter the symbols in Figure 2-1, which are commonly found on electrical drawings



Types of Electrical Drawings



Pictorial Diagrams

Component layout in 3D representation

Connection/Wiring Diagrams

Shows actual wire connections

Ladder/Schematic Diagrams

Shows circuit function

Block Diagrams

Shows component relationships

It is important for the gas technician/fitter to recognize and interpret the different types of electrical drawings and diagrams used in the gas industry.

Pictorial Diagrams

Usage

Pictorial diagrams are often used in instruction manuals and installation guides.

Appearance

Pictorial diagrams are generally three-dimensional and show components as they would appear in real life.

Component Positioning

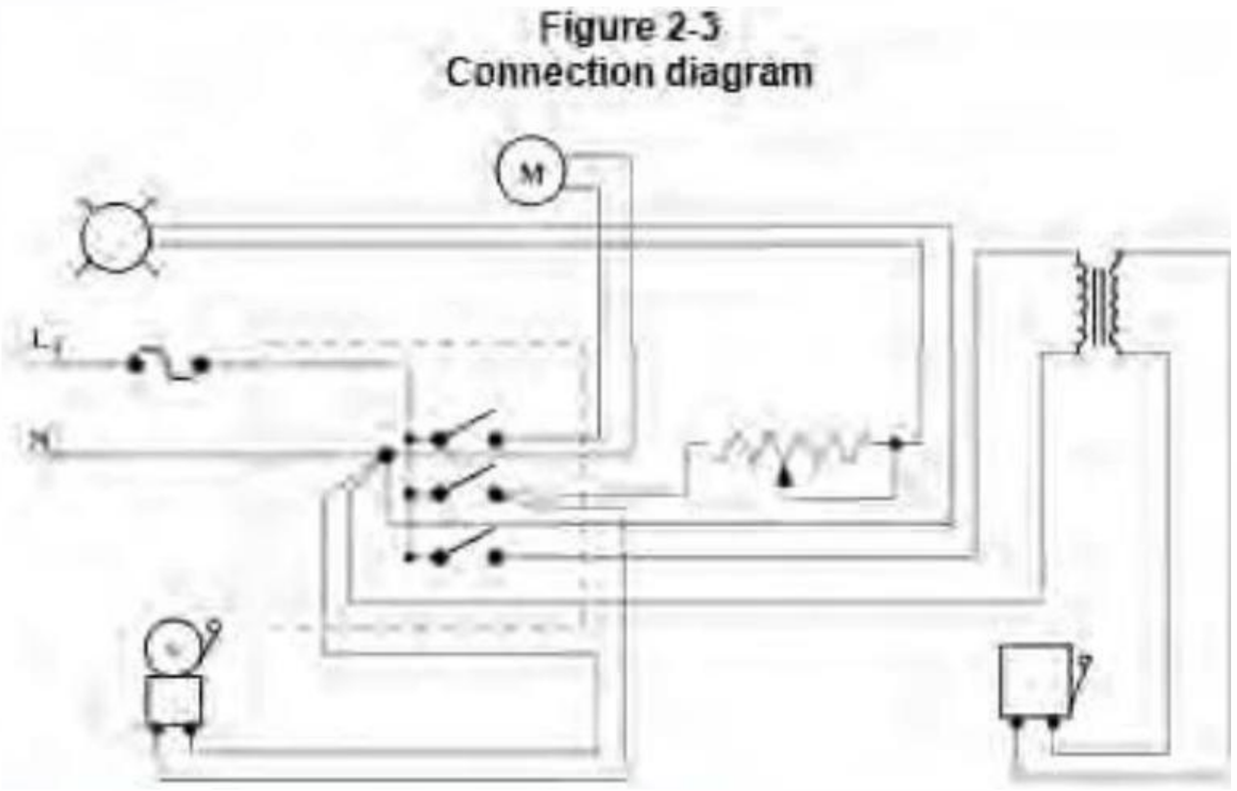
Components are located relative to their actual position.

Identification

Wires and other items are identified by colour, value or rating (although not shown in this example).

Figure 2-2
Pictorial circuit diagram

Connection Diagrams



Definition

Connection or wiring diagrams are similar to pictorial diagrams, but are not as detailed.

Key Characteristics

- Components are represented in symbol form rather than as they appear in reality
- Components are located relative to their actual position
- They attempt to show how the actual wires are connected to the component terminals

Figure 2-3 is the connection diagram for the circuit shown in Figure 2-2.

Ladder and Schematic Diagrams

Purpose

The purpose of electrical ladder or schematic diagrams is to show how circuits work and the function of their components.

Sequence

This type of diagram often shows a logical sequence of events.

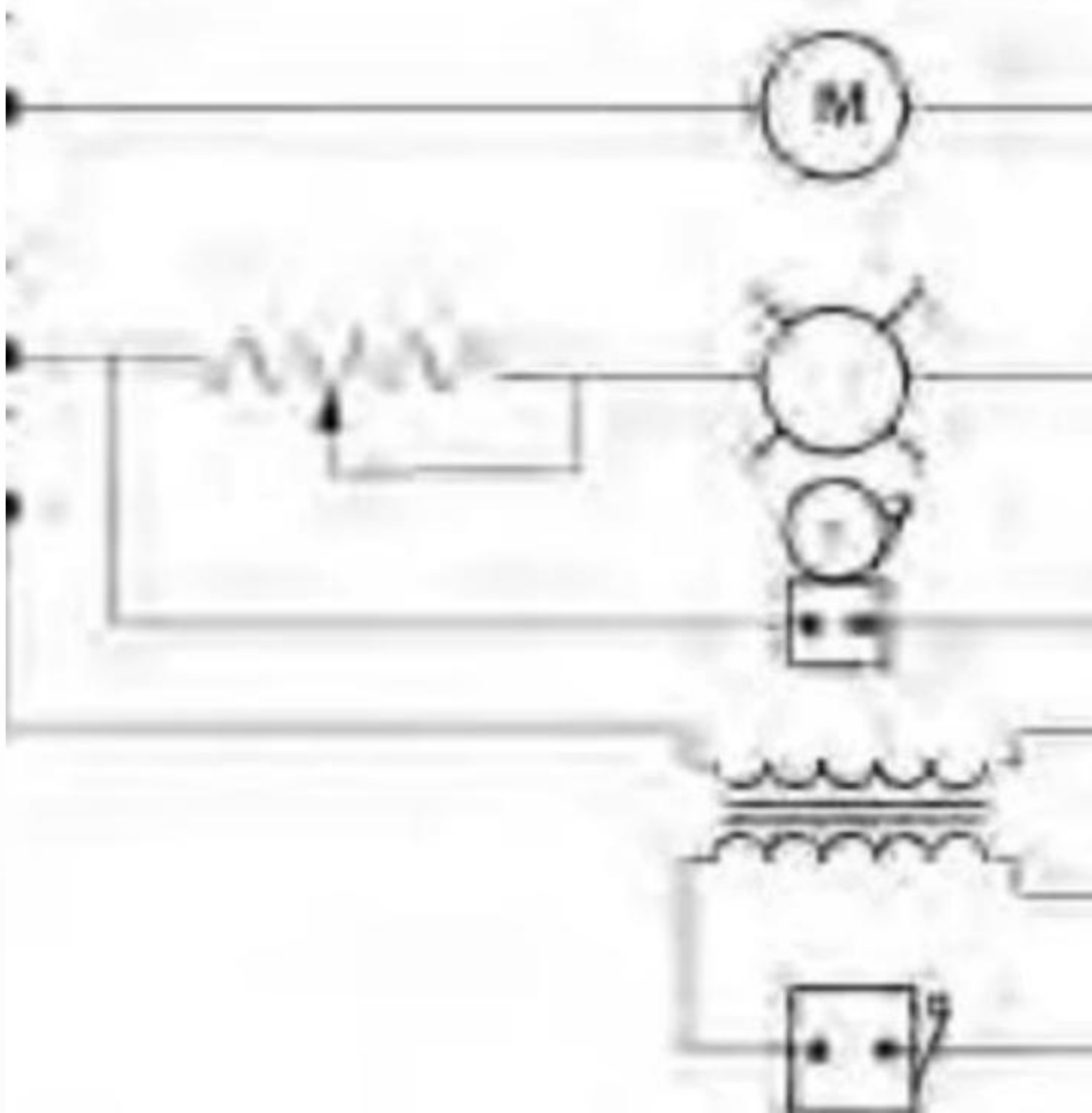
Representation

Components are represented by standard electrical symbols and are labelled to indicate such things as their name, type, value, and part number.

Connections

Components are connected by single lines indicating their relationship to each other in the circuit and are shown in their de-energized state.

Figure 2-4
Schematic circuit diagram



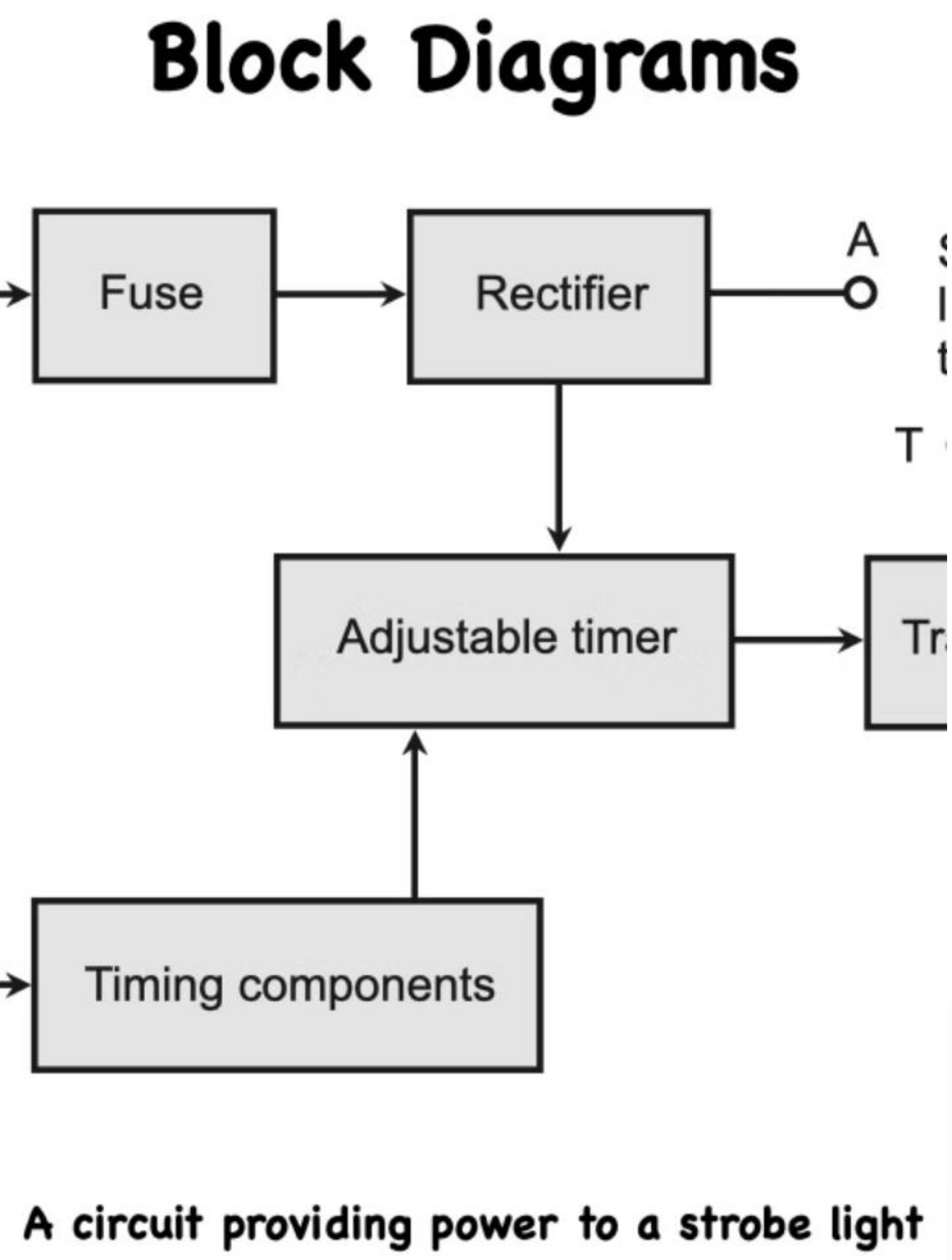
Block Diagrams

Definition

A block diagram is a type of flow chart that indicates the relationship between individual circuits, components or groups of components within the same housing.

Characteristics

- Components are drawn in the form of blocks
- Components are labelled to indicate such things as their name, type, value, and part number
- Components are not shown in their actual location in the circuit
- Components are connected by single lines indicating their relationship to each other
- Components do not show a return path for the circuit



Block Diagram Example

Block Diagram Components

Figure 2-5 Block diagram shows 1/4 HD 115V motor, Lamp and bell, and Transformer and buzzer

Representation

In block diagrams, the components of the circuit are drawn in the form of blocks, and their relationship to each other is indicated by appropriately connected lines.

Usage

Block diagrams provide a simplified overview of system components and their relationships without showing detailed connections.

Use of Electrical Drawings

Pictorial Diagrams

Best for recognizing and locating components on actual appliances

Connection Diagrams

Ideal for finding how wires are connected between devices

Block Diagrams

Provides overview of system components and relationships

Schematic Diagrams

Shows relationship of components and circuit operation

Each of the different types of electrical drawings has advantages and disadvantages. Therefore it is important to select the appropriate drawing for the activity and often you may require more than one.

Applications of Electrical Drawings

Pictorial Diagrams

The pictorial diagram is helpful for recognizing and locating components on the actual appliance as each item is easily recognized and shown in its relative position to each other. Another useful point is that the wiring colour coding is clearly labelled.

Connection Diagrams

The connection or wiring diagram is a map of an electrical circuit. It is best used for finding exactly how and where wires are connected between devices. They are also useful for field-wiring a circuit and for tracing wires when troubleshooting.

Limitations

Both the pictorial and wiring types of diagrams can be difficult to use when trying to understand how a circuit operates. For example, they don't show how switches are activated whether by time, temperature, pressure or manual operation. Unless you are familiar with each component, the order of sequence is impossible to determine.

Ladder Diagrams

Structure

A schematic or ladder diagram is designed to show the relationship of the components to each other. The ladder diagram gets its name from its appearance. The two vertical outside lines that make the ladder could be thought of as the rails.

Voltage Representation

Notice in Figure 2-6 they are labelled L1 (Hot) and N (Neutral) representing a 120 alternating voltage potential between them. A ladder diagram also shows a clear separation of the different voltages above and below the transformer.

Circuit Layout

Separate circuits are shown as rungs of the ladder. Each circuit will then have a source voltage from the left, with one or more switches and a load.

Reading Technique

It is sometimes easier to read ladder diagrams from right to left identifying each of the loads and the devices that would control them. Notice the fan motor in Figure 2-6 could be activated by either the manual switch or the temperature activated switch that closes on a temperature rise.

Thermostatically Controlled Circuit

Circuit Principles

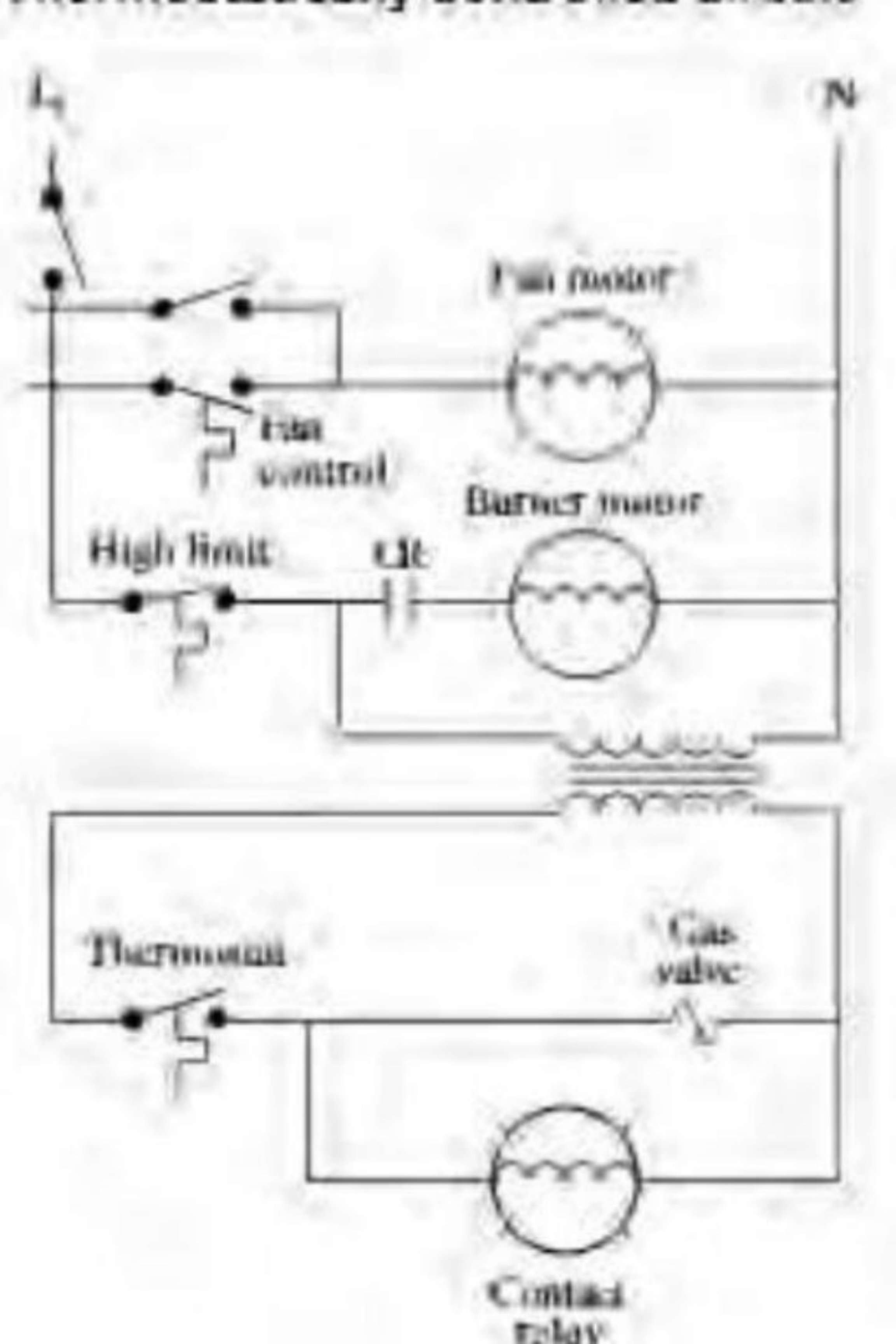
No matter how simple or complex the wiring diagram, the principle is the same – in order for any electrical function to take place, you must have a completed circuit. With this in mind it is important that you are consistent in regard to what state the appliance is in when it is drawn.

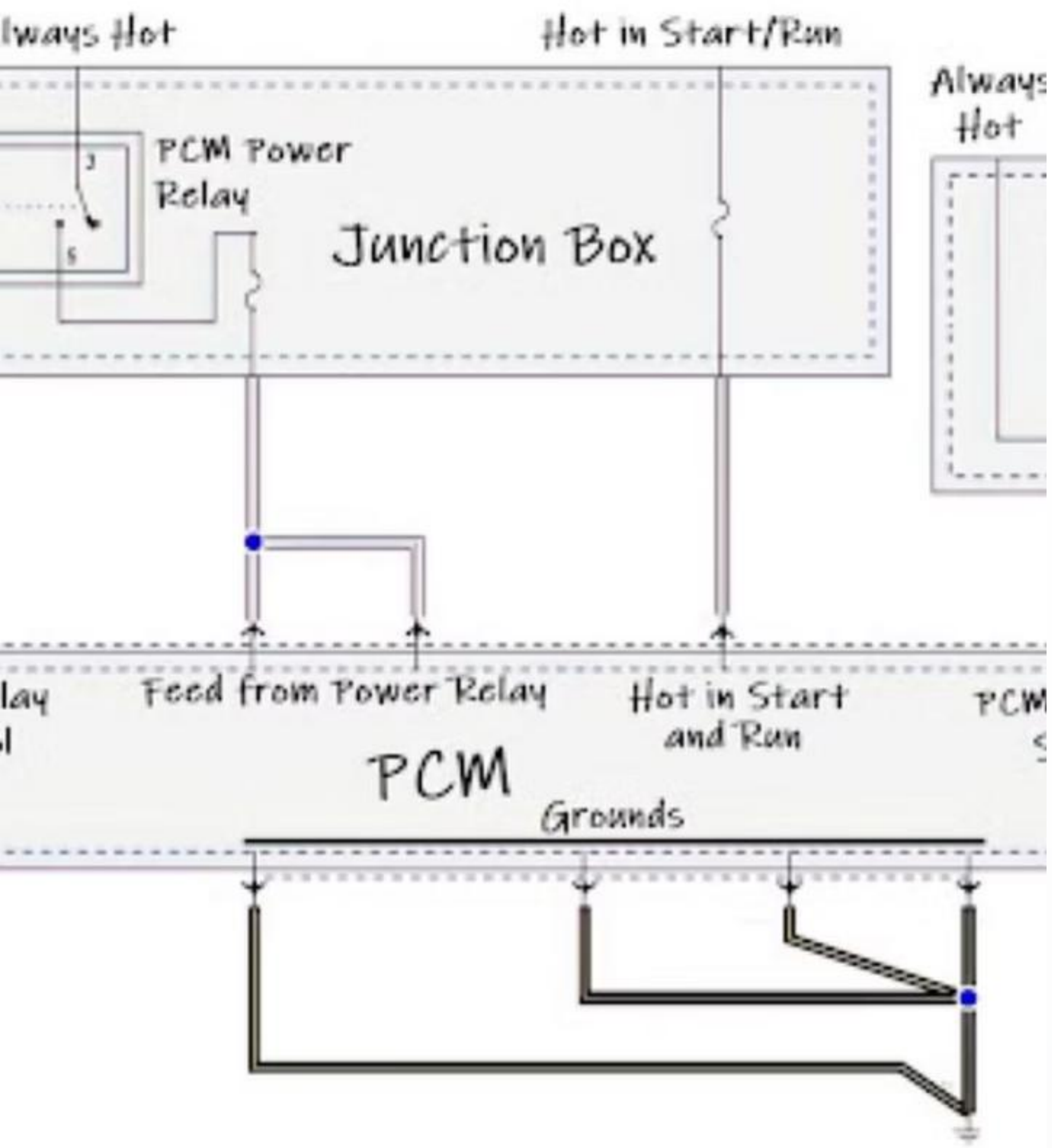
Switch Representation

Besides just showing what load a switch will control on the drawing, the switches/controls are also drawn in such a way to indicate what causes them to open or close.

Circuit Completion

For any electrical function to take place, there must be a completed circuit from power source through control devices to the load and back to the source.





"At Rest" State

Definition

All wiring diagrams are drawn in an "at rest" state (de-energized state)

Circuit Condition

The circuit's main disconnect device is in the open position

Equipment Status

Any heating or cooling devices connected to the circuit are not operating or at rest

Component Position

No devices in the circuit are energized or operating, and all devices and switches are in their normal positions with power off

Switch Positions

A switch drawn in the	Is said to be	Will not change position until
Open position	Normally open (NO)	It is switched manually, remotely or automatically
Closed position	Normally closed (NC)	It is switched manually, remotely or automatically

To say a switch's position is changed remotely could mean indirectly by a relay. Automatically is usually by way of a mechanical device connected to the contacts that respond to a change in the environment to which it is exposed. For example, here is a Temperature Activated Switch (T.A.S.) that is normally open and will make or close on a drop in temperature.

Remote and Automatic Switching

Remote Switching

To say a switch's position is changed remotely could mean indirectly by a relay.

Automatic Switching

Automatically is usually by way of a mechanical device connected to the contacts that respond to a change in the environment to which it is exposed.

Example

A Temperature Activated Switch (T.A.S.) that is normally open and will make or close on a drop in temperature.

Wiring Diagram Interpretation

Required Knowledge

Correct interpretation of wiring diagrams and sequences of operation requires an understanding of certain electrical terms

Control Device

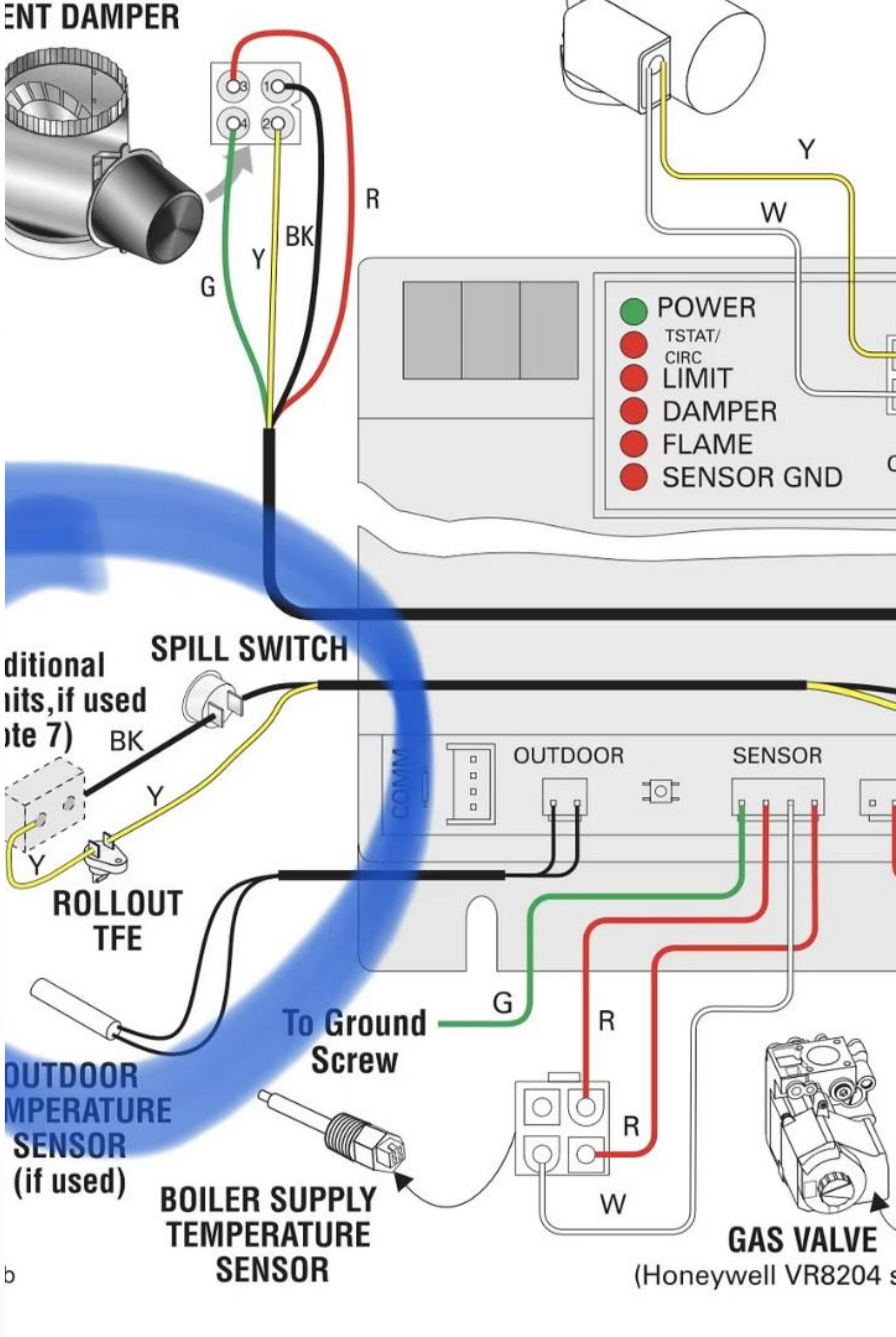
Components that regulate system operation based on various inputs

Factory Wiring

Permanent wiring installed during manufacturing

Field Wiring

Wiring installed by technicians during equipment installation



Control Device Callup

Types of Control Devices

- Temperature controls
- Pressure controls
- Humidity controls
- Flow controls
- Level controls

Diagram Representation

- Represented by symbols
- Identified by position, type and action

Proper Identification

It would be incorrect to identify a temperature control as a heating thermostat on a drawing unless it is known for sure that that is its function. The proper way to identify it would be as "a normally open temperature control that breaks or opens on temperature rise and closes on temperature drop"

Control Device States

Normal States

Controls are normally open or normally closed.

Response Triggers

All controls open or close in response to an increase (rise) or decrease (fall) in:

- Temperature
- Pressure
- Humidity
- Fluid flow

Factory Wiring

Definition

Factory wiring is done at the time of manufacture. It is permanent and may include printed circuits, wiring harness assemblies, and individual cables and conductors.

Diagram Representation

Factory wiring is usually designated on diagrams by solid lines.

Characteristics

Factory wiring is permanent and installed during the manufacturing process.

Field Wiring

Definition

Field wiring is done by a gas technician/fitter at the time of installation.

Applications

It usually includes the cabling required for connection to the power supply and may include certain modifications or changes to the wiring required for specific applications or conditions.

Diagram Representation

Field wiring is usually designated on diagrams by broken lines.

Furnace Electrical Control Drawings

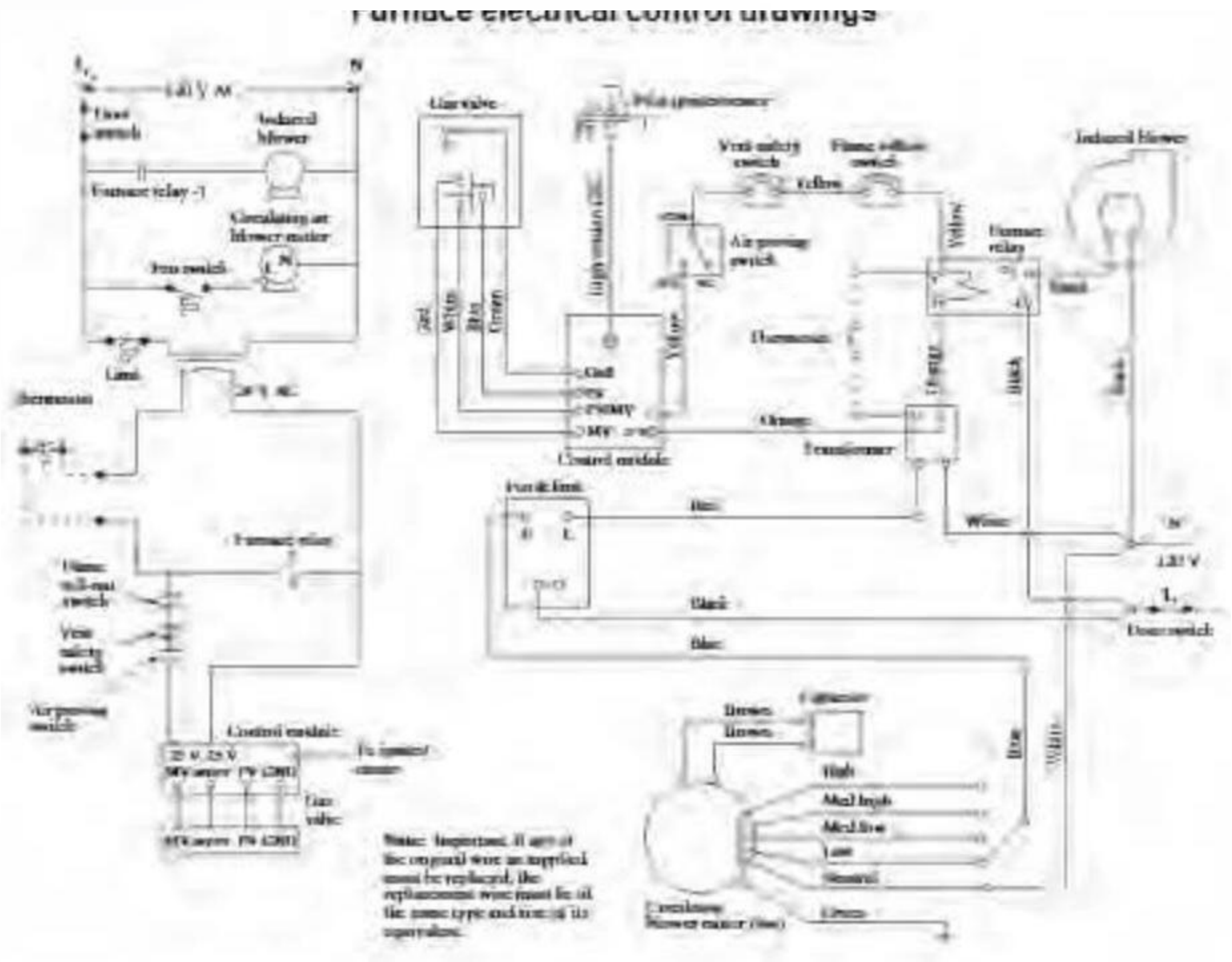


Diagram Types

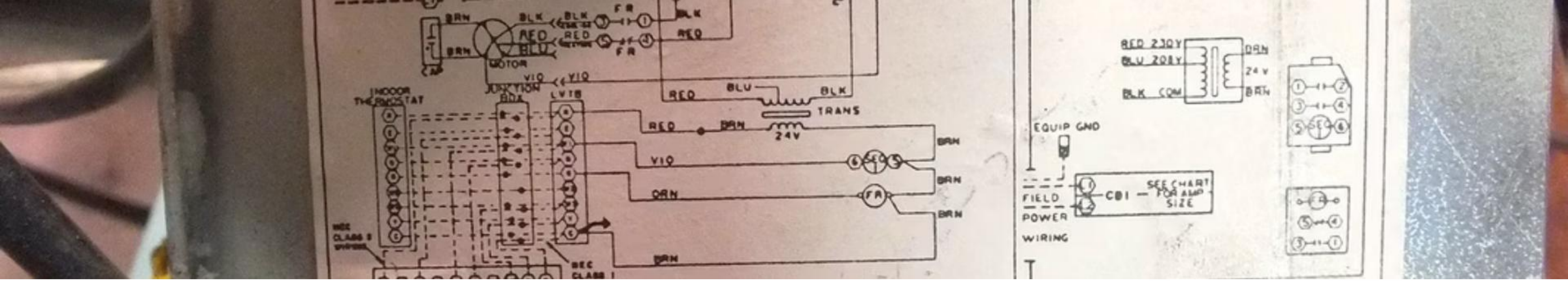
In Figure 2-8, you have two separate electrical drawings for a gas-fired furnace. On the left is a schematic ladder type diagram, and on the right, you see a wiring diagram.

Circuit State

In these diagrams, the circuit is shown "at rest" with all switches in their normally open or normally closed positions depending on their function. For relay contacts, "normal" is the position with no power on in the circuit.

Field Wiring

Notice the only field wired control is the thermostat.



Troubleshooting with Diagrams

Identify the Problem

If you were troubleshooting the circulator blower motor, you would first need to identify which components control it.

Consult Ladder Diagram

By looking at the ladder diagram, you could see quite easily that the blower motor is simply controlled by a normally open heat activated fan switch.

Locate Components

To locate that switch, you would be better off looking at the wiring diagram where you would see that it is housed in the same unit as the limit switch.

Verify Connections

You could also verify the colour coded wires connected to the switch using the wiring diagram.

Advantages of Pictorial Diagrams

Component Recognition

Helps in recognizing and locating components on the actual appliance

Relative Positioning

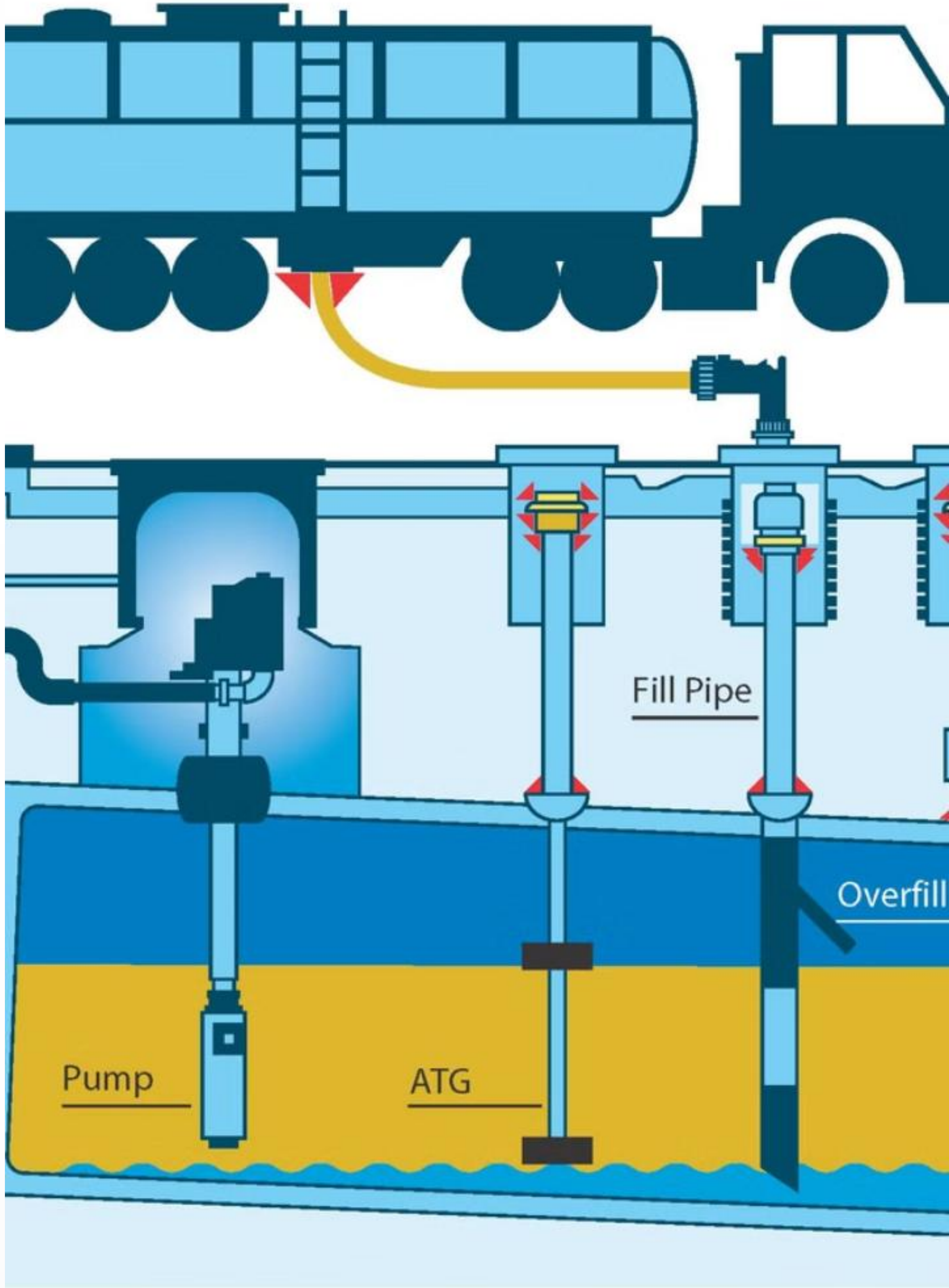
Each item is easily recognized and shown in its relative position to each other

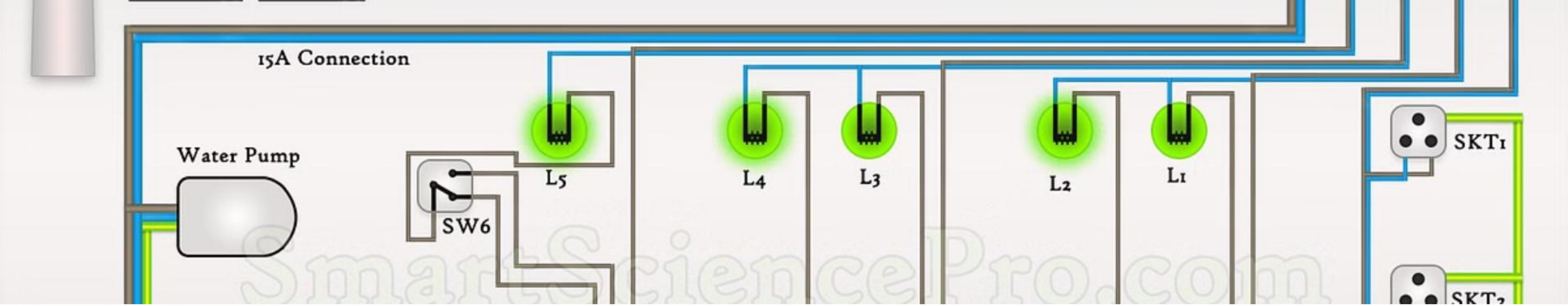
Color Coding

Wiring colour coding is clearly labelled

Visual Representation

Components are drawn as they would appear in real life





Advantages of Connection Diagrams

Circuit Mapping

Acts as a map of an electrical circuit

Wire Connections

Best used for finding exactly how and where wires are connected between devices

Field Wiring

Useful for field-wiring a circuit

Troubleshooting

Helpful for tracing wires when troubleshooting

Advantages of Ladder Diagrams

Component Relationships

Shows the relationship of components to each other

Circuit Operation

Designed to show how circuits work and the function of their components

3

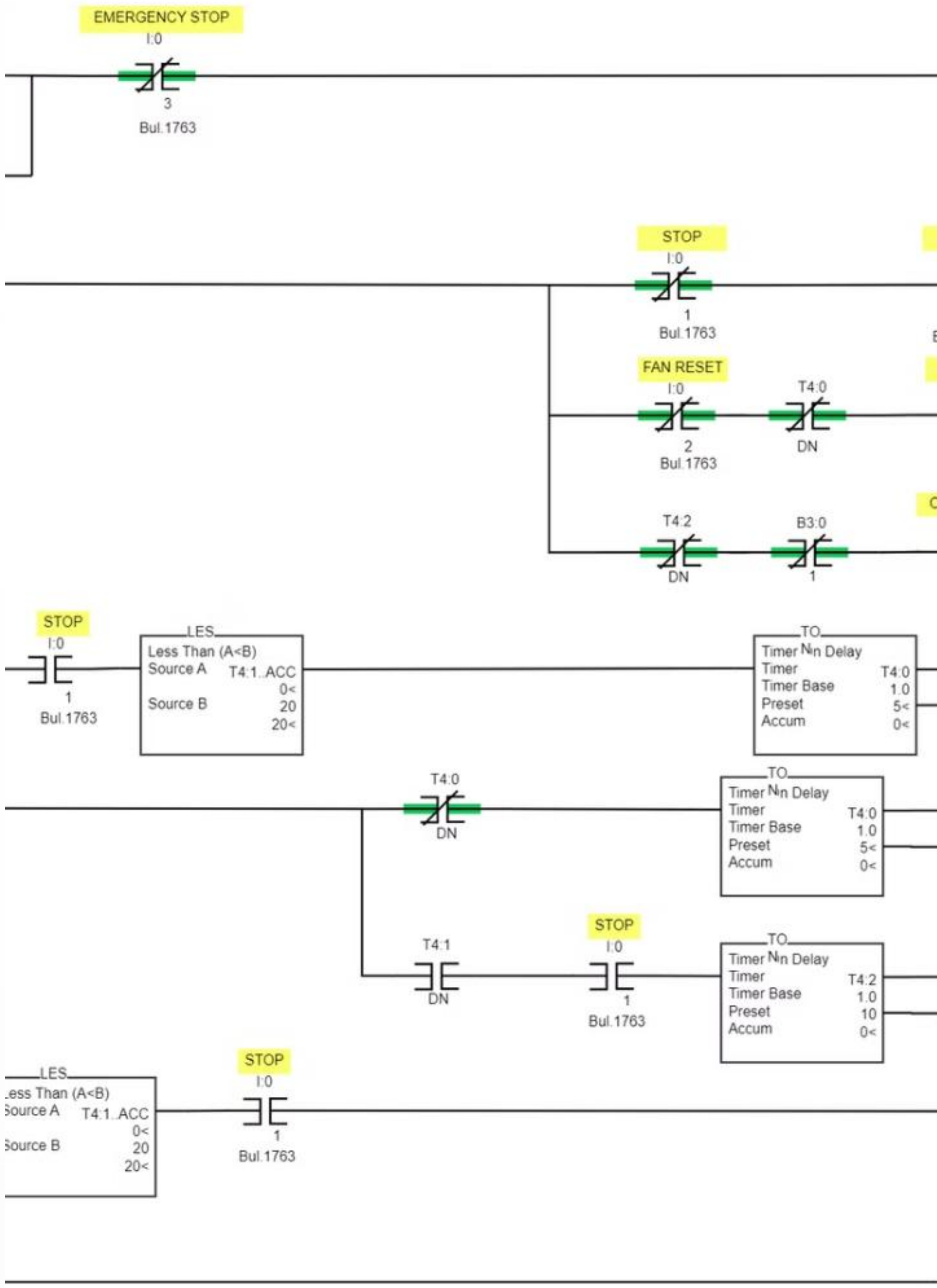
Operational Sequence

Shows a logical sequence of events in circuit operation

4

Voltage Separation

Shows clear separation of different voltages



Advantages of Block Diagrams

System Overview

Provides a simplified overview of system components and their relationships

Component Grouping

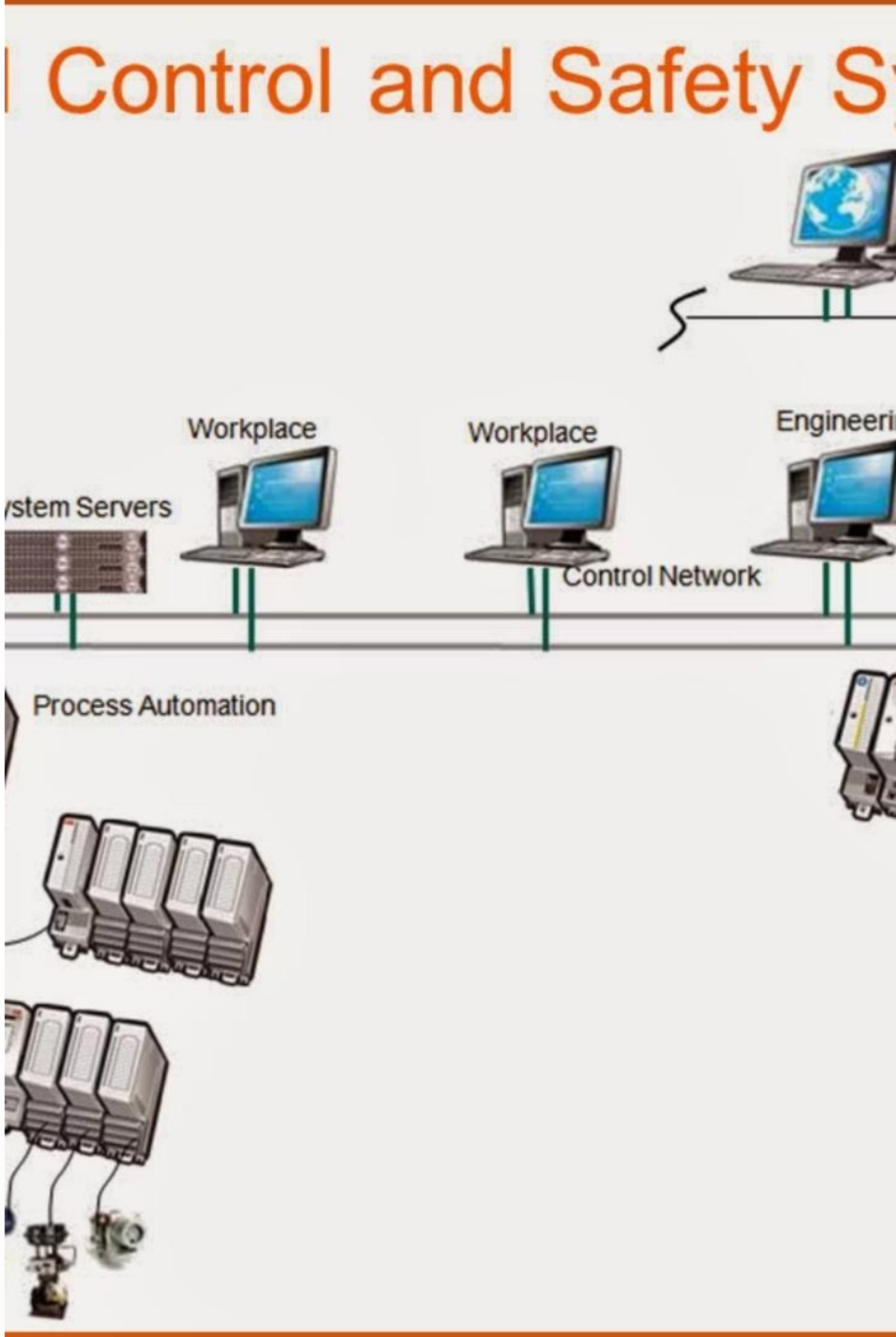
Indicates the relationship between individual circuits, components or groups of components within the same housing

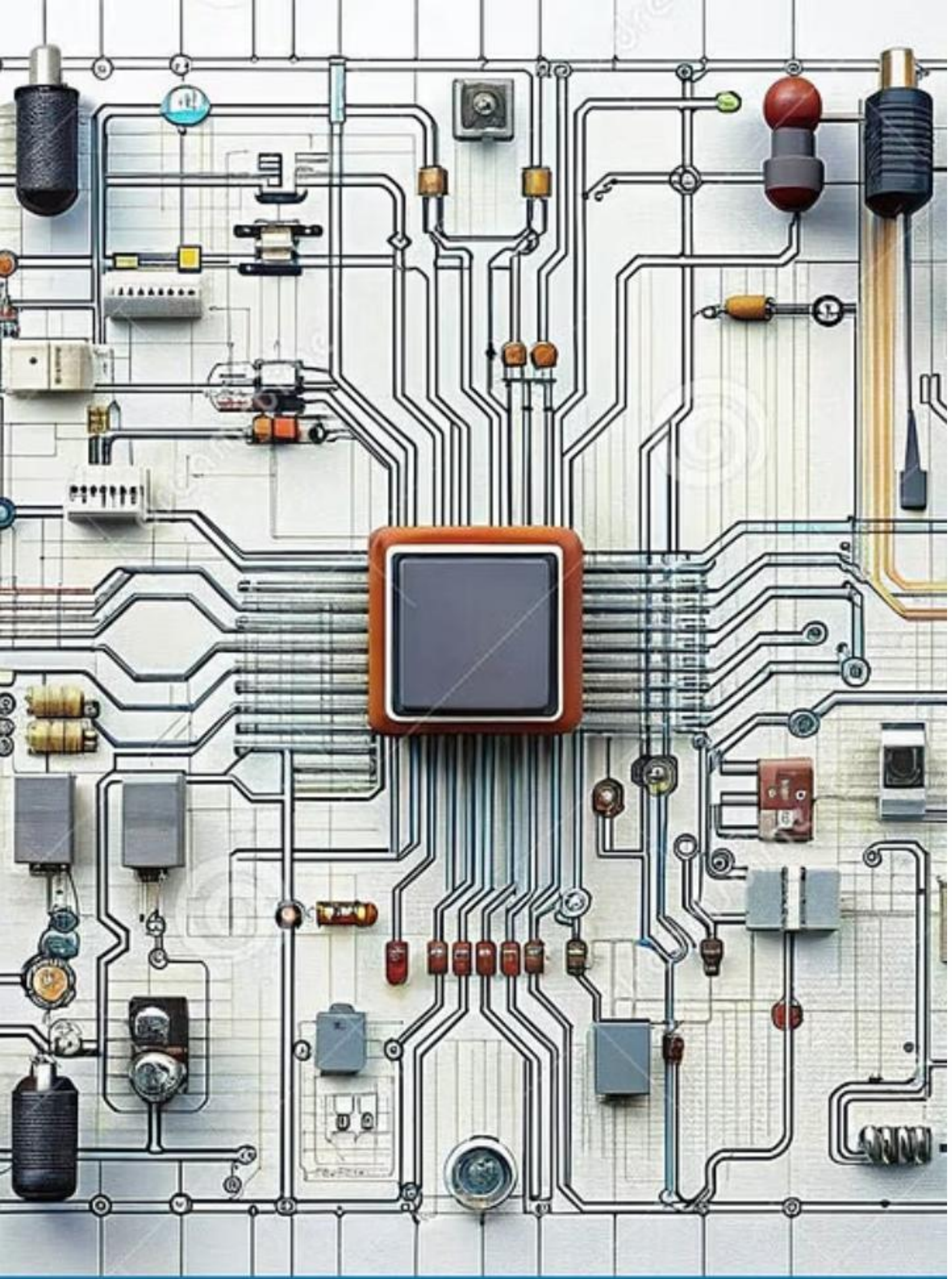
Simplified Representation

Components are drawn in the form of blocks with their relationships indicated by connected lines

Functional Understanding

Helps understand the overall function of a system without getting lost in detailed connections





Limitations of Pictorial and Wiring Diagrams

Circuit Operation

Can be difficult to use when trying to understand how a circuit operates

Switch Activation

Don't show how switches are activated whether by time, temperature, pressure or manual operation

Operational Sequence

Unless you are familiar with each component, the order of sequence is impossible to determine

Complex Systems

Can become very cluttered and difficult to follow in complex systems

Reading Ladder Diagrams

Identify Power Rails

The two vertical outside lines that make the ladder could be thought of as the rails, typically labelled L1 (Hot) and N (Neutral)

Examine Circuit Rungs

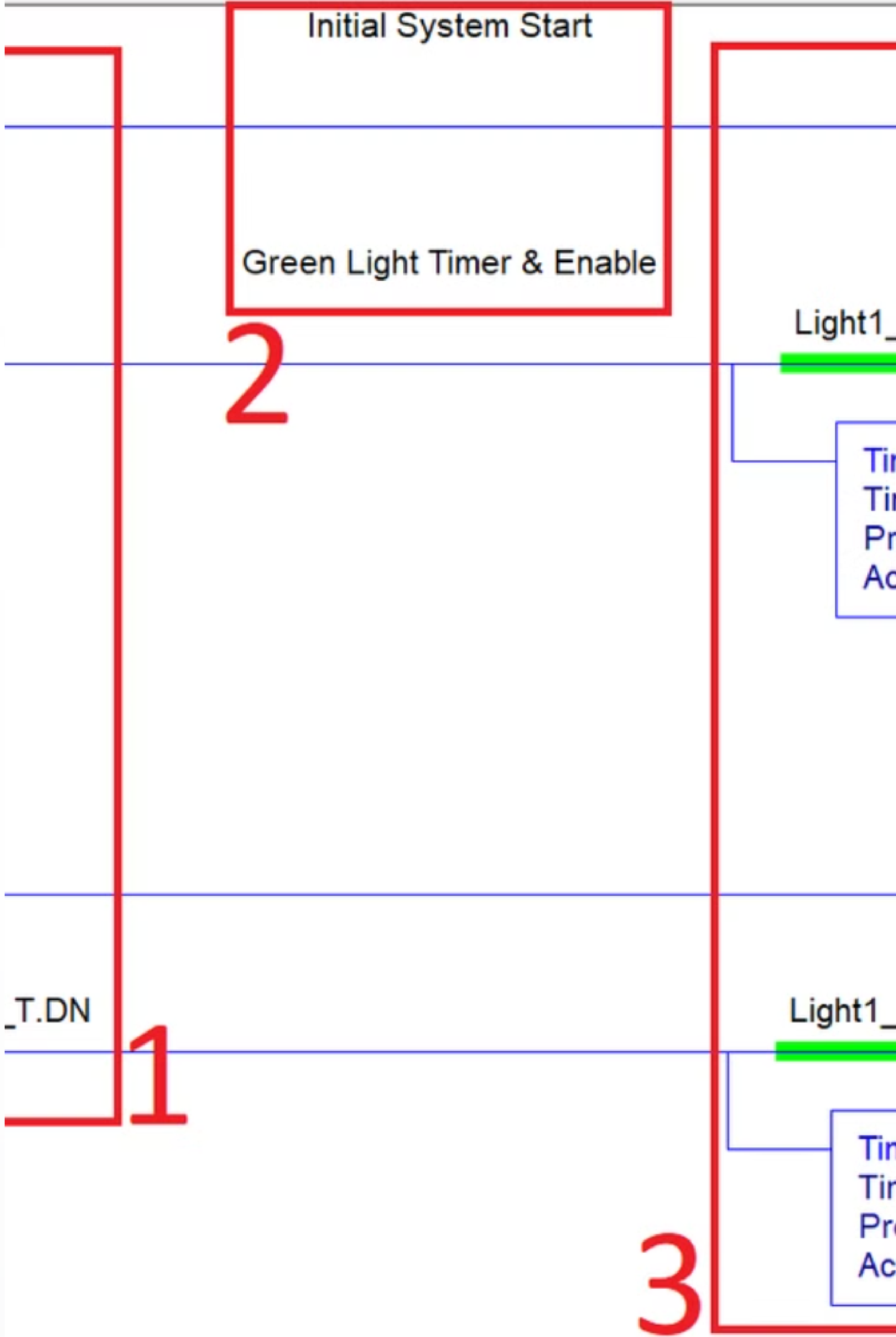
Separate circuits are shown as rungs of the ladder, each with a source voltage from the left, with one or more switches and a load

Read Right to Left

It is sometimes easier to read ladder diagrams from right to left identifying each of the loads and the devices that would control them

Understand Switch Functions

Switches/controls are drawn to indicate what causes them to open or close



Proper Control Device Identification

Incorrect Identification

It would be incorrect to identify a temperature control as a heating thermostat on a drawing unless it is known for sure that that is its function.

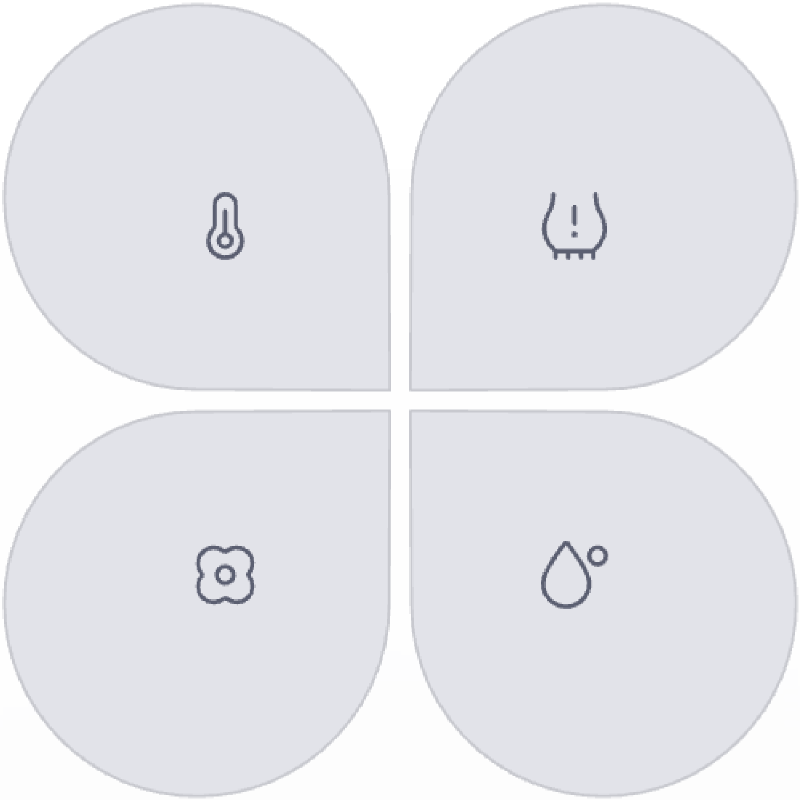
Correct Identification

The proper way to identify it would be as "a normally open temperature control that breaks or opens on temperature rise and closes on temperature drop"

Important Characteristics

- Normal state (open/closed)
- Type of control (temperature, pressure, etc.)
- Response to environmental changes

Control Device Response



Temperature

Controls respond to increases or decreases in temperature

Pressure

Controls respond to increases or decreases in pressure

Fluid Flow

Controls respond to increases or decreases in fluid flow

Humidity

Controls respond to increases or decreases in humidity

Factory vs. Field Wiring

Factory Wiring

- Done at time of manufacture
- Permanent installation
- May include printed circuits, wiring harness assemblies, and individual cables
- Designated on diagrams by solid lines

Field Wiring

- Done by gas technician/fitter at installation
- Includes cabling for power supply connection
- May include modifications for specific applications
- Designated on diagrams by broken lines

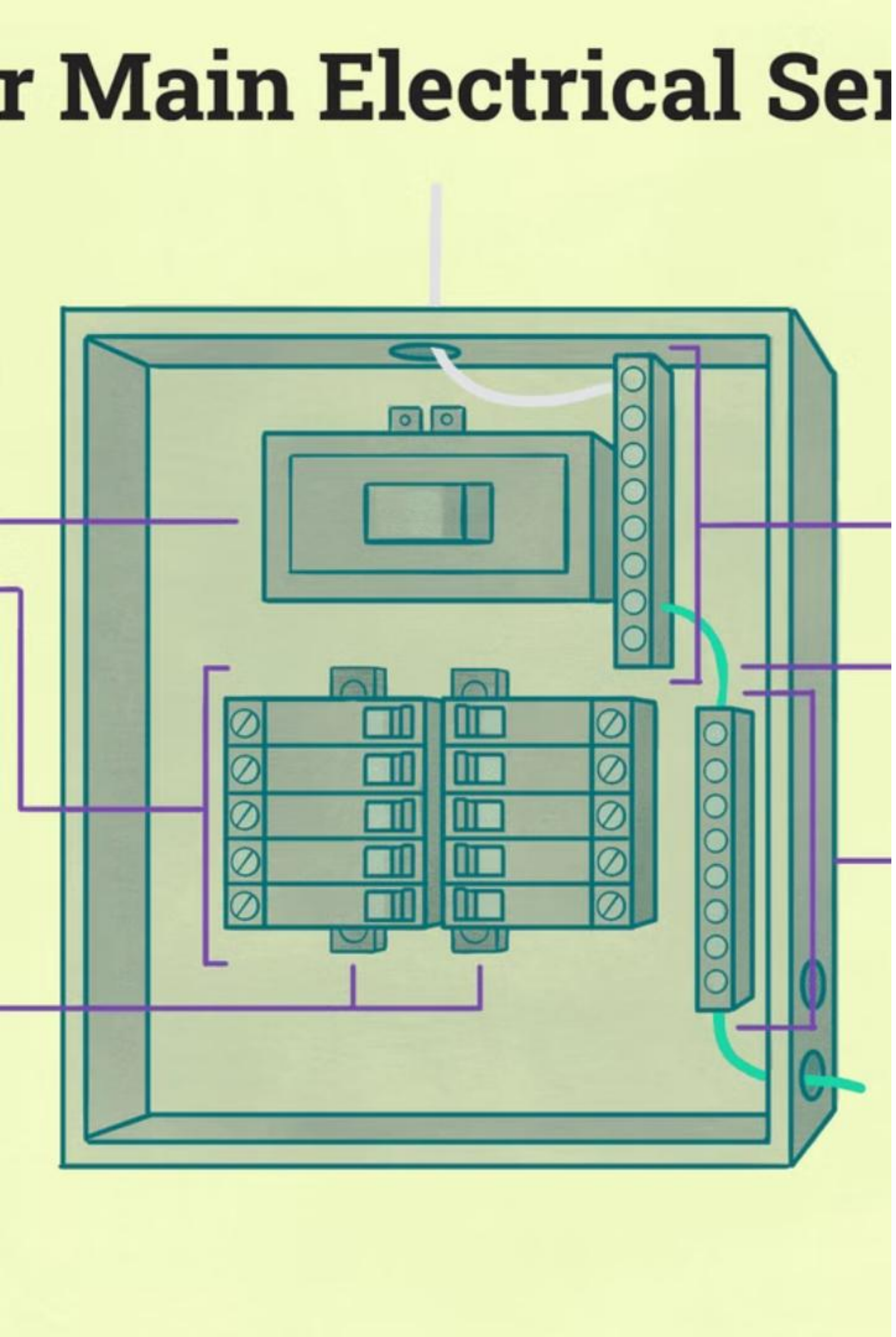
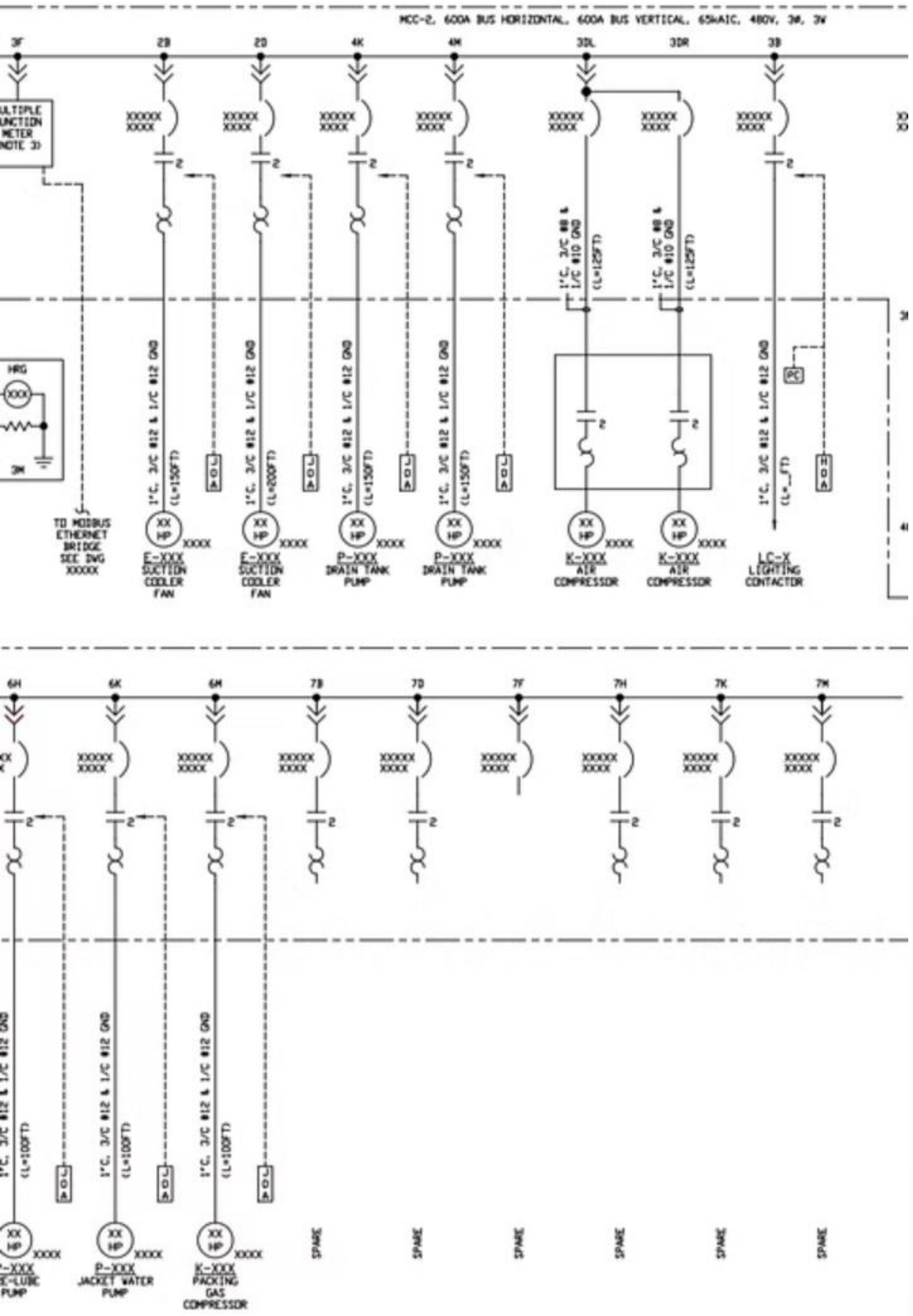


Diagram Selection for Different Tasks

Task	Best Diagram Type	Reason
Locating components	Pictorial	Shows actual appearance and position
Tracing wires	Connection/Wiring	Shows exact wire connections
Understanding circuit operation	Ladder/Schematic	Shows functional relationships
System overview	Block	Shows component relationships



Combining Diagram Types

Multiple Diagram Approach

Often you may require more than one type of diagram for complete understanding

2

Troubleshooting Example

Use ladder diagram to understand circuit function, then wiring diagram to locate components

Installation Example

Use pictorial diagram to identify components, then connection diagram for wiring

System Analysis

Use block diagram for overview, then schematic for detailed operation

Practical Application: Furnace Troubleshooting

Identify the issue

Determine which component is malfunctioning

2

Consult schematic

Use ladder diagram to understand circuit function

Locate components

Use wiring diagram to find physical location

Test and repair

Verify connections and replace components as needed

Importance of "At Rest" State

Consistent Reference Point

All wiring diagrams are drawn in an "at rest" state (de-energized state) to provide a consistent reference point

Component Status

In the "at rest" condition, no devices in the circuit are energized or operating, and all devices and switches are in their normal positions with power off

Troubleshooting Advantage

This standard representation allows technicians to understand how the circuit will behave when power is applied

Switch Positions

Switches are shown in their normal position (open or closed) as they would be with no power applied

Temperature Activated Switches

Function

Temperature Activated Switches (T.A.S.) respond to changes in temperature by opening or closing contacts

Types

- Normally open - closes on temperature drop
- Normally open - closes on temperature rise
- Normally closed - opens on temperature drop
- Normally closed - opens on temperature rise

Applications

Used in heating and cooling systems to control when equipment activates based on temperature changes

Practical Example: Fan Control

Thermostat Call

Thermostat closes on temperature drop

Gas Valve Opens

Current flows through closed thermostat

Heat Exchanger Warms

Temperature rises in furnace

Fan Switch Activates

Fan switch closes on temperature rise

Notice the fan motor in Figure 2-6 could be activated by either the manual switch or the temperature activated switch that closes on a temperature rise.

Key Takeaways

4

Diagram Types

Pictorial, Connection, Ladder/Schematic, and Block diagrams each serve different purposes

2

Wiring Types

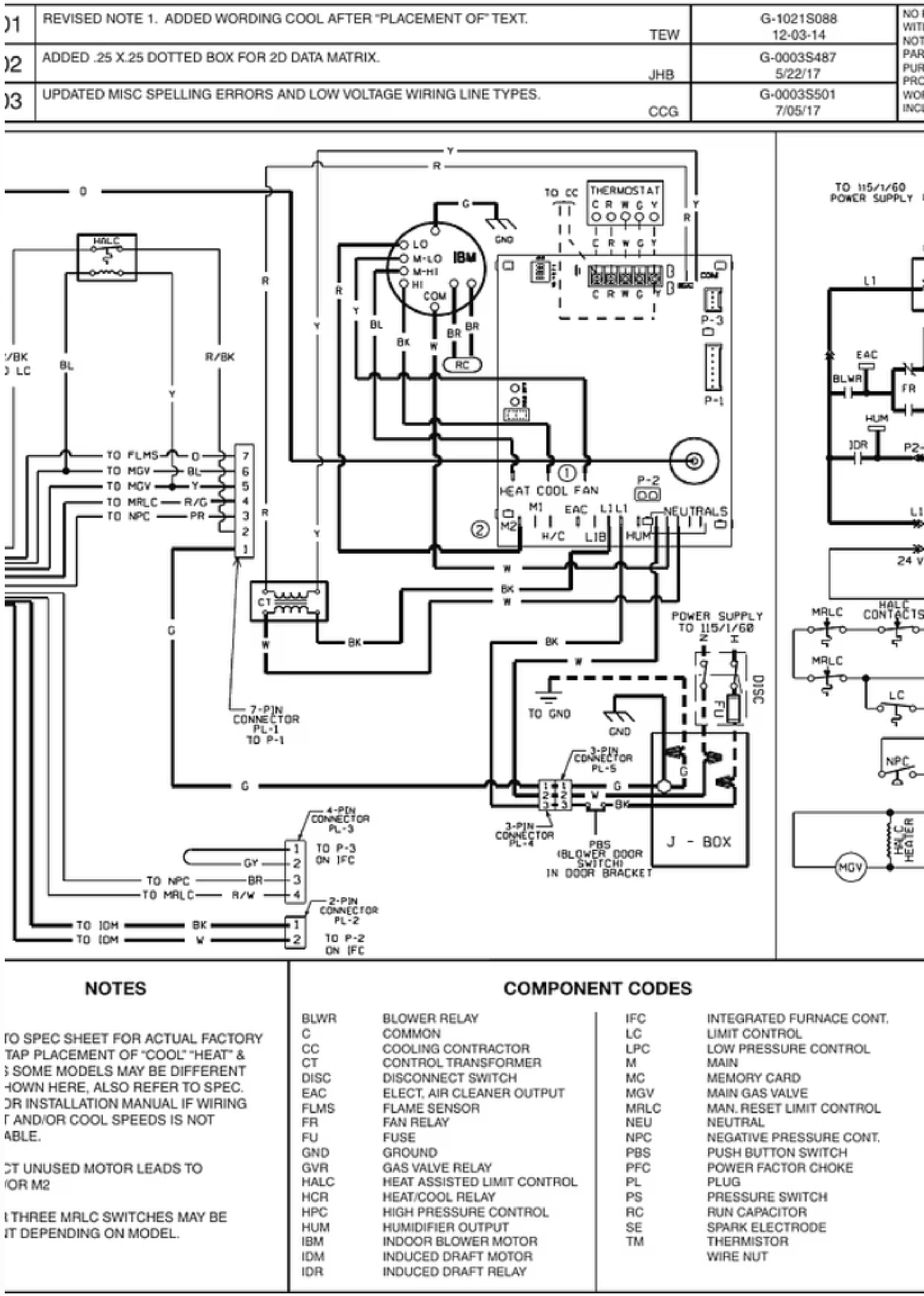
Factory wiring (solid lines) and field wiring (broken lines) are represented differently

1

Standard State

All diagrams show components in their "at rest" (de-energized) state

Having a working knowledge of the various types of electrical drawings and electrical symbols is very important as this enables the gas technician/fitter to understand the entire sequence of operation of the gas equipment.



CSA Unit 12

Chapter 3
Measuring and Test Instruments

A gas technician/fitter must be capable of solving problems on a regular basis. In many cases, these problems will be electrical ones. Solving these problems requires a thorough knowledge of the system and the tools required to determine where the problems lie. This means that the gas technician/fitter must be familiar with the various types of electrical measuring and test devices, as well as how and where they are applied.

Purpose of Electrical Testing Equipment

Safety First

When working with electrical testing equipment, gas technicians/fitters must protect themselves from electrical hazards. Reviewing Unit 1 Safety is recommended.

For information on the basic selection, use, and maintenance of common electrical testing and measuring instruments, refer to Unit 5 Introduction to electricity, Chapter 7. Electrical measuring instruments.

Learning Objectives

Describe Types and Applications

Understand the various types and applications of measuring and test instruments used in gas fitting work

Describe Safe Operation

Learn the safe operation and connection of measuring and test instruments when working with gas equipment

Key Terminology

Term	Abbreviation (Symbol)	Definition
Digital multimeter	DMM	Digital electronic measuring instrument that combines several functions in one unit
Volt-Ohm-milliammeter	VOM	Electronic measuring instrument that combines several functions in one unit

Types of Measuring and Test Instruments

Analog Instruments

Analog instruments indicate measured values with a scale and pointer display. The pointer's movement is directly and continuously related to the measured quantity.

Digital Instruments

Digital instruments interpret the measured quantity electronically in discrete numerical data (digits). They have a numerical display that is formed by light-emitting diodes (LEDs) or liquid crystal displays (LCDs).

Digital Multimeter (DMM)

Multiple Functions

A digital multimeter (DMM) combines the functions of a voltmeter, an ammeter, and an ohmmeter.

Advanced Features

Digital multimeters also have advanced features that vary among DMM models from different manufacturers.

Function Dial

The function dial normally has positions that will allow a technician to measure AC volts, DC volts, DC amps, and resistance.

Additional Capabilities

Some DMMs have function switch positions that will allow a technician to measure AC amps and to test diodes and capacitors.

Voltage Functions of DMM

Measuring Electrical Potential

Electrical potential and voltage are measured in volts (V) or millivolts (mV).

The voltage function measures the difference in electric potential between two points in a circuit.

Types of Voltage Sources

AC voltage: Current flow changes in both magnitude and direction at regular intervals.

DC voltage: Current flow does not change direction.

Applications of Voltage Measurement

AC Voltage Function

Commonly used to test and troubleshoot receptacles, gas appliance power supply, transformers, and other AC control circuits.

DC Voltage Function

Used to test battery banks and to troubleshoot DC motors, DC generators and other DC circuits.

Millivolt Function

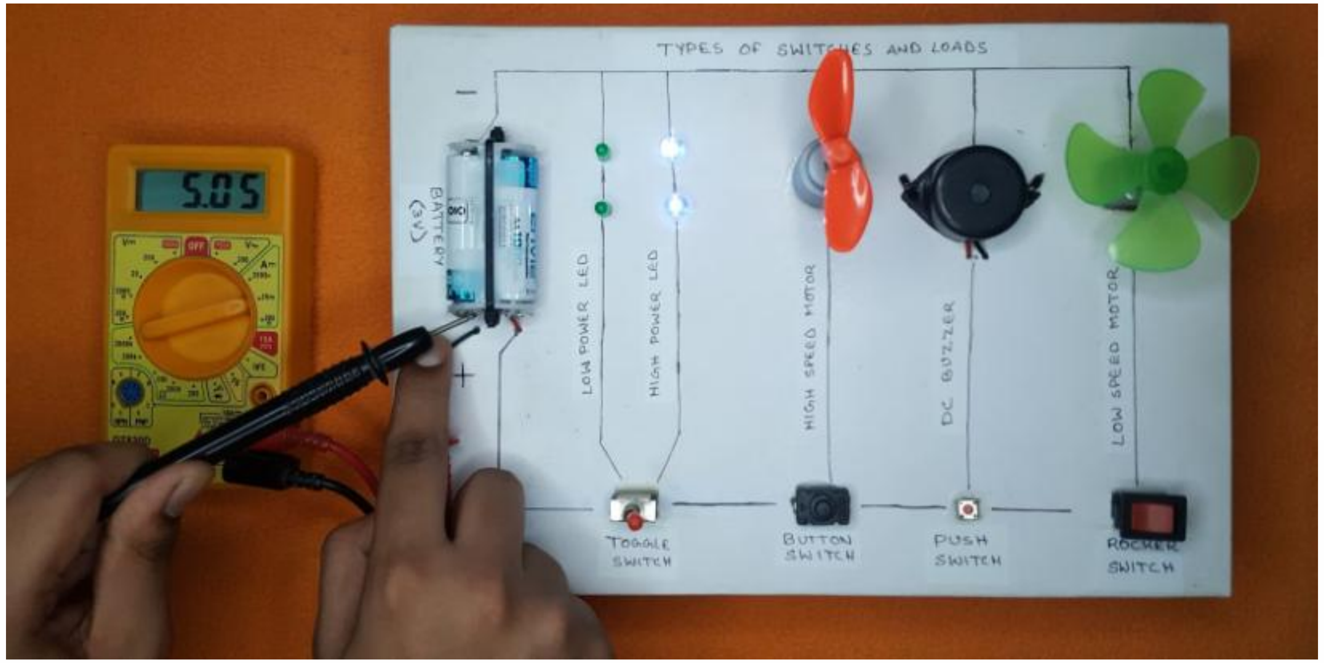
Some DMM may have a dedicated DC millivolt setting that is more accurate than the DC autorange voltage function. This function is useful for testing very low millivolt systems such as thermocouples.

Ammeter Function

Measuring Current Flow

Electric current flow is measured in amperes (A), milliamperes (mA), or microamperes (μA). The word "ampere" is commonly shortened to "amp".

The DMM has a setting for AC and DC current. Most DMMs can measure DC or AC currents from the micro-amp range to a maximum of 10 amps.



For higher amperage circuits, a clamp-on ammeter is recommended.

Clamp-On Ammeter

Purpose and Design

Clamp-on ammeters are designed to eliminate the need to interrupt circuit operation to measure current in the circuit.

Clamp-on meters are generally used to measure alternating current or direct current only, but some digital clamp-on meters will measure AC and DC, as well as voltage and resistance.

Advantages of Clamp-On Ammeter

Minimal Circuit Loading

It causes minimal circuit loading because it is not connected in series with the load.

No External Shunts

It does not require the use of external shunts, as some in-line ammeters do.

Durability

It is generally more rugged than an in-line ammeter.

Ohmmeter Function

Measuring Resistance

Any circuit with an ability to conduct some electrical current is said to have electrical continuity. The amount of resistance there is to current flow is measured in ohms (Ω) or kilohms (kΩ).

The ohmmeter function can be used to measure both resistance and continuity in a circuit.

An ohmmeter function is powered by a small battery that causes current flow through the tested circuit's resistance, therefore a DMM set for ohms must not be used on an energized circuit.

Applications of Ohmmeter

Testing Fuses

A DMM set for ohms can be used to test the continuity of a fuse. The resistance of a faulty fuse would indicate OL (infinity) on the display.

Testing Switches

A DMM set for ohms can be used to test the continuity of a switch. The resistance of an open switch would indicate OL (infinity) on the display, and a closed switch would indicate a very small resistance value.

Safety Note

Never use an ohmmeter on an energized circuit as it can damage the meter and potentially cause injury.

Specialized Meters: Megohmmeter

Purpose and Function

An Insulation resistance tester also called a megohmmeter is used for measuring the resistance of electrical insulation in, for example, motor and transformer windings.

It measures values in the 20 kilohm to 2000 megohm range.

The component being tested is disconnected from the circuit and the megohmmeter leads connected (one to the frame and one to the windings).

Using a Megohmmeter

Disconnect Component

The component or apparatus being tested is disconnected from the circuit.

Connect Leads

Connect megohmmeter leads (one to the frame and one to the windings).

Apply Voltage

The instrument applies a DC voltage to the component.

Take Readings

The insulation value is read at 30 seconds and again at 1 minute after being connected. If the insulation is in good condition, the value will increase slowly. The reading taken at 1 minute should be higher than the one taken at 30 seconds.

Specialized Meters: Capacitor Analyzer

Purpose and Function

Unlike an ohmmeter, which only indicates if a capacitor has capacitance, a capacitor analyzer can test actual capacitance.

Its principal function is the detection of current leakage that would normally only be obvious during circuit operation. It can also detect if a capacitor is open or shorted-out.

Operation and Connection of Measuring Instruments

Read Instructions

Always read the manufacturer's operation and maintenance instructions for testing instruments and equipment prior to use.

Seek Clarification

If you are unsure of how to use them, contact your supervisor for clarification.

Safety First

Safety is the single most important concern when working on electrical equipment.

Use PPE

Always wear the required personal protective equipment.

Safety Awareness Before Testing

Presence of Electricity

Never trust that the power has been switched off. Always measure the voltage before working on any equipment or wiring.

Lockout/Tag Out

Follow proper lockout/tag out procedures to ensure equipment cannot be energized during work.

Grounding

Understand and follow proper grounding procedures to prevent electrical hazards.

System Potential

Be aware of system potential energy or category of short-circuit current.

Meter Condition and Testing

1. **Inspect for Visible Damage**

   Check the meter housing for cracks or other damage that could compromise safety.

2. **Inspect Test Leads**

   Visually inspect the test lead insulation, probe, and connection for wear or damage.

3. **Test Lead Resistance**

   Perform a resistance test of the leads to confirm they are reliable and well connected.

4. **Zero Adjustment**

   Ensure the meter is properly zeroed before taking measurements.

5. **Test on Known Source**

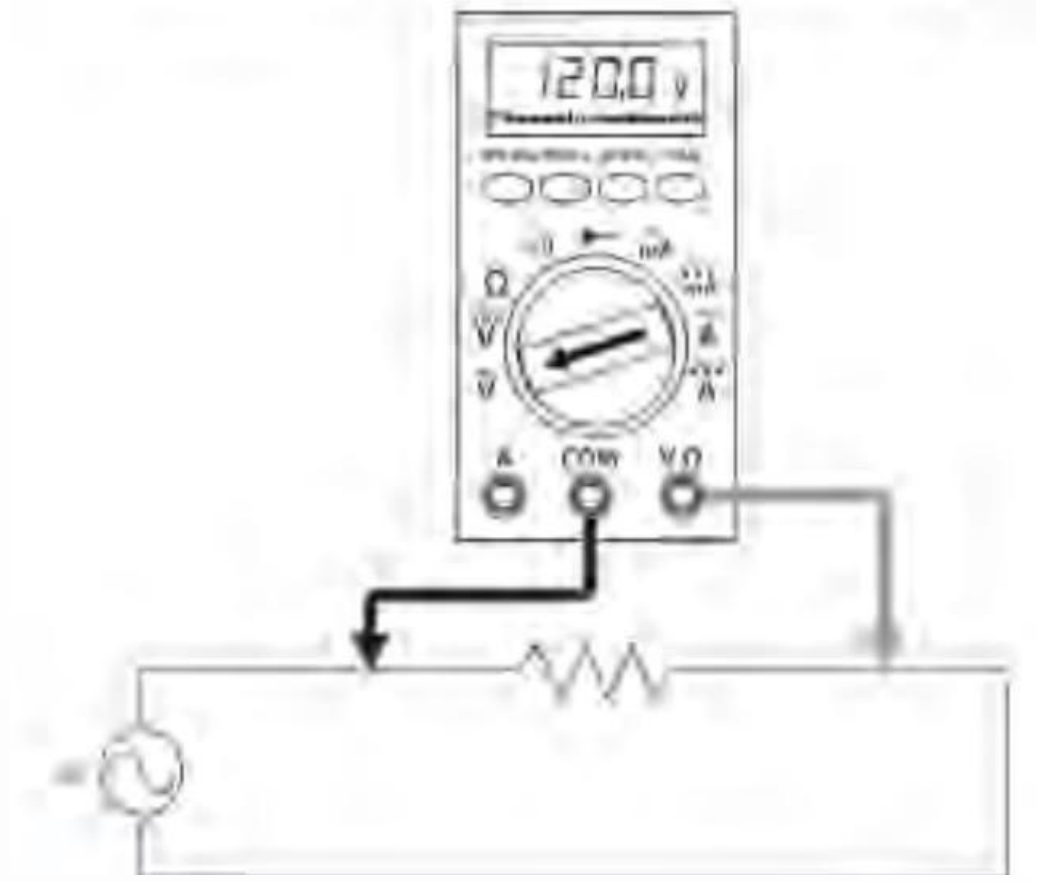
   Test the meter and leads on a known source before using them to test a circuit or component to ensure that the meter is working properly.

Measuring Voltage

Connection Method

To measure voltage, a voltmeter must be connected across the two points in the circuit where the voltage appears.

AC and DC digital voltmeters must be connected in parallel with the device or circuit being tested.

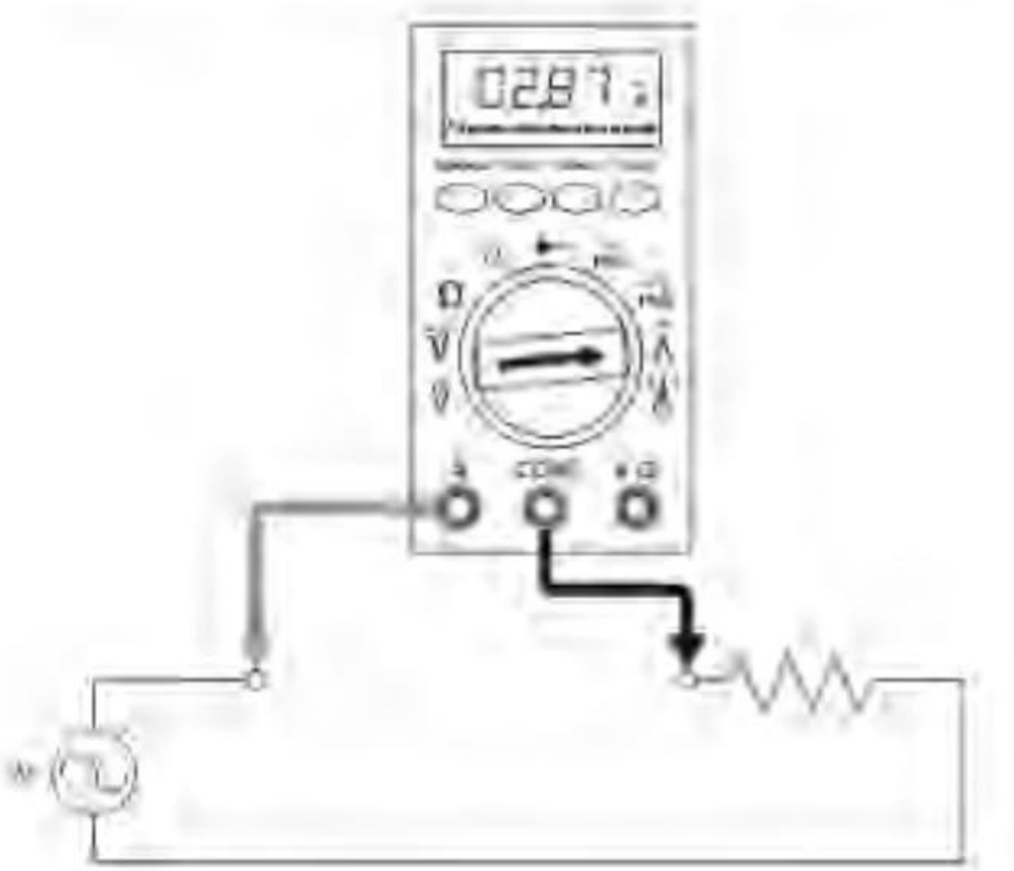


Measuring Current: In-line Ammeter

Fuse Protection

Most digital multimeters are protected by fuses on the current measuring scales. These fuses help prevent injury and protect the meter from damage.

If a fuse is damaged and requires replacement, it must be replaced with one specified by the manufacturer to provide proper protection.



To measure current with an in-line ammeter, the circuit must be broken at the point where the current is to be measured and the ammeter inserted in series.

Measuring Current: Clamp-On Ammeter

Open the Jaws

Open the jaws of the ammeter by squeezing the handle.

Close Around Conductor

Close the jaws over the conductor.

Ensure Single Conductor

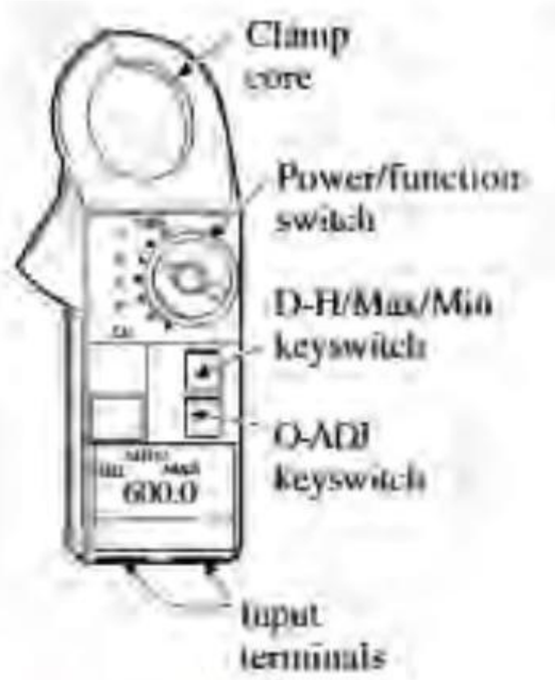
Ensure that only one conductor is enclosed in the jaws. If the live and neutral conductors are both enclosed by the jaws, the meter will read zero.

Check Jaw Closure

Ensure that the jaws of the ammeter are completely closed. If the contact points of the jaws are dirty or obstructed and do not make good contact, the reading will be inaccurate.

Read Display

The current reading will be indicated on the ammeter display.



Measuring Resistance

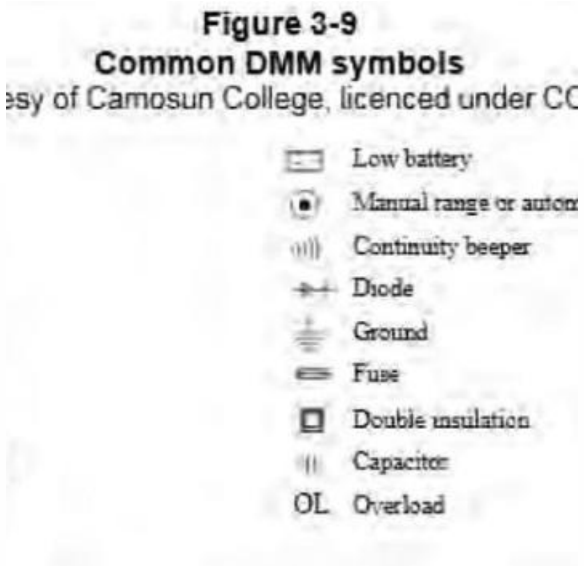
Connection Method

An ohmmeter is used to measure resistance.

The ohmmeter is connected across the unpowered device or circuit. To protect the ohmmeter, it is best if you isolate the devices being tested from the circuit.

Never measure resistance on a powered circuit as this can damage the meter.

Common Symbols on Digital Meters



The digital meter has a display where numbers appear to indicate the numeric value of the electrical quantity being measured. The digital meter also uses symbols on the display, switch, and connections.

Reading Digital Multimeter Displays

Numerical Display

The digital meter has a display where numbers appear to indicate the numeric value of the electrical quantity being measured.

The digital meter also uses symbols on the display, switch, and connections to indicate different functions and settings.

Bar Graph

The bar graph on a DMM reacts like the needle on an analogue meter.

The bar graph responds faster than the numerical reading, which can help identify problems caused by loose connections.

Testing Circuits with a Multimeter

Electrical Troubleshooting

Many service calls are for problems of an electrical nature. To quickly identify the circuits affected and accurately troubleshoot the problem requires the use of a multimeter.

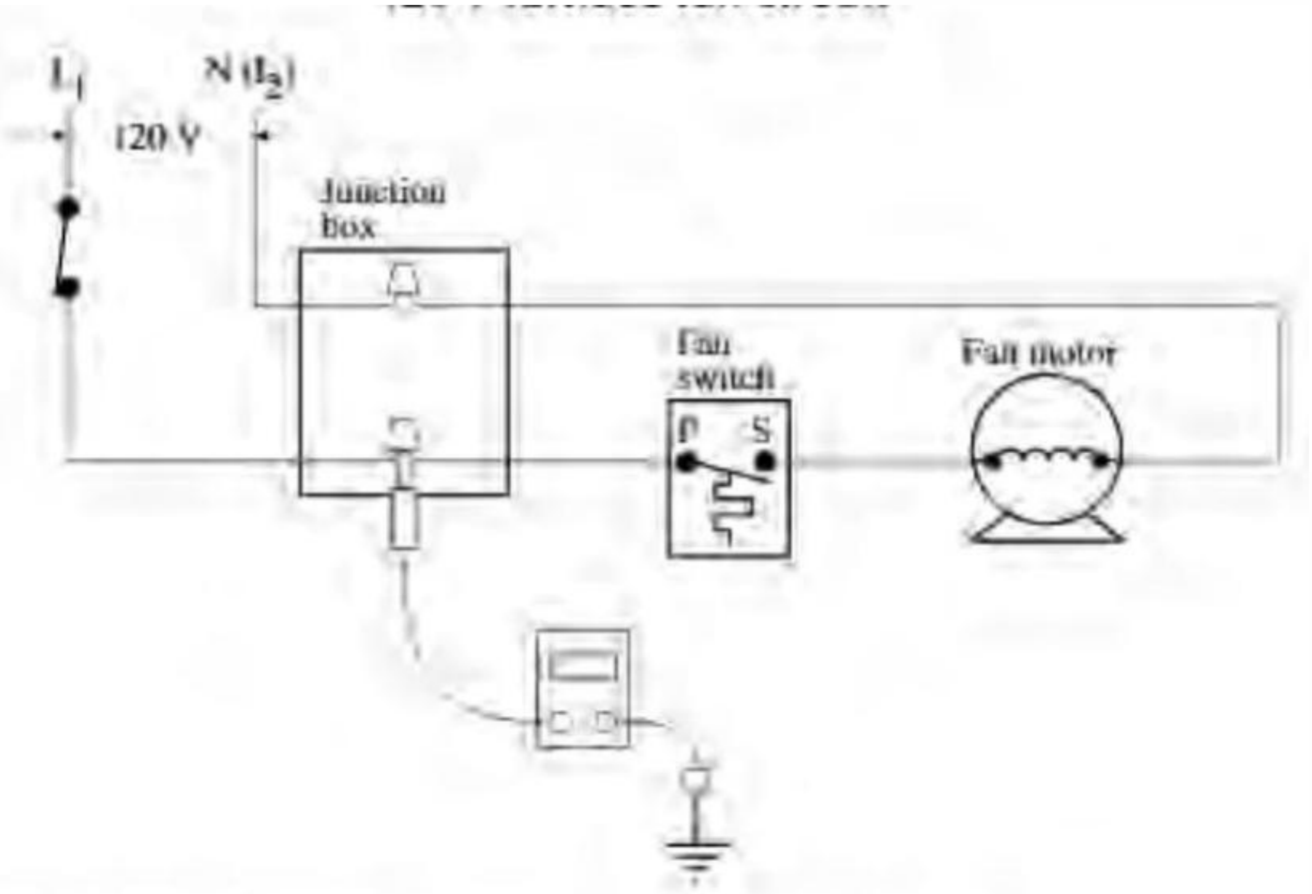
Safety Warning

Caution: Testing circuits may require working with live voltage. Use extreme caution when doing any live testing.

Fan Circuit Testing

Circuit Diagram

Figure 3-11 is a diagram of a 120 V fan circuit associated with a forced-warm-air furnace.



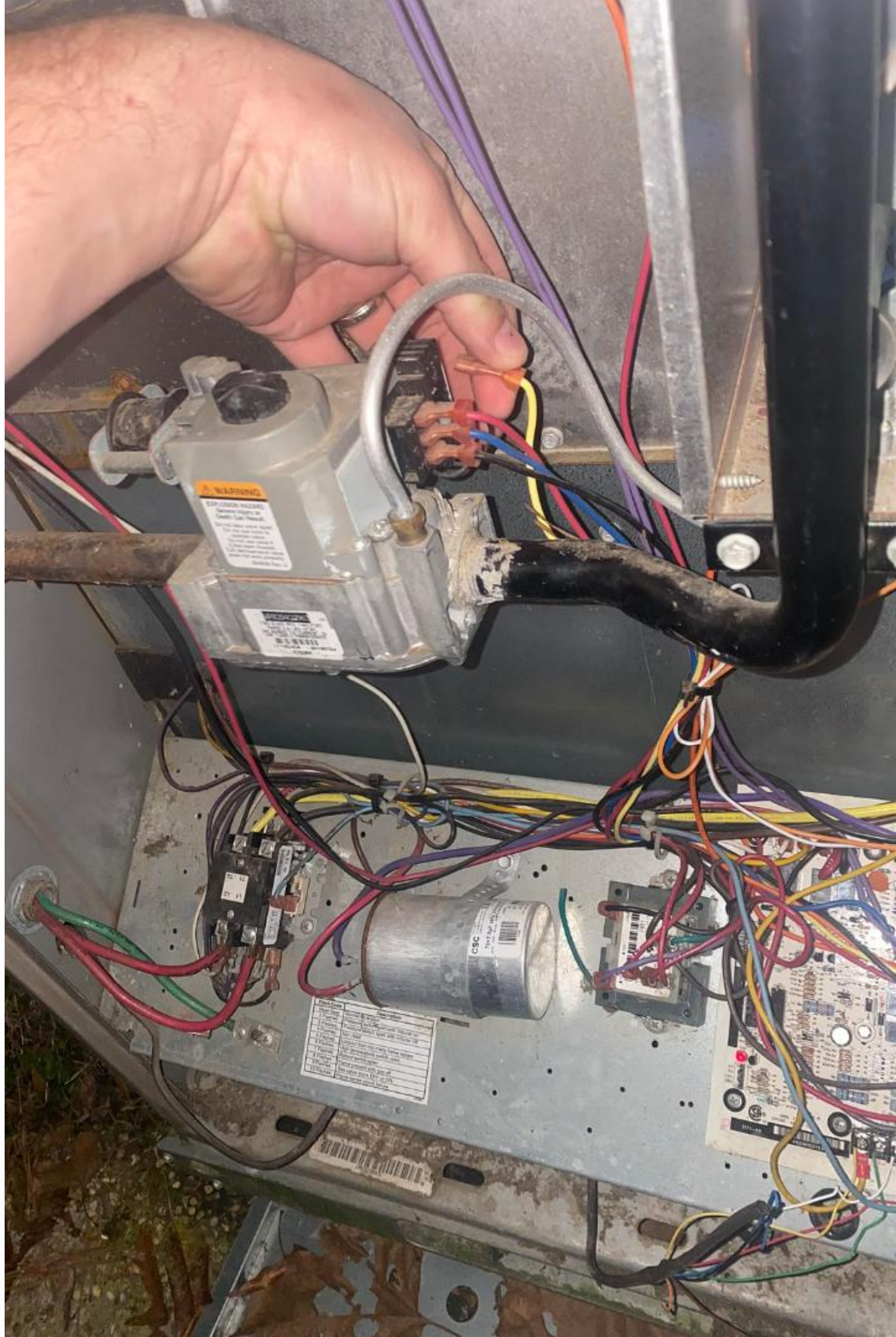
Fan Circuit Testing: Step 1

Check Appliance Disconnect Switch

Make sure that the appliance disconnect switch is wired into L1.

Verify Power Shutoff

Ensure that the disconnect switch shuts off the power supply.



Fan Circuit Testing: Step 2

Set Meter Function

Set the meter to Voltage AC function.

Measure L1 to Ground

Take a reading from the L1 connection in the junction box to ground.

Verify Voltage

Verify that the reading with the disconnect switch closed is 120 V.

Measure N to Ground

Take a reading from the N connection in the junction box to ground.

Verify Neutral

Verify that the reading between N and ground is 0 V.

Fan Circuit Testing: Step 3

1

Open Disconnect Switch

Open the disconnect switch.

2

Retake L1 to Ground Reading

Verify that the reading between L1 and ground is 0 V.

3

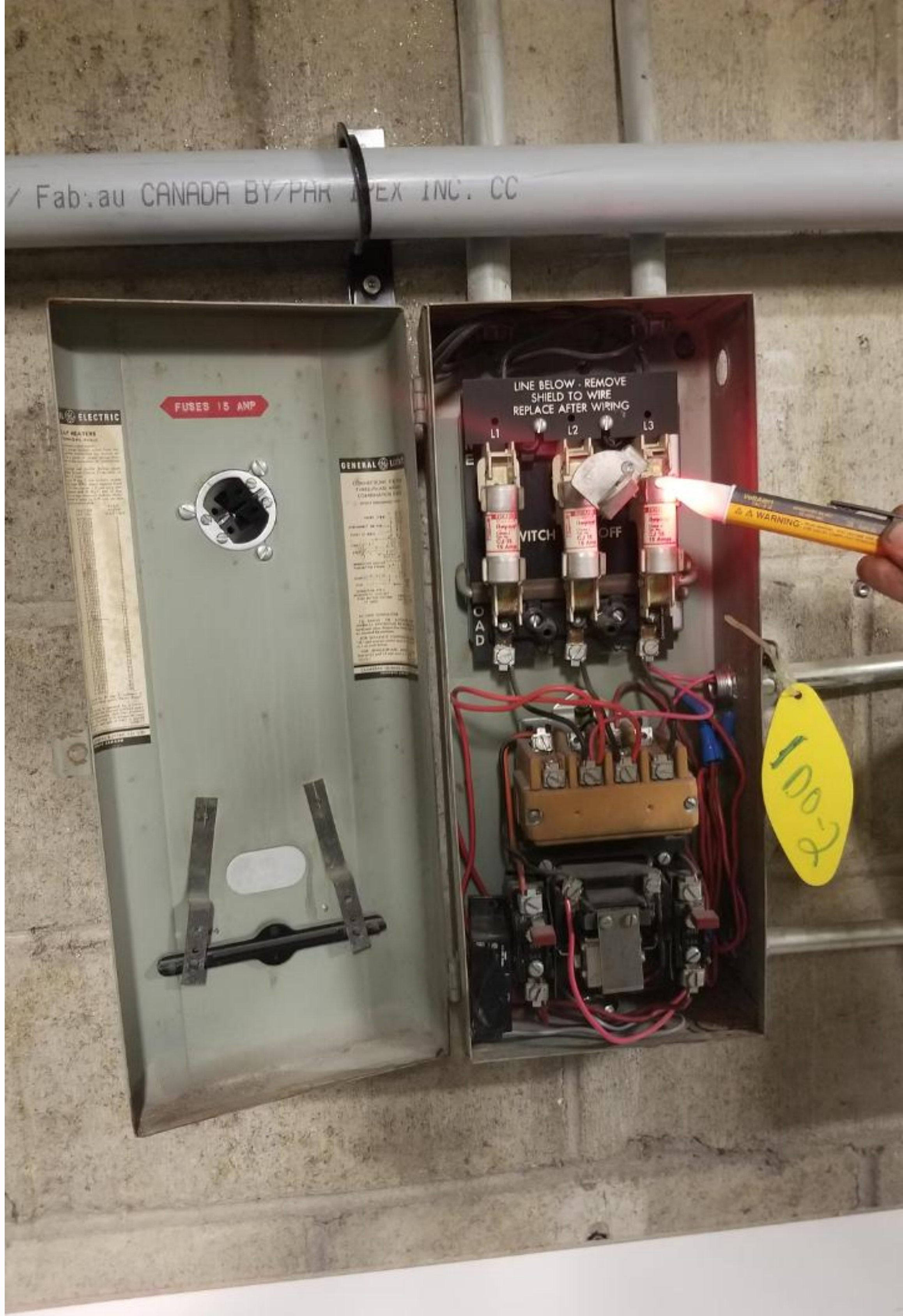
Retake N to Ground Reading

Verify that the reading between N and ground is also 0 V.

4

Verify Disconnect Function

These readings should verify that the disconnect switch is located on the L1 or hot line and that it shuts off power to the unit.

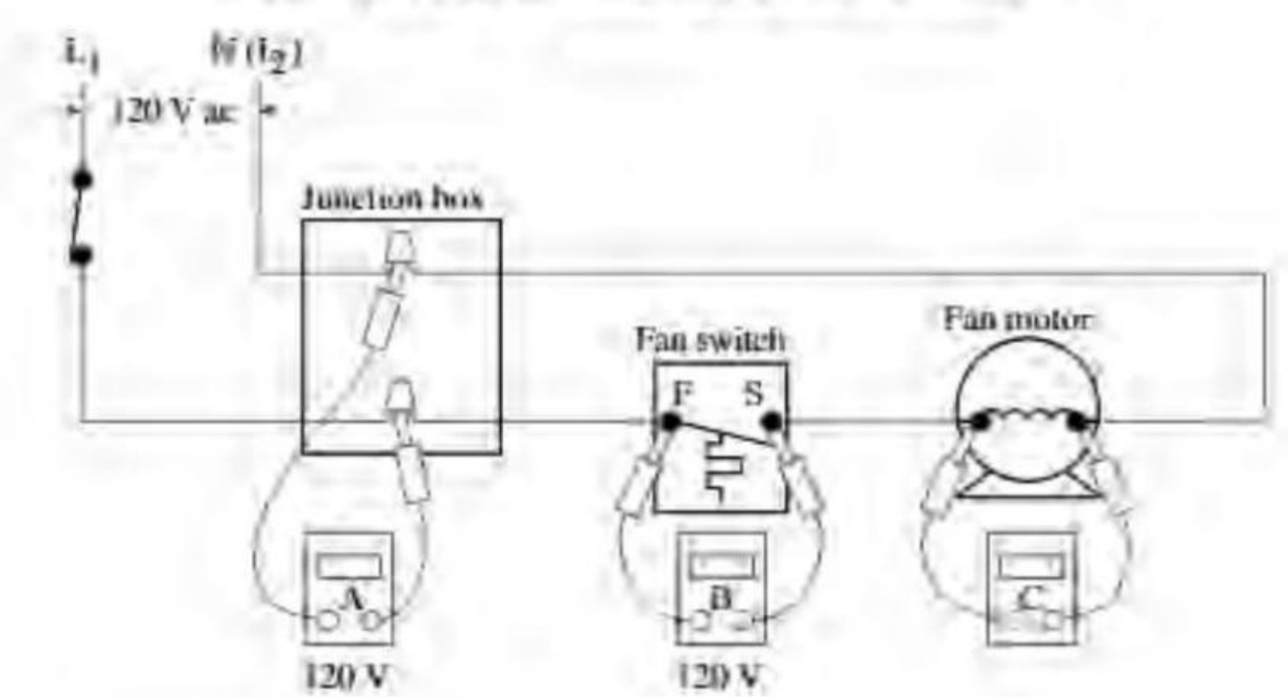


Fan Circuit Testing: Step 4

Measure Source Voltage

The second reading on this circuit determines the source voltage between L1 and N.

1. Set the meter to the proper voltage scale.
2. Take a reading between L1 and N.
3. Verify that the meter indicates 120 V.



Fan Circuit Testing: Step 5

Measure Across Fan Switch

Take a reading across the terminals of the open fan switch.

Verify Open Switch Voltage

Verify that the reading is 120 V when the switch is open.

Verify Closed Switch Voltage

Verify that the reading across the fan switch is 0 V when the fan switch closes.

Fan Circuit Testing: Step 6

Measure Across Motor Terminals

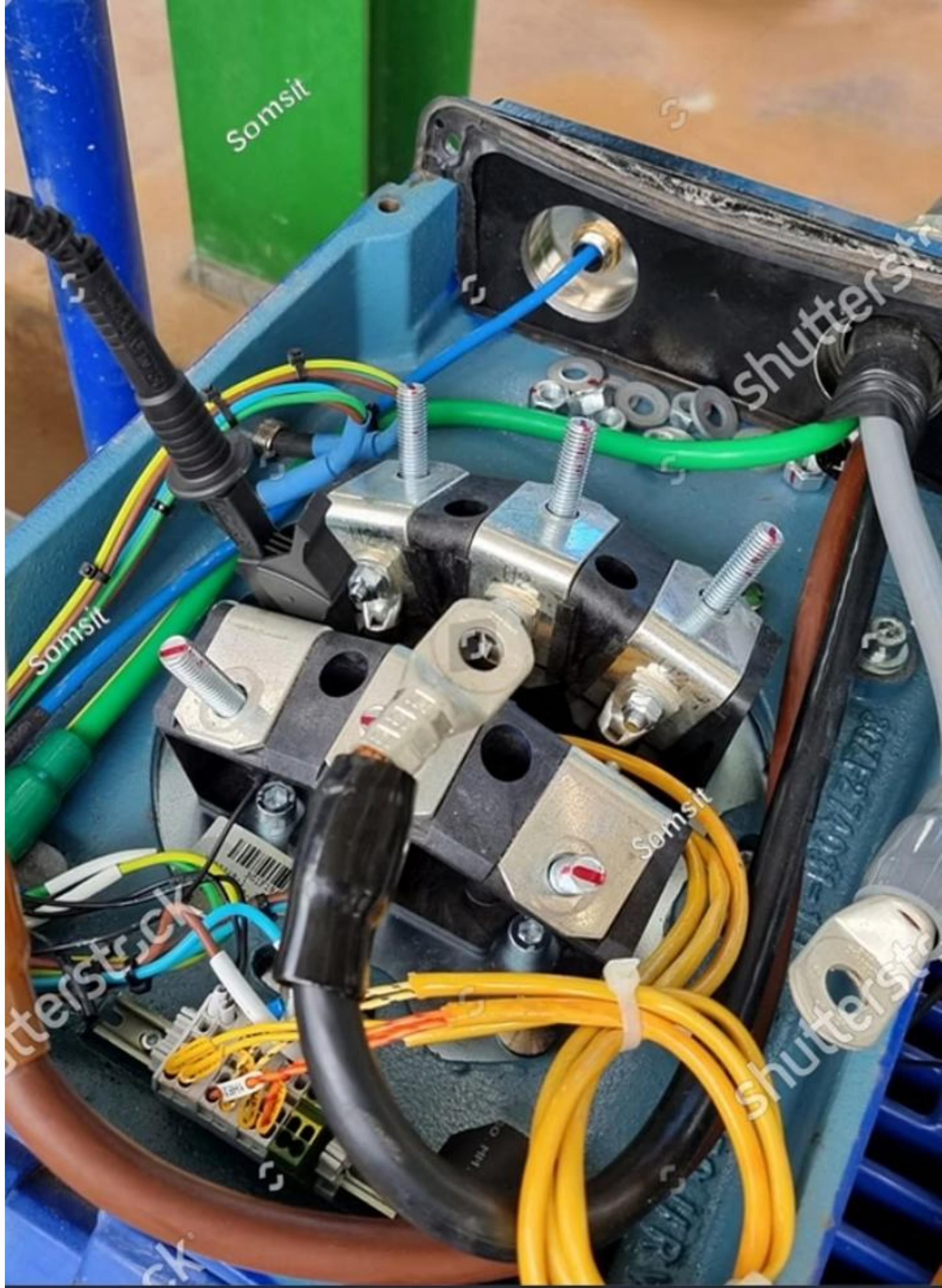
Take a reading across the motor terminals when the fan switch is open.

Verify Open Switch Reading

Verify that the reading is 0 V when the switch is open.

Verify Closed Switch Reading

Verify that, when the fan switch closes to energize the motor, the reading is 120 V.

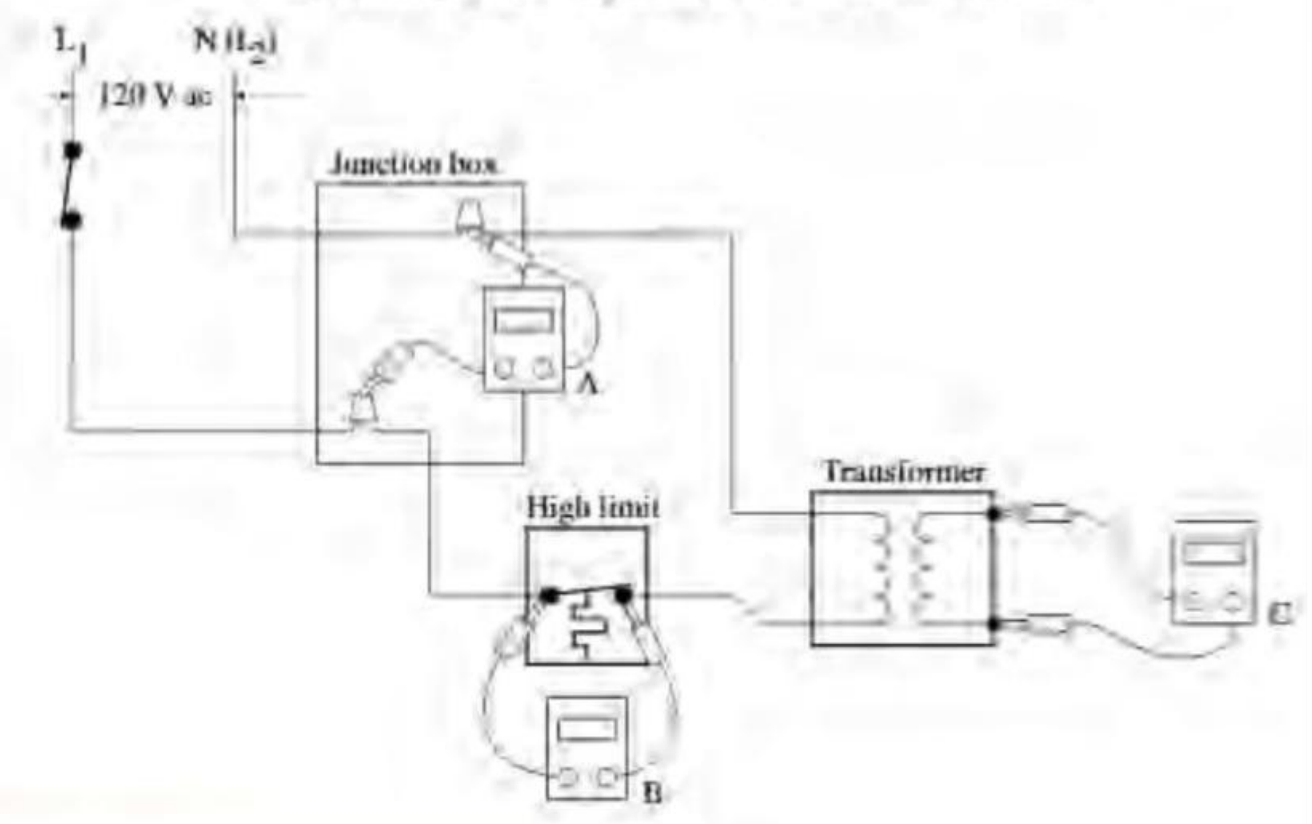


Transformer Circuit Testing

Circuit Description

Figure 3-13 shows the line voltage circuit to the high limit (optional location) and step-down transformer.

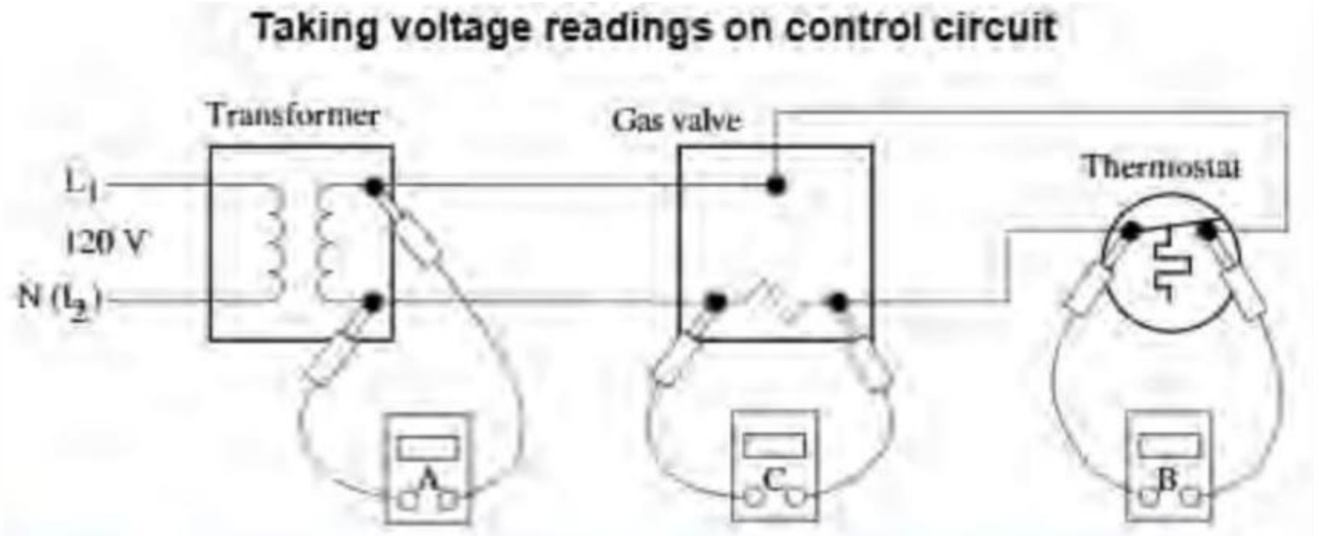
- If you take a reading with meter A, it indicates a source voltage of 120 V.
- Meter B indicates a reading of 0 V if the high limit is closed. If it is open, it should read 120 V.
- Meter C indicates 24 V on the secondary side of the transformer or slightly higher if there is no load connected.



Control Circuit Testing

Circuit Description

Figure 3-14 shows the 24 V control circuit for a forced warm-air furnace. It consists of a 24 V AC power supply, a three-terminal gas valve, and a thermostat.



Control Circuit Meter Readings

Meter A: Source Voltage

Indicates the source voltage to be 24 V. If there were no load on the transformer, it would read 26 or 27 V. Once the control circuit is energized, the voltage at A should return to 24 V.

Meter B: Thermostat

Placed across the terminals of the thermostat. With the thermostat switch contacts in the open position (no call for heat), the meter should read 24 V. Once the thermostat contacts close on a call for heat, the meter should read 0 V.

Meter C: Gas Valve

Placed to read the voltage drop across the coil of the gas valve. When the thermostat contacts are open and not calling for heat, the meter should read 0 V. When the thermostat contacts are closed and calling for heat, the meter should read 24 V.

Handling of Electrical Measuring Instruments

Proper Care

Always take care when using, handling, and storing a DMM. Always refer to the manufacturer's instructions for proper care of the meter.

Inspection

Regular inspection of meter and test leads for damage or wear.

Storage

Store in a clean, dry place protected from impact and extreme temperatures.

Calibration

Ensure regular calibration according to manufacturer's recommendations.

Maintenance

Perform battery and fuse replacement as needed, using only manufacturer-specified parts.

Common Electrical Testing Scenarios

Thermostat Testing

Verify proper voltage and continuity at thermostat terminals

Transformer Testing

Check primary and secondary voltages

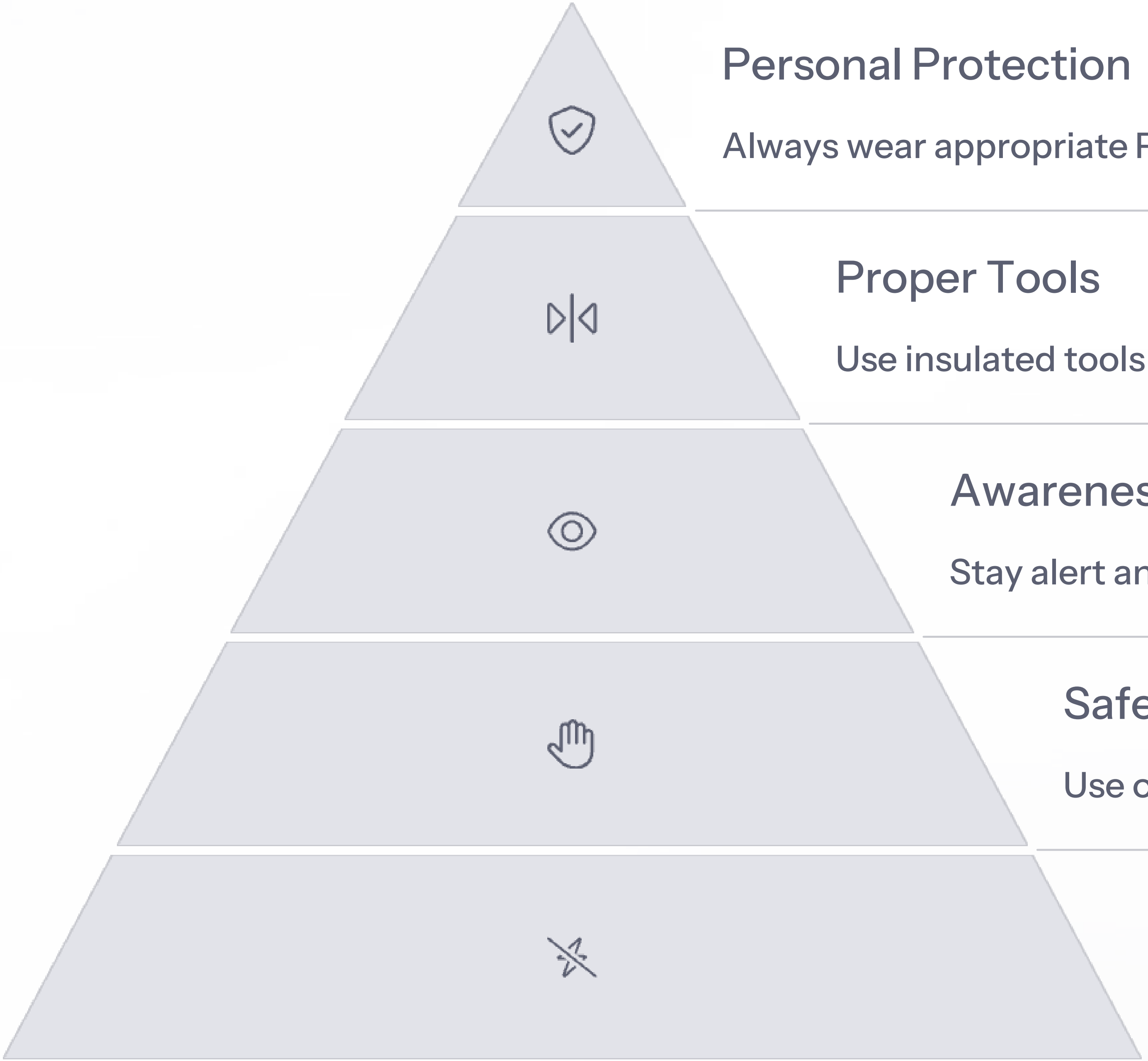
Fan Motor Testing

Check voltage, current draw, and winding resistance

Gas Valve Testing

Measure voltage at valve terminals during operation

Safety Precautions When Testing Live Circuits



Personal Protection

Always wear appropriate PPE

Proper Tools

Use insulated tools rated for voltage

Awareness

Stay alert and focused on the task

Safe Practices

Use one-hand rule when possible

Assume Energized

Always test before touching

Troubleshooting Common Electrical Issues

Identify Symptoms

Determine what's not working properly

Test Components

Use multimeter to check voltages and continuity

Repair or Replace

Fix or replace faulty components

Verify Operation

Test system to ensure proper function

Measuring Voltage in Gas Appliance Circuits

120V

Line Voltage

Standard voltage for most residential gas appliances

24V

Control Voltage

Common voltage for thermostats and gas valves

750mV

Thermocouple Output

Typical millivolt range for thermocouples

Electrical Testing Documentation

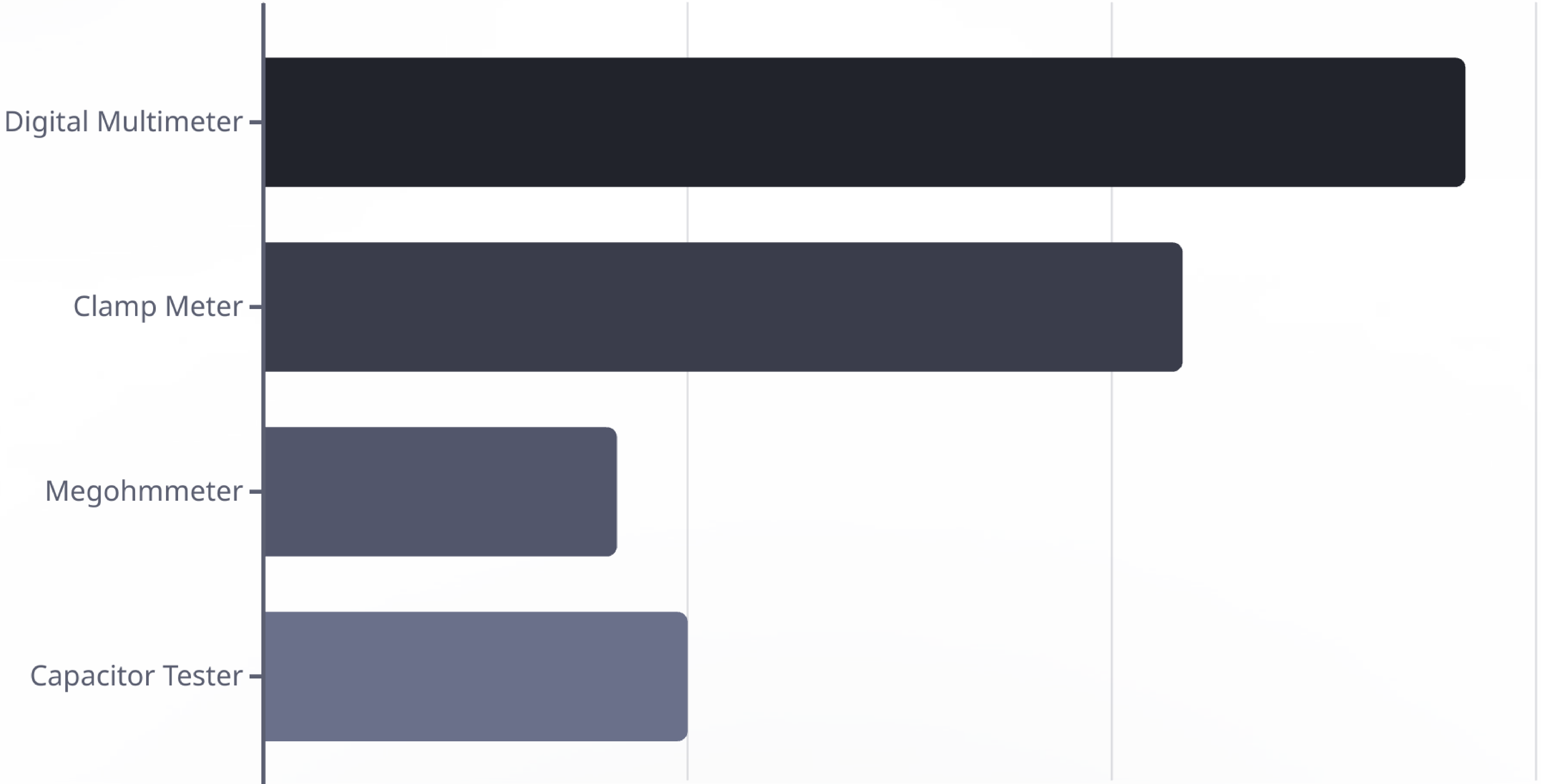
Importance of Documentation

Properly documenting electrical measurements and test results is crucial for:

- Establishing baseline readings for future reference
- Tracking changes in system performance over time
- Providing evidence of proper system operation
- Supporting warranty claims when necessary

Always record date, time, test points, readings, and any observations during testing procedures.

Selecting the Right Meter for the Job



Meter Calibration and Maintenance

Regular Calibration

Follow manufacturer's recommended schedule

Battery Replacement

Replace when low battery indicator appears

Cleaning

Keep contacts and surfaces clean

Proper Storage

Store in protective case away from extreme conditions

Summary: Electrical Testing for Gas Technicians

Essential Tools

Digital multimeters, clamp-on ammeters, and specialized testing equipment are essential tools for gas technicians to diagnose and troubleshoot electrical problems in gas-fired systems.

Safety First

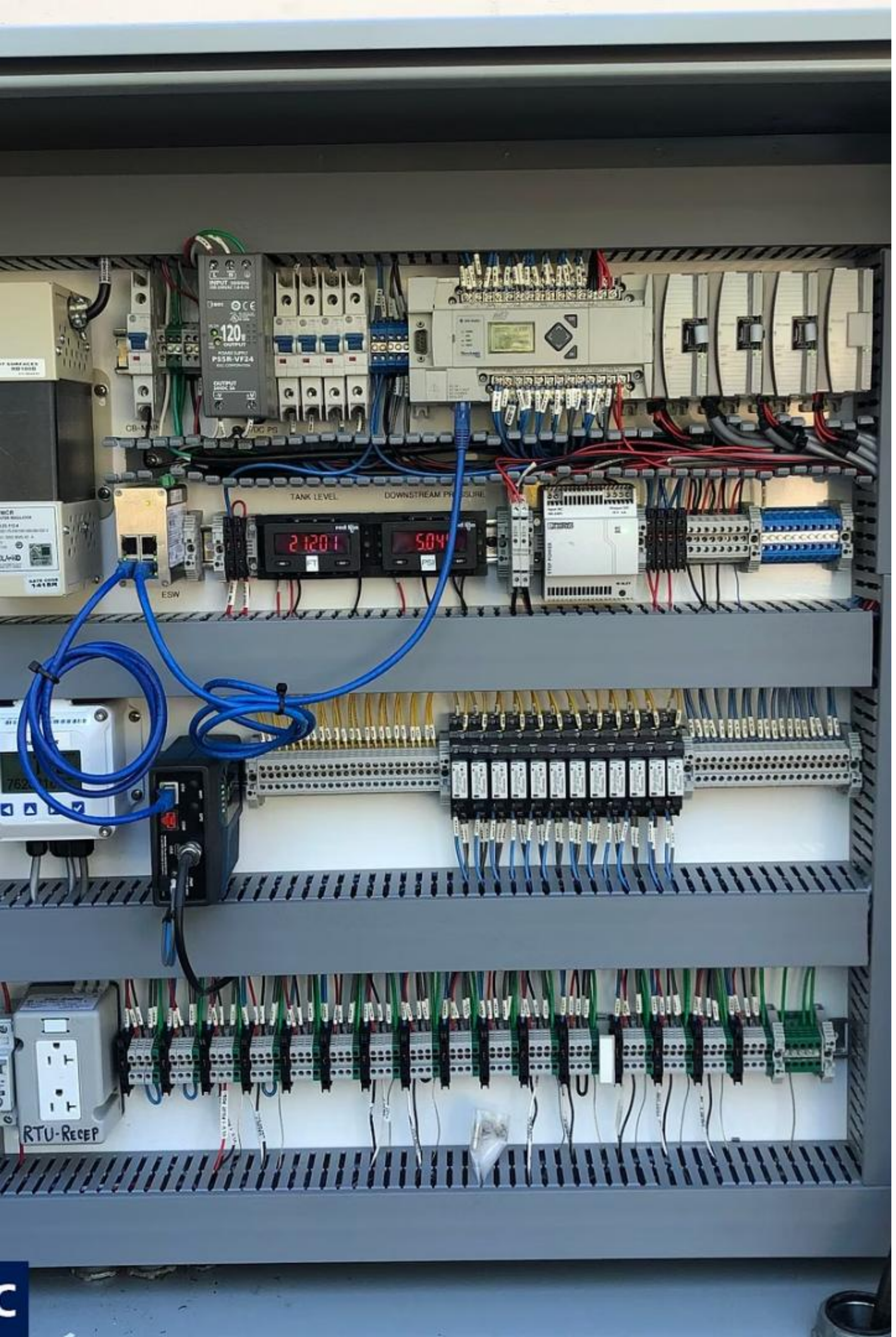
Always prioritize safety when working with electrical testing equipment. Follow proper procedures, use appropriate PPE, and never work on live circuits without proper training and authorization.

Proper Technique

Understanding how to correctly connect and operate measuring instruments is crucial for accurate readings and effective troubleshooting.

Regular Maintenance

Proper care, calibration, and maintenance of testing equipment ensures reliability and accuracy when diagnosing electrical issues in gas appliances.

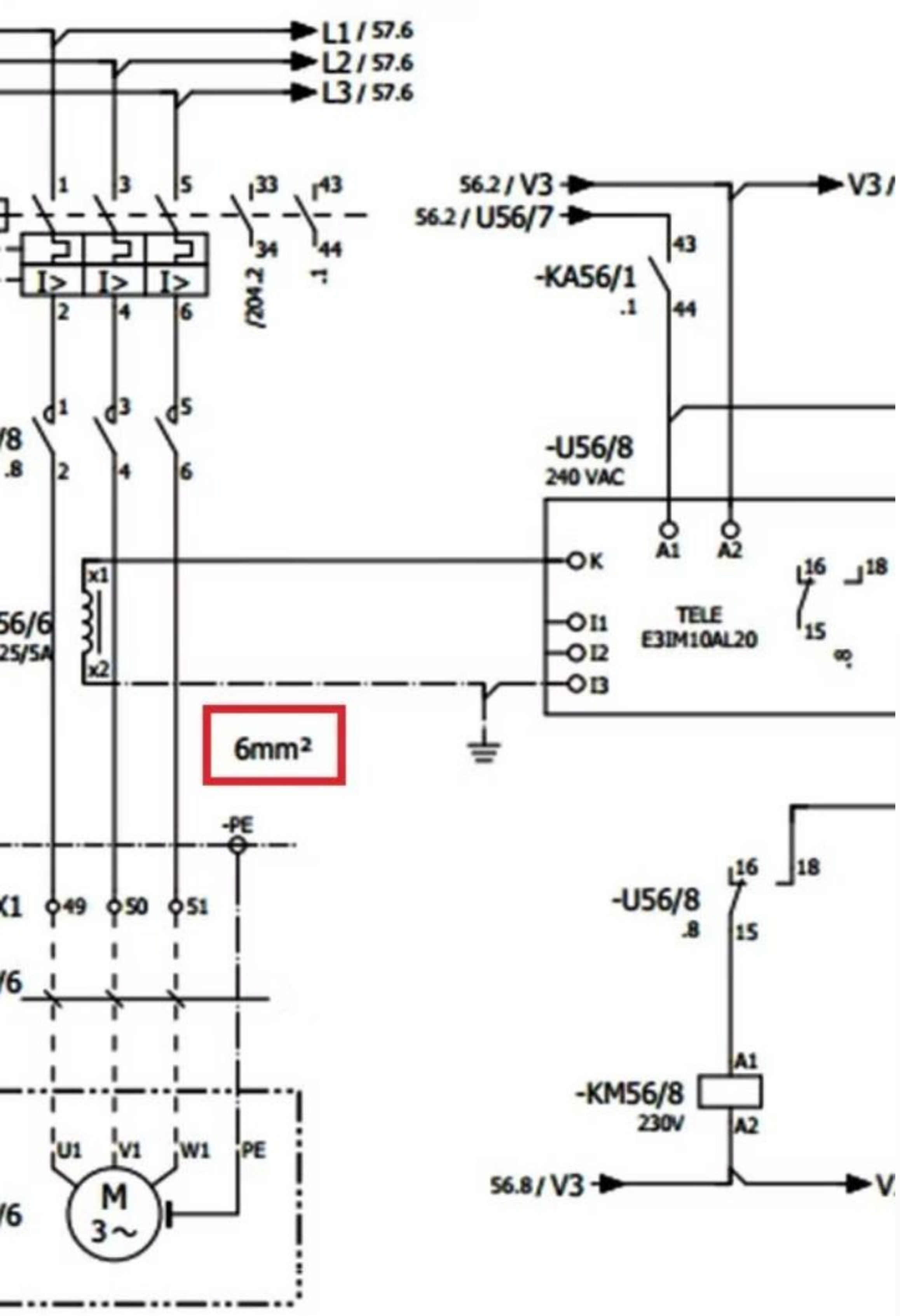


CSA Unit 12

Chapter 4
Circuits and Hardware

Knowing how and from where electricity is supplied helps the gas technician/fitter install and maintain gas equipment. Whether the source is an electrical panel, a junction box, or a transformer, a basic knowledge of the relevant hardware and circuitry is important.

It should be noted that electricians are required to perform electrical work under a permit in all jurisdictions in Canada. Gas technicians/fitters should check with the local electrical authority having jurisdiction (AHJ) for requirements. Gas and mechanical trades are permitted to perform elementary electrical work in some Canadian jurisdictions.



Learning Objectives

Describe Electrical Panels and Transformers

Understand the components and functions of electrical distribution panels and transformers used in gas equipment installations.

Describe Electrical Hardware

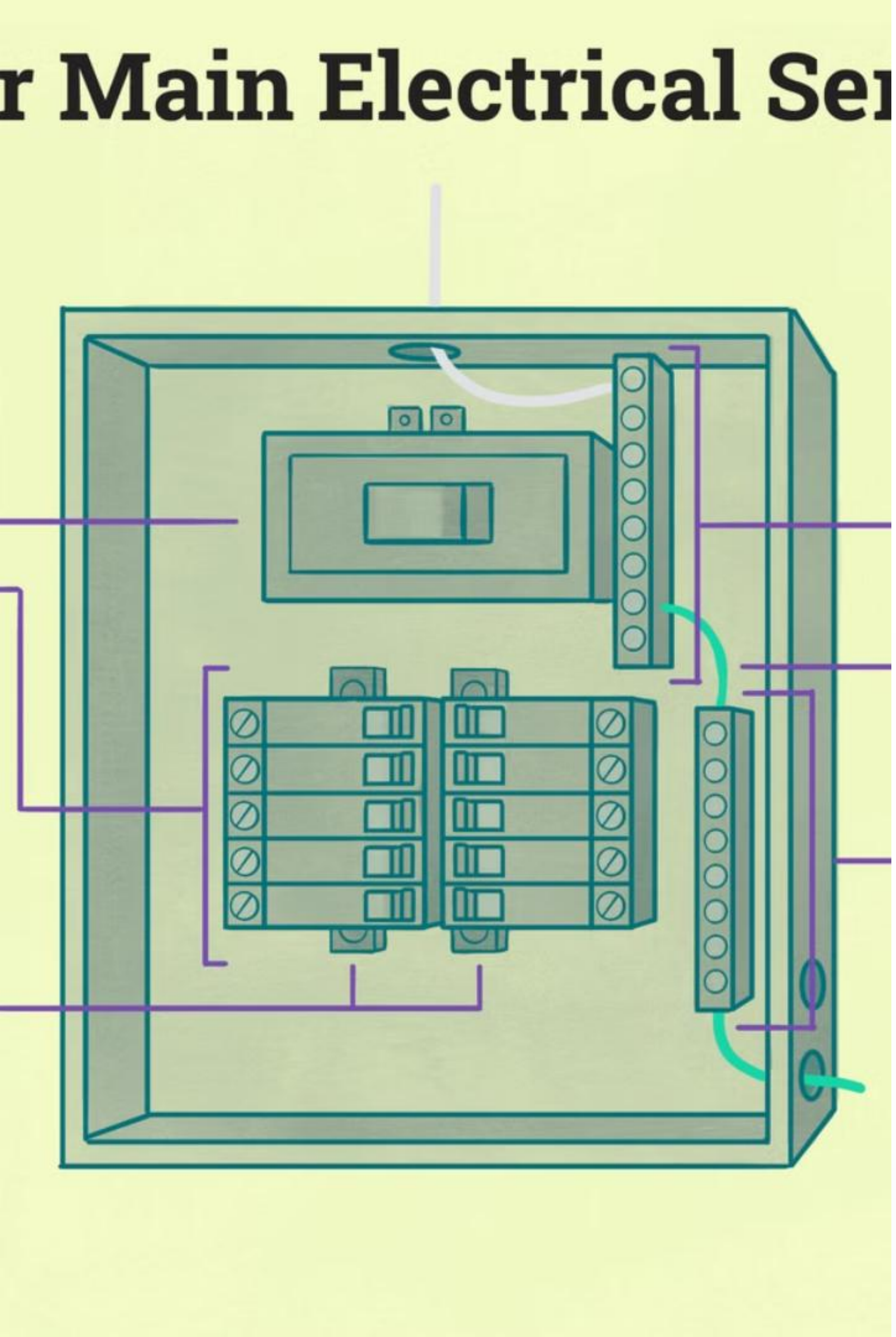
Identify and understand the various electrical components and hardware used in gas appliance installations.

Explain Wiring Diagrams

Interpret and understand electrical wiring diagrams for proper installation and troubleshooting of gas equipment.

Key Terminology

Term	Abbreviation (Symbol)	Definition
Conduit		A raceway of circular cross-section, other than electrical metallic tubing (EMT) and electrical non-metallic tubing, into which it is intended that conductors be drawn. Conduit may be either metallic or non-metallic.
Contactor		Very similar to a relay, except that it contains heavy-duty contacts designed to control larger amounts of current
Device box		Container for electrical connections used to support electrical devices such as receptacles or switches
Horsepower-rated contacts		Motor starting switch can safely interrupt the inrush current or locked-rotor current of the motor
Junction box		An approved container for electrical connections, joints and splices
Relay		Control device that contains small, light-duty contacts designed to operate only low-current loads



Residential Electrical Service

The electrical service coming into a residential distribution panel is 240 volts M, single-phase, 60 hertz (240/1/60). The service conductors consist of:

Two Live Conductors

Also known as "line wires" that carry the electrical current

Neutral Conductor

Completes the circuit and is permitted to be grounded only once

Grounding Conductor

Connects the neutral and the metal distribution panel to a grounding electrode

Branch Circuits

The 240 V supply coming into a building is divided into branch circuits at the distribution panel. Branch circuits are 240 V or 120 V, depending on the characteristics of the circuit they supply.

240 V Circuits

Protected by two-pole breakers

- A double overcurrent that feeds two ungrounded (live) branch circuit conductors coming into the panel
- May or may not have a neutral conductor
- A bonding conductor connected to metallic panel box by means of a bonding bus

120 V Circuits

Protected by single-pole breakers

- A single overcurrent that feeds an ungrounded (live) branch circuit conductor coming into the panel
- An identified conductor from the neutral bar in the panel
- A bonding conductor connected to metallic panel box by means of a bonding bus

Bonding Requirements

Continuous Bond Requirement

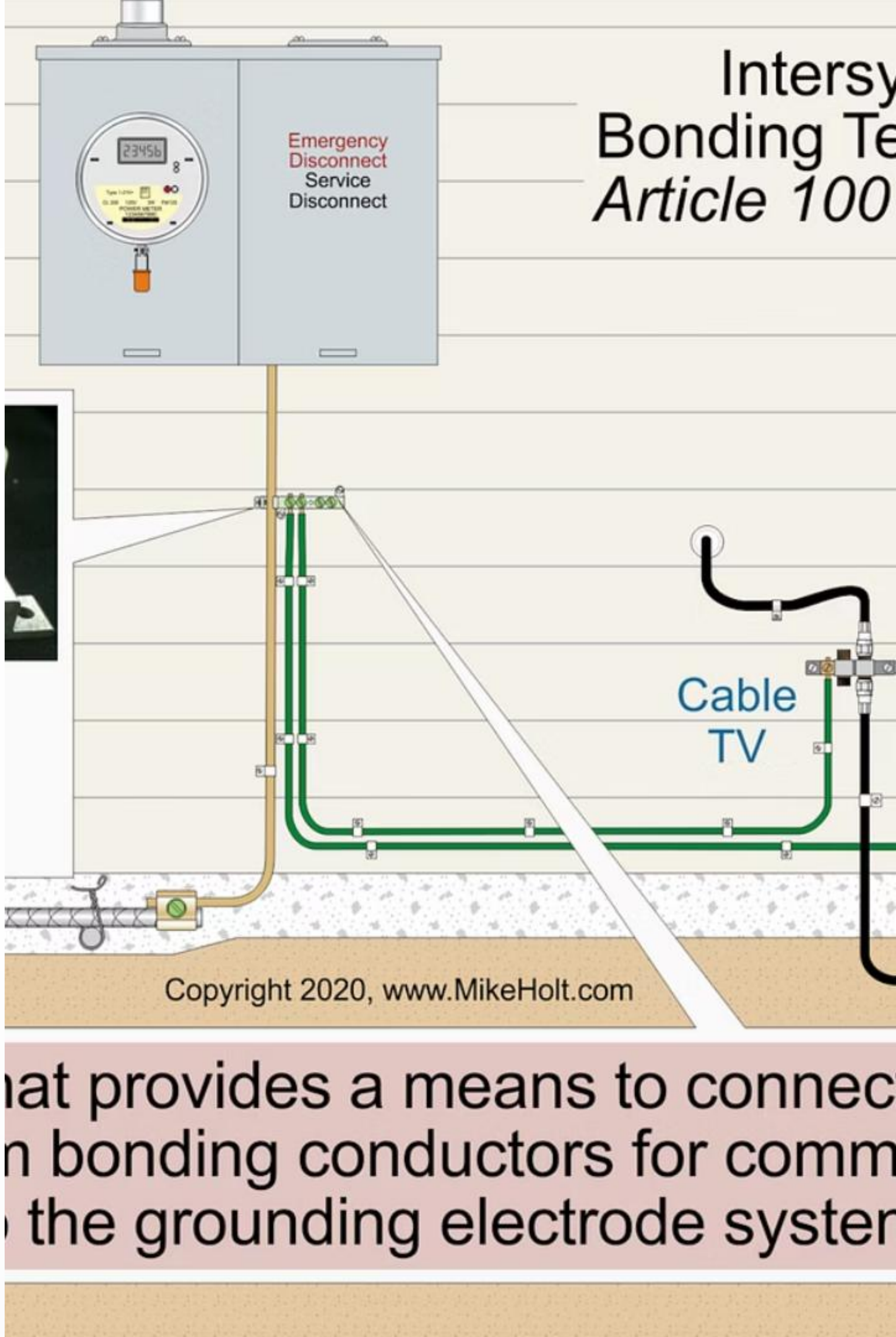
All line-voltage circuits must have a continuous bond running from the main distribution panel to each junction box, receptacle, and appliance.

CE Code Requirement

The CE Code states that non-current-carrying conductive parts of electrical equipment shall be connected to a bonding conductor.

240 V Branch Circuits

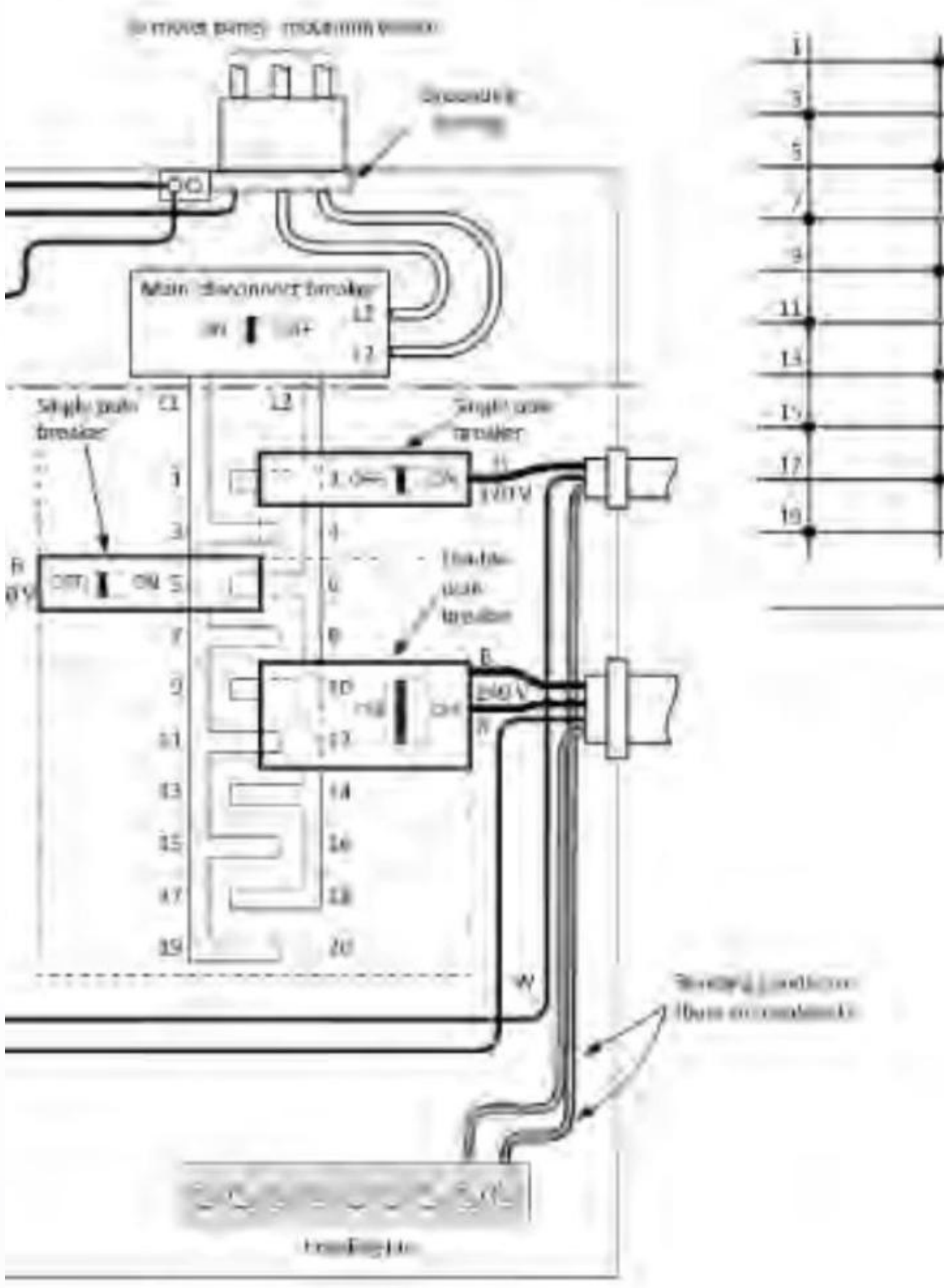
240 V branch circuits may have a neutral conductor included in the wiring run. This is necessary if the equipment has any 120 V components (e.g., lights).

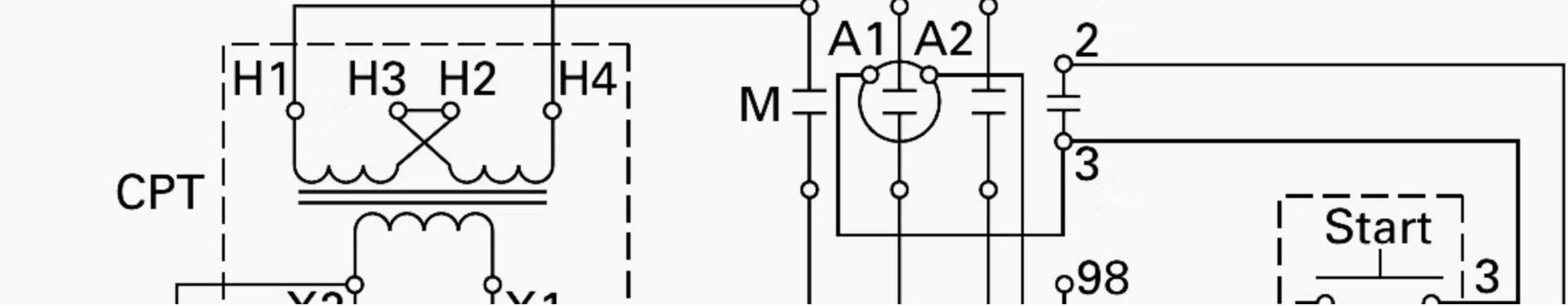


Combination Panel and Schematic

The figure shows a combination panel and schematic, illustrating branch circuit connections. This diagram helps gas technicians understand how electrical power is distributed from the main panel to various branch circuits that may supply gas equipment.

Understanding this schematic is essential for properly connecting gas appliances to the electrical system and for troubleshooting electrical issues that may affect gas equipment operation.





Control Circuit Transformers

Some gas appliance control circuits and other electrical devices operate at lower voltages than 120 V. The voltage for control devices is usually 24 V AC (typical residential appliance control voltage). A 240/24 or 120/24 step-down transformer is required to obtain the necessary 24 V supply.

Core of Iron Plates

Separated by insulation to create the transformer core

Primary Winding

Connected to the 120 V supply

Secondary Winding

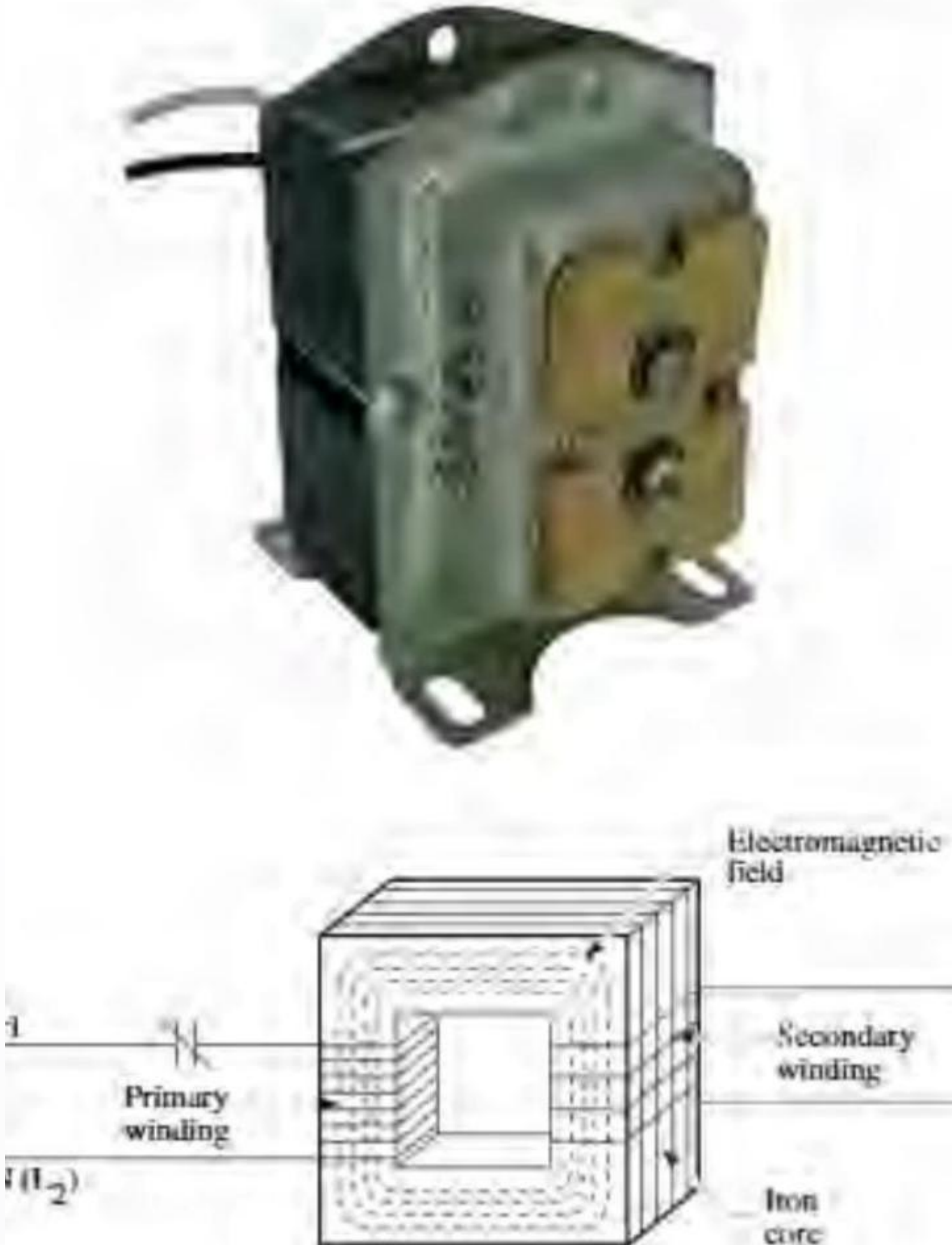
Connected to the 24 V appliance control circuit

Transformer Operation

A typical step-down transformer consists of a core of iron plates separated by insulation, a primary winding, and a secondary winding. The 120 V supply is connected to the primary winding terminals of the transformer and the appliance control circuit connected to the 24 V secondary winding terminals.

The 120 V alternating current flow through the primary winding induces a 24 V current in the secondary winding to power the appliance control circuit. It is important to make sure transformers are bonded by a bonding conductor to the cabinet bond. This is critical for troubleshooting.

Figure 4-2
Typical step-down transformer and schematic
Courtesy of Terry Bell



Transformer Ratings

Voltage Ratings

Manufacturers always specify the voltage rating of a transformer's primary and secondary windings. Secondary winding rated voltages are specified for full-load conditions with the rated primary voltage.

Operating Considerations

Operating a transformer's primary at higher than rated voltage may cause the transformer to overheat, damaging its insulation. Operating the primary at lower than rated voltage does no harm, but secondary voltages will be less than rated values.

Current Ratings

Current ratings are generally specified for secondary windings only. If the secondary current rating is not exceeded, the primary current capacity cannot be exceeded.

Transformer Power Ratings

Volt-Ampere (VA) Rating

The volt-ampere rating of a transformer is the product of the voltage and amperage (VA = V x A).

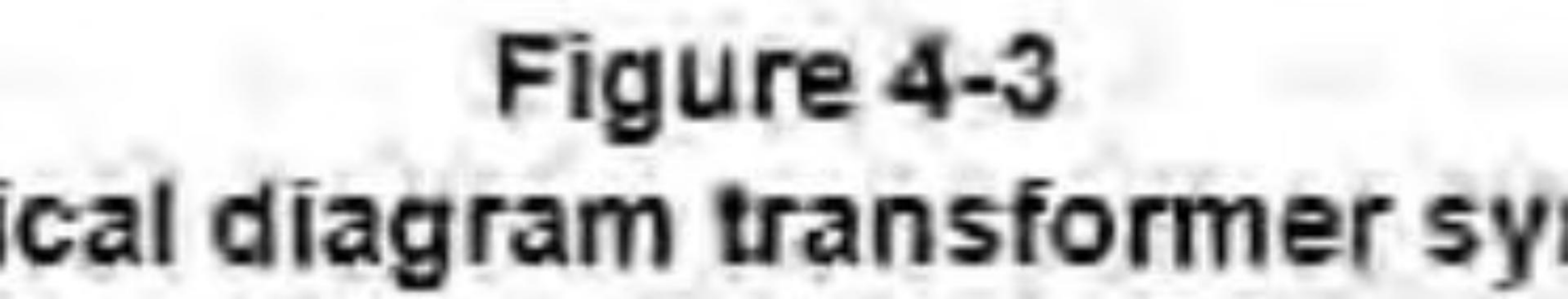
This rating indicates the capacity of the transformer to handle electrical load.

Power Rating in Watts

A power rating specified in watts is understood to be the power that a transformer can deliver to a resistive load.

The power rating in watts is the product of the current rating and the voltage rating of the secondary winding (P = E x I).

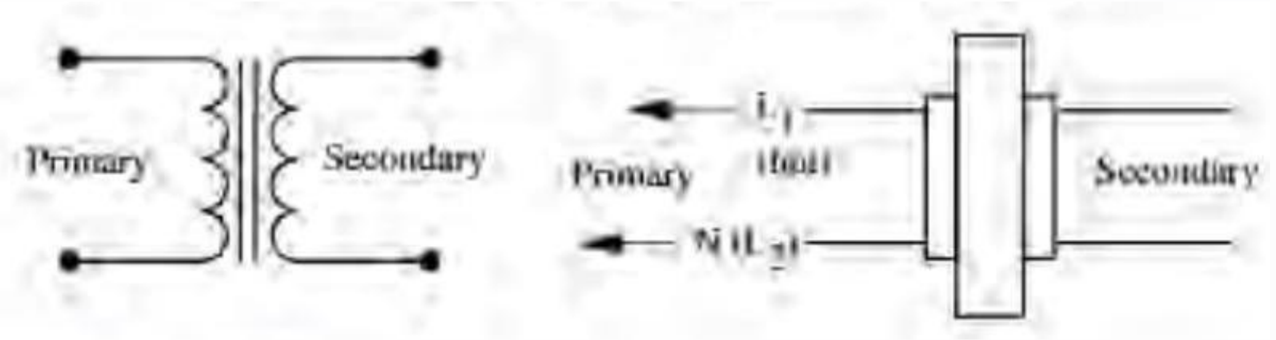
Some transformers are fused internally. If there is no indication of fusing, it is good practice to include fusing when replacing or installing new transformers. New equipment usually has the transformer integral to the main circuit board, which may be equipped with a fuse.



Transformer Diagram Representations

Transformers are indicated on electrical diagrams in two ways, as shown in the figure. Understanding these diagram symbols is essential for gas technicians when reading electrical schematics for gas appliances that incorporate control transformers.

The second representation of a transformer is shown below:



Electrical Hardware Overview

In order to properly install and service gas appliances and equipment, gas technicians/fitters must be able to identify and use the following types of electrical hardware:

Connection Devices

Used to join electrical conductors safely

Switches, Relays, and Contactors

Used to control electrical circuits

Boxes

Provide safe enclosures for electrical connections

Sockets and Plugs

Connect equipment to power sources

Fasteners

Secure electrical components in place

Conduit or Raceways

Protect electrical conductors

Connection Devices

The CE Code requires that all connections be made only in outlet or junction boxes. The electrical connections used for the installation of gas appliances and equipment fall into two basic groups:

Solderless Terminals and Insulators

- Crimp-on-type connectors
- Insulated cap-type connectors

Soldered Connections

- Joined mechanically first
- Then soldered for electrical security
- Provides excellent electrical connection

Crimp-on Connectors

Crimp-on connectors are used to secure twisted and untwisted wire joints. This type of connector can be a slip-on metal cap for pig-tail joints, or a metal sleeve for splicing two straight wires.

The two-part connector shown in the figure has a conductor retaining sleeve that is compressed by using special crimping pliers and an insulated screw cap into which the crimped retainer is inserted.

Insulated Cap Connectors

Types of Connectors

There are several types of insulated-cap connectors. Also known as wire nut connectors or marrettes by the manufacturer Marr. This type of connector is used for pig-tail joints of two or more conductors.

The two most common insulated-cap connectors are the twist-on type and the set-screw type. They are both available in several colour coded sizes to accommodate a wide range of conductors.

Connector Construction

The set-screw connectors consist of a brass connector body and an insulated cap. The twisted conductors are slid into the brass connector body and secured with the hold-down screw before the plastic insulating cap is screwed in place.

Twist-on connectors have a cone-shaped coiled wire insert that grips the twisted conductors to ensure good electrical contact. When the connector is twisted onto the stripped end of the wires, the wire is drawn and squeezed into the metal insert.

Connector Installation Best Practices

Follow Instructions

Follow the instructions that are included with each type of connector to ensure the connector is correctly joining the wire.

Periodic Maintenance

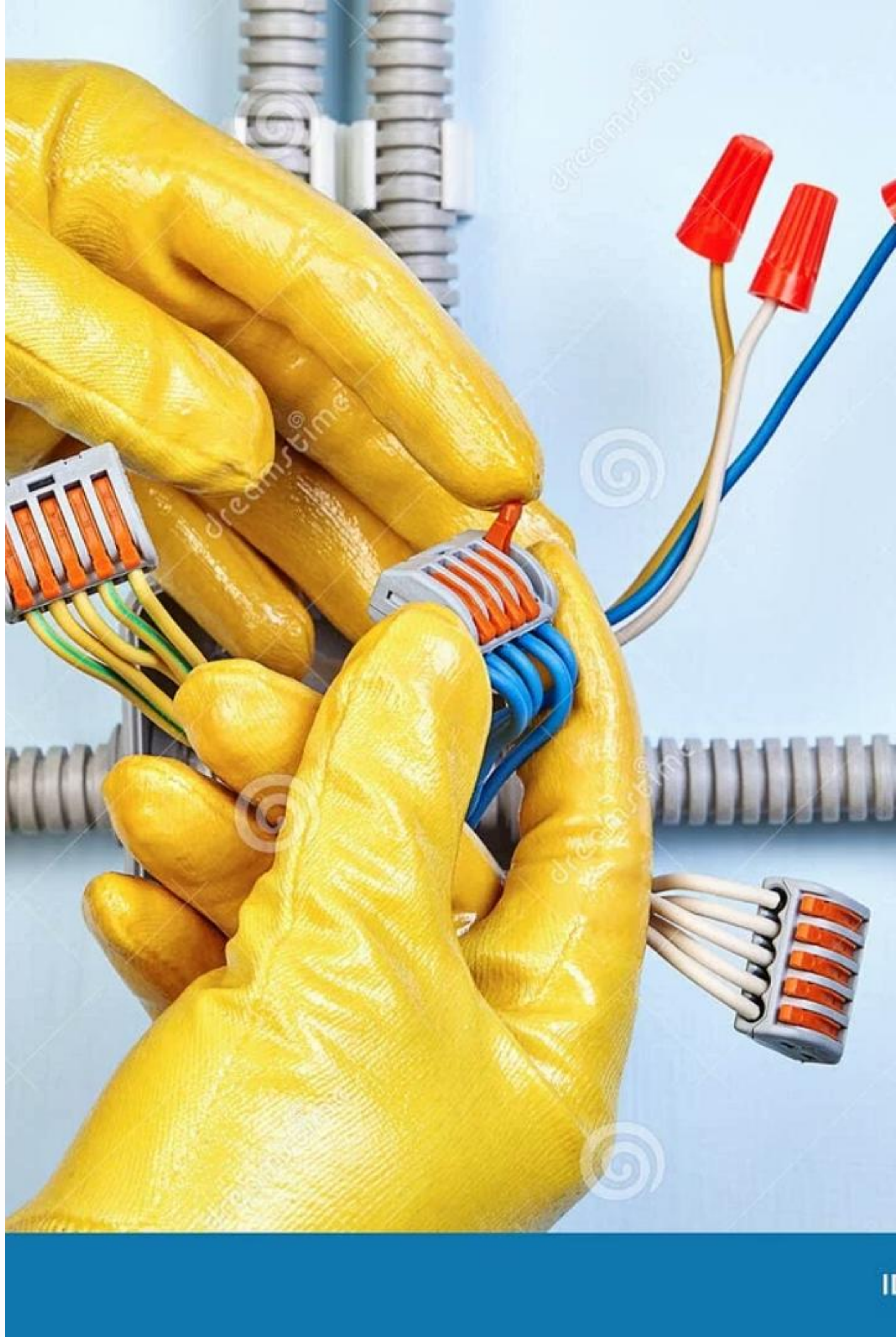
It is good practice to check these connectors periodically to tighten them if required since expansion and contraction loosen them over time.

Proper Wire Stripping

Ensure wires are stripped to the correct length as specified by the connector manufacturer.

Secure Connections

Make sure all connections are tight and secure to prevent arcing and potential fire hazards.



Modular Connectors

Figure 4-6
Cat5 patch cable
Courtesy of Fo0bar - Own work, licenced under CC BY

Modular connectors were originally designed for use in telephone wiring but have since been used for many other purposes. Many applications that originally used a bulkier, more expensive connector have converted to modular connectors. Probably the best-known applications of modular connectors are for telephone and Ethernet.

Connector Design

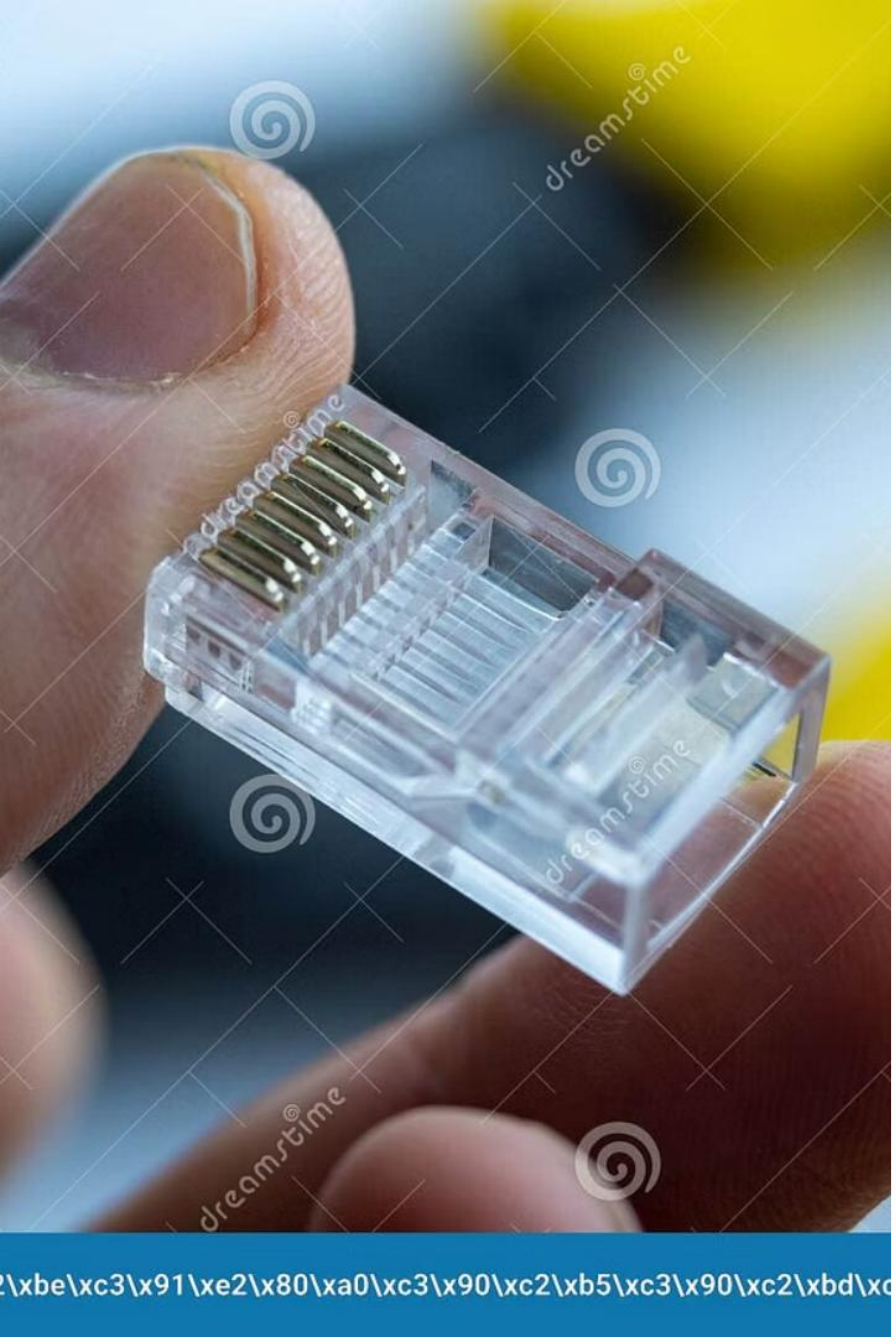
Modular connectors are designed to latch together. As a plug is inserted into a jack, a plastic tab on the plug locks so that the plug cannot be pulled out. To remove the plug, the latching tab must be depressed against the plug to clear the locking edge.

Connector Designation

Modular connectors are designated using two numbers that represent the maximum number of contact positions and number of installed contacts, with each number followed by P and C, respectively. For example, 6P2C is a connector having six positions, and two installed contacts.

Connector Sizes

Modular connectors are manufactured in four sizes, with 4-, 6-, 8-, and 10-positions.

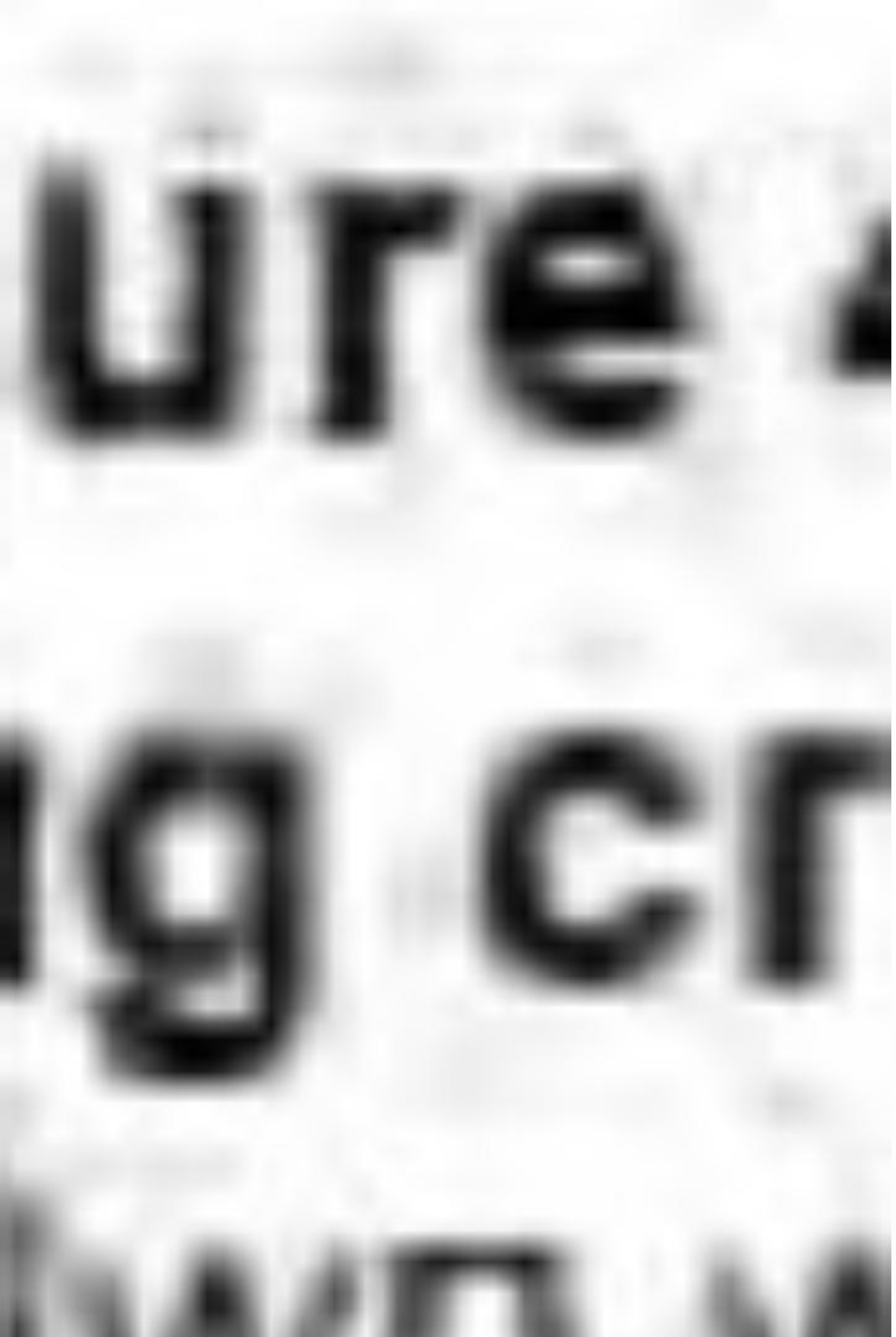


8P8C Connector

The 8-position, 8-contact (8P8C) connector is a modular connector commonly used to terminate category 5 (Cat5e) cable, which is commonly used for Ethernet over twisted pair.

Internally, the contacts on the plugs have sharp prongs that, when crimped, pierce the wire insulation and connect with the conductor.

The registered jack specifications define the wiring patterns of the jacks so the termination of cables similar across the various number of positions and contacts in the plug. The crimping tool contains a die that is often exchangeable and is closely matched to the shape and pin count of the modular plug.



Modular Connector Crimping Tool

It is important to follow the proper termination procedure when terminating a cable in a modular plug as the order is important.

The crimping tool shown in the image is designed specifically for modular connectors. The tool ensures proper connection between the wires and the connector contacts.

Soldered Connections

Best Joining Method

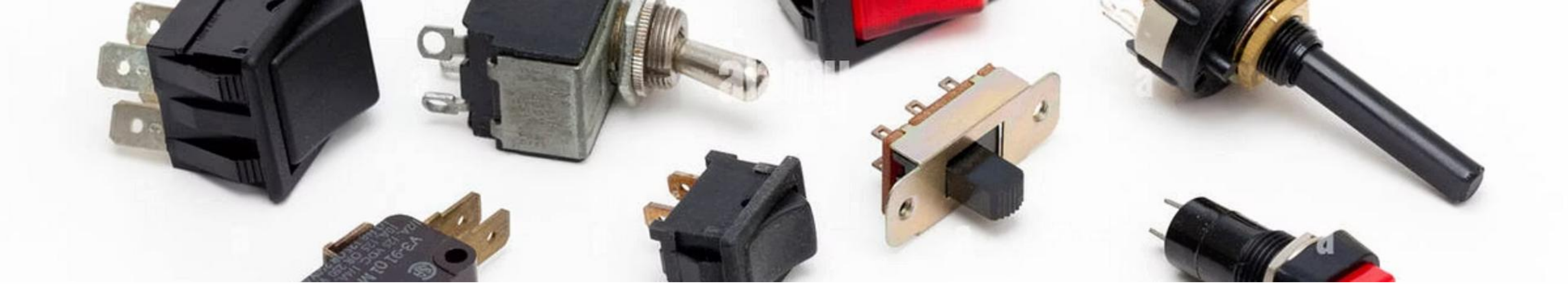
Soldering is probably the best method for joining circuit conductors. However, it takes longer and requires more equipment than other methods.

CE Code Requirement

Rule 12-112 in the CE Code: Soldered splices shall first be spliced or joined so as to be mechanically and electrically secure without solder and then be soldered.

Proper Technique

Ensure proper mechanical connection before applying solder to create a reliable electrical connection.



Switches Overview

A switch is a device that opens or closes an electrical circuit. It has two positions: open and closed.

Proper Placement

Switches are always located in the (ungrounded) or live conductor of the circuit, never in the (grounded) neutral, or identified conductor.

Series Circuit Operation

Electricity cannot flow through a series control circuit unless all switches are closed, and the circuit is complete. If even one of the switches is open, the circuit cannot conduct electrical current.

Rating Importance

All switches are rated for the amount of current that can flow through them. Always ensure that the switch is rated at or above the circuit current flow and voltage.

Switch Terminology

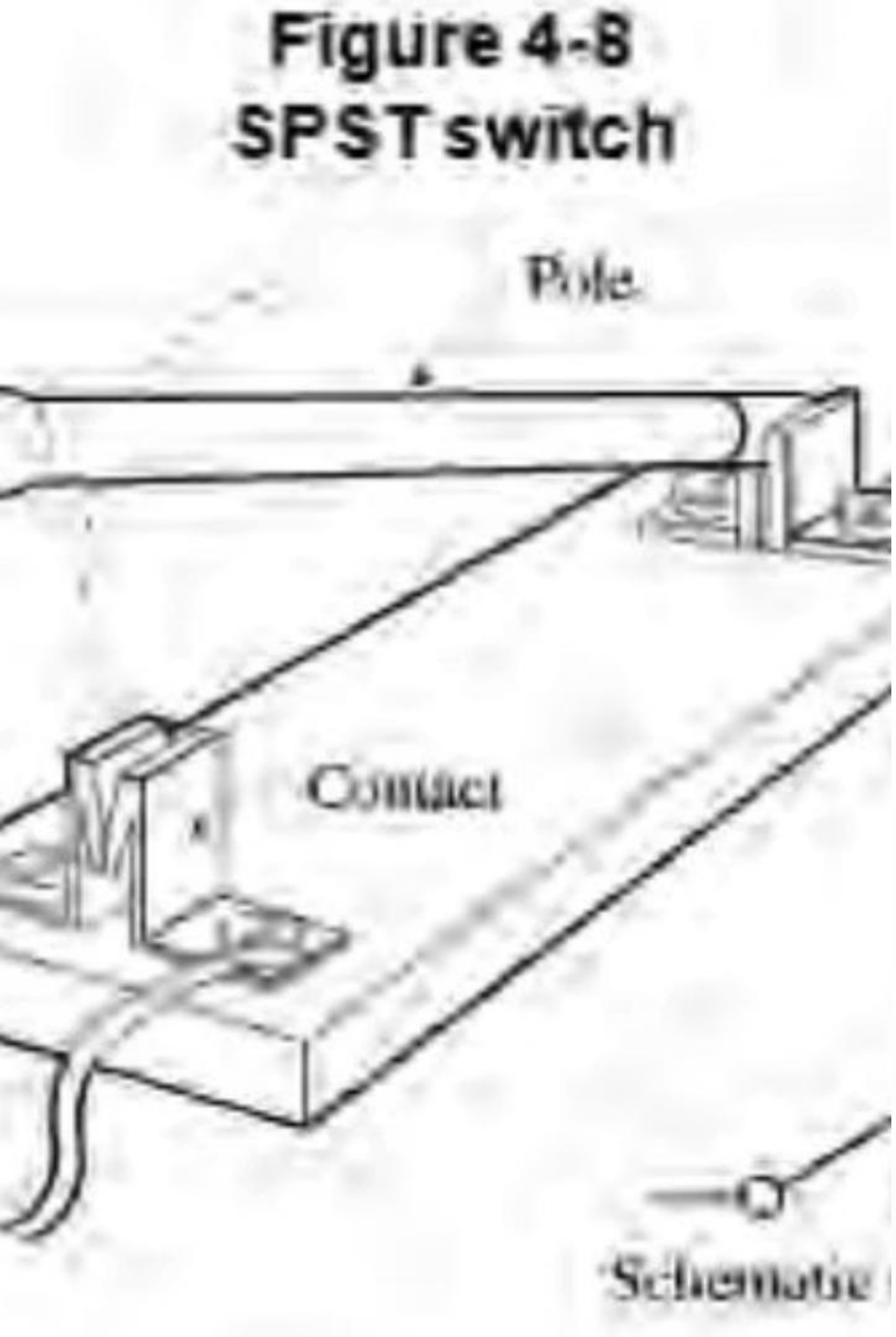
Switches are designated by the number of poles and throws they have. When a switch is thrown, the pole is moved to another position. A throw is, therefore, one position of the pole.

Pole

A pole refers to the number of separate circuits that can be controlled by a switch. A single-pole switch controls one circuit, while a double-pole switch controls two separate circuits.

Throw

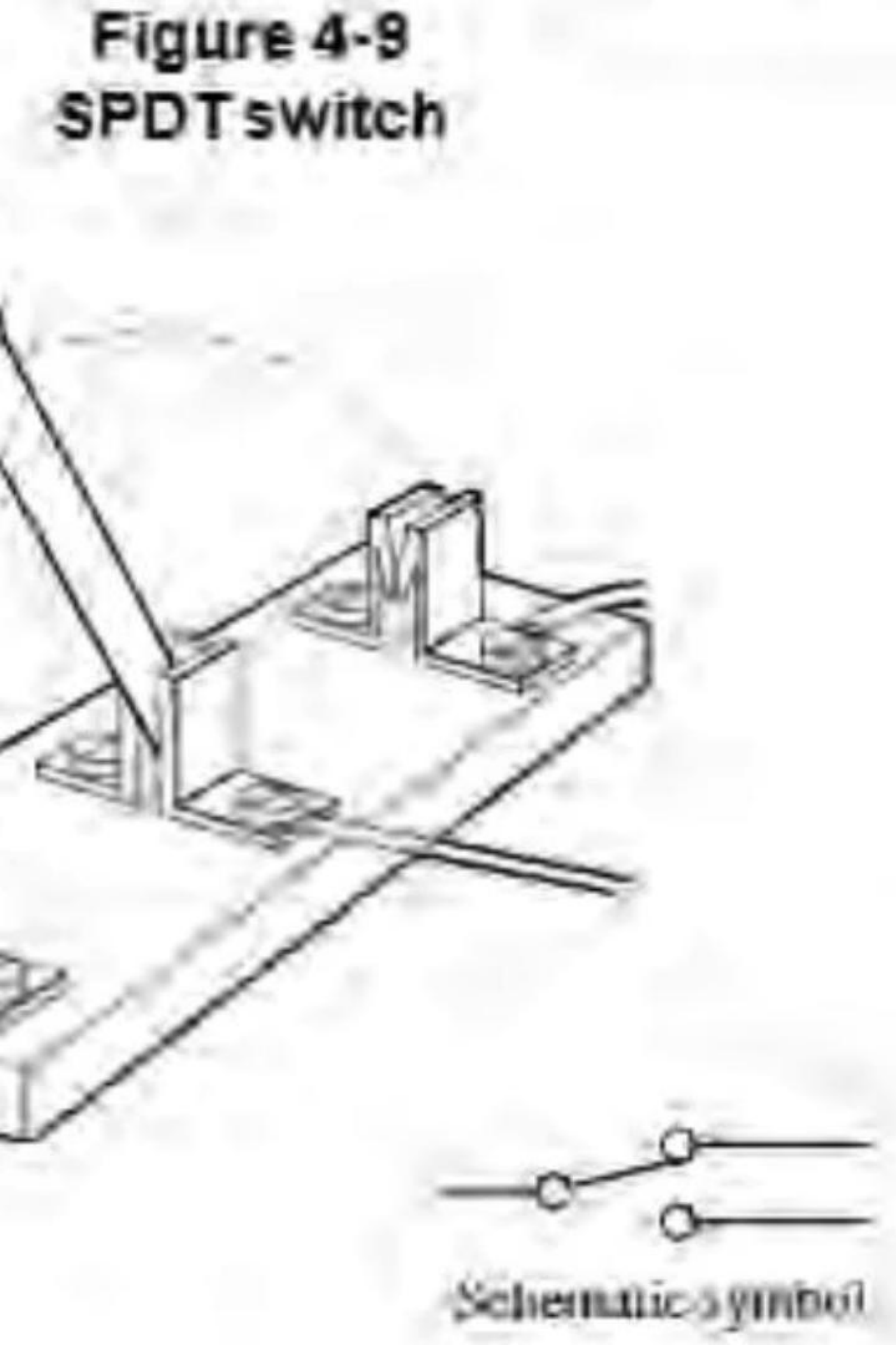
A throw refers to the number of positions each pole can be connected to. A single-throw switch has one "on" position, while a double-throw switch can connect to either of two positions.



Single Pole, Single Throw Switch

The simplest switch is a single pole, single throw (SPST) switch. This means the switch has one pole and one contact.

This type of switch is commonly used for simple on/off control of a single circuit, such as a light switch in a home. When the switch is in the "on" position, current flows through the circuit. When the switch is in the "off" position, the circuit is open and no current flows.



Single Pole, Double Throw Switch

If another contact is added to a SPST switch, the switch becomes a single pole, double throw (SPDT) switch.

The pole can be thrown to one of two positions, energizing one of two different circuits or loads. This type of switch is often used in applications where a single input needs to be directed to one of two possible outputs.

DIP Switches

Manufacturers often want to group together multiple SPST switches into one package. They are called dual in-line package (DIP) switches and are used on printed circuit boards to customize the behaviour of an appliance controller for specific situations.

DIP switches allow for configuration changes without requiring reprogramming or circuit modifications. They are commonly found in gas appliance control boards to set operating parameters or enable/disable specific features.

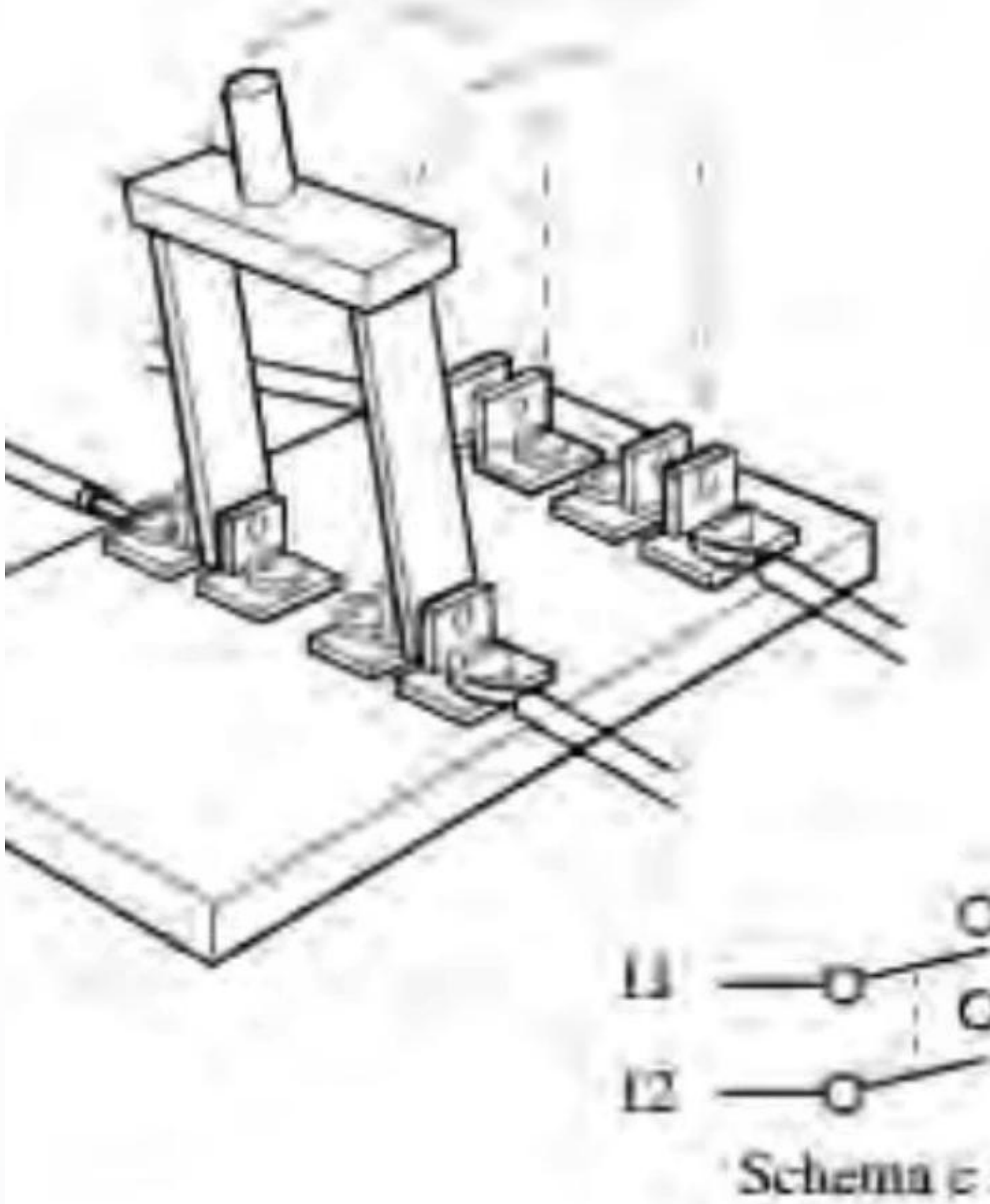
Double Pole, Single Throw Switch

Some household appliances require 240 V. In this case, two poles each carrying 120 V are linked mechanically to move together.

This type of switch is called a double pole, single throw (DPST) switch. The poles are connected to two separate ungrounded conductors called L1 and L2. The poles make and break two independent circuits at the same time.

A common use of a DPST switch is the disconnect switch on a window air conditioner.

Figure 4-11
DPST switch

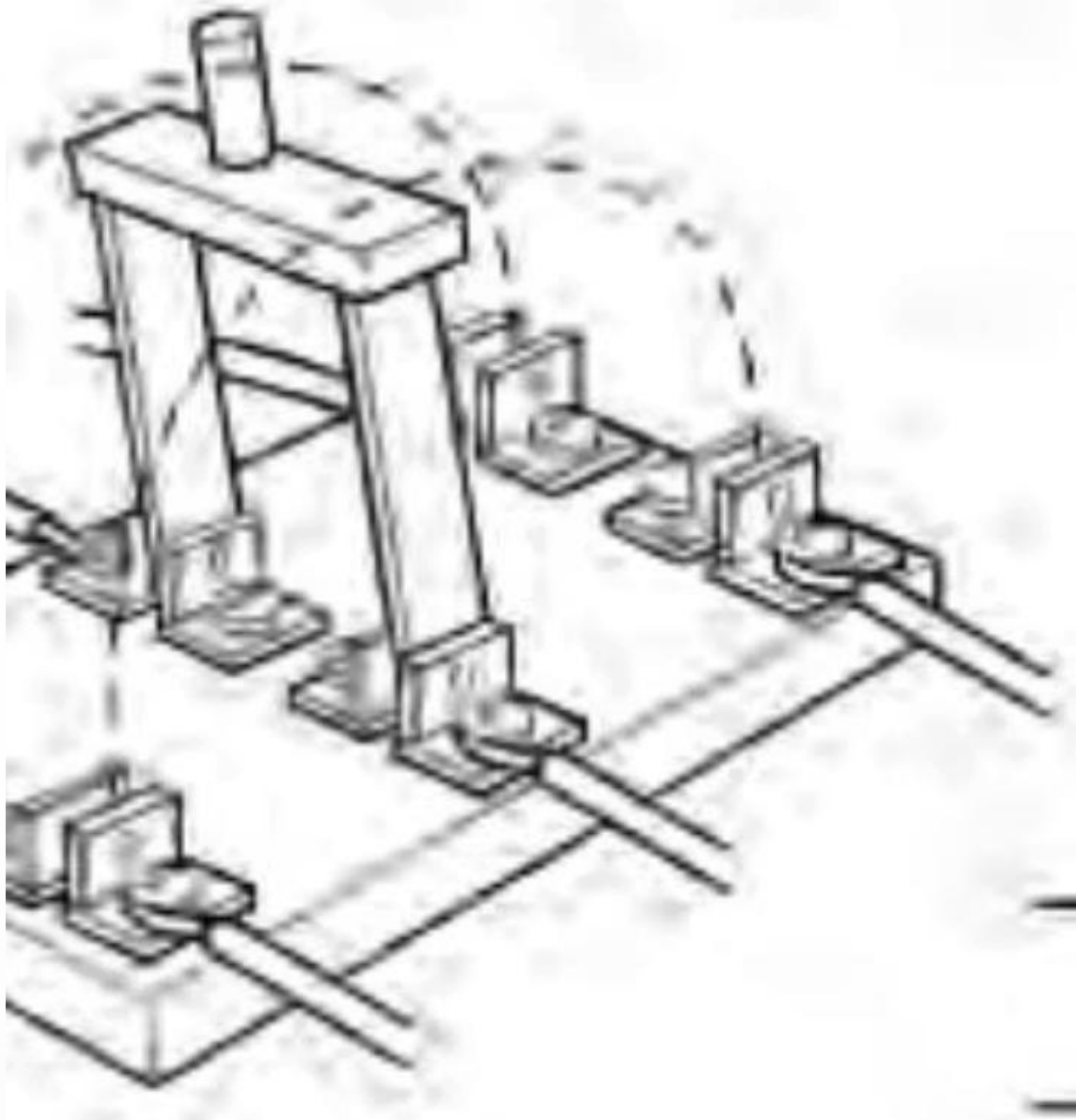


Double Pole, Double Throw Switch

If another throw is added to the DPST switch, it becomes a double pole, double throw (DPDT) switch.

The poles can make contact in two positions. This type of switch allows for more complex control scenarios, such as reversing the direction of a motor or switching between two different power sources.

Figure 4-12
DPDT switch



Switch Operation

Switches can be operated by hand or be actuated in response to changes in temperature, fluid movement, and pressure. Each of these conditions creates a force that moves the poles to the opposite position.

Normally Open Switch

For a switch designated as normally open, the force moves the pole to close the circuit.

These switches are used when the default state should be "off" and the circuit should only be energized when the actuating condition is present.

Normally Closed Switch

For a switch designated as normally closed, the force moves the pole to open the circuit.

These switches are used when the default state should be "on" and the circuit should be de-energized when the actuating condition is present, such as in safety circuits.

Motor-Starting Switches

Electric motors use various types of starting switches. Two switches in common use are the toggle switch and push-button switch.

Toggle Switch

Provides simple on-off control with a lever mechanism

Push-Button Switch

Uses separate buttons for start and stop functions

Overload Protection

Many motor switches include thermal overload protection

Horsepower Rating

Motor switches have contacts rated for the high inrush current of motors

Toggle Starter Switch

The toggle motor-starter is a snap-action switch, providing simple on-off control. It may consist of one contact (single pole) or two contacts (double pole). A toggle lever on the front of the starter operates the contacts. A thermal overload device may be next to the contact assembly.

This manual starter may be mounted in a standard switchbox installed on the wall and covered with a standard switch plate. The ON and OFF positions are clearly marked on the lever, and the switch is similar in appearance to a standard lighting switch.

Toggle Switch Features

Horsepower-Rated Contacts

The main difference is that the motor starting switch has horsepower-rated contacts, which means that it can safely interrupt the inrush current or locked-rotor current of the motor.

Overload Protection

It also may contain overload protection for sensing higher-than-normal currents drawn by the motor.

Series Connection

The starter is connected in series with the supply line and the motor terminals so that it can switch current to the motor.

Compact Design

The compact construction of this manual starter switch allows it to be installed directly on driven machinery and in tight spaces.

Toggle Switch Overload Operation

Current Increase

If a motor overload occurs, line current to the motor increases.

Heater Element Activation

This causes a small heater element to warm up considerably.

Switch Trip

This heating automatically trips the switch contacts, which breaks the circuit.

Reset Procedure

After a cooling period, the toggle is reset by pulling down the switch lever and then switching on again.

Push-Button Starter Switch

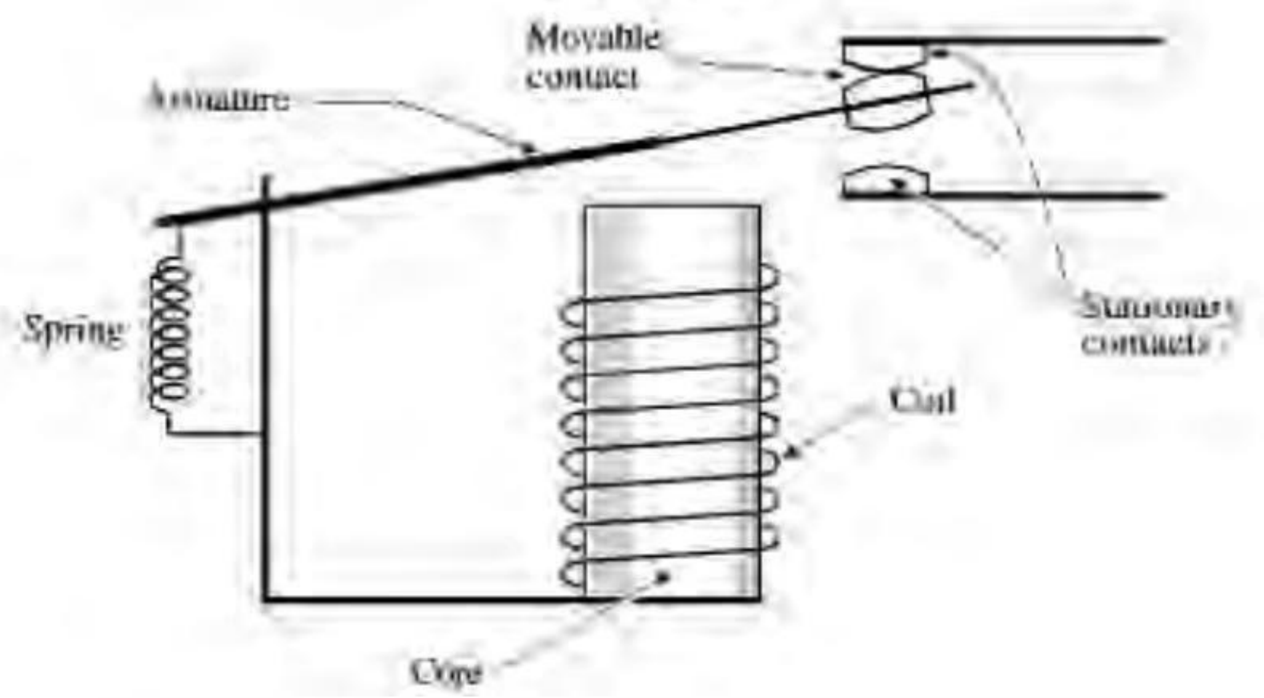
Push-button starters are similar in operating principle to toggle switches, except that they use two separate buttons to activate contacts.

The figure shows an external view of a push-button, manual starter in the on (START) position. To switch the motor on, press the START button so that it moves inward and stays there.

A mechanical interlocking device forces the STOP button outward so that it projects beyond the START button. Once activated, these buttons remain in position until the opposite button is pressed. To turn the motor off, press the STOP button in so that the START button moves out again.

Relays

Figure 4-15
A simple relay



A relay is a magnetically operated switch that operates on the solenoid principle. It can have multiple sets of contacts, which can be open or closed. A solenoid, which is basically a coil of wire wound around an iron core, converts electrical energy to linear motion.

Current Flow

When current flows through the coil of the solenoid, a magnetic field develops in the core.

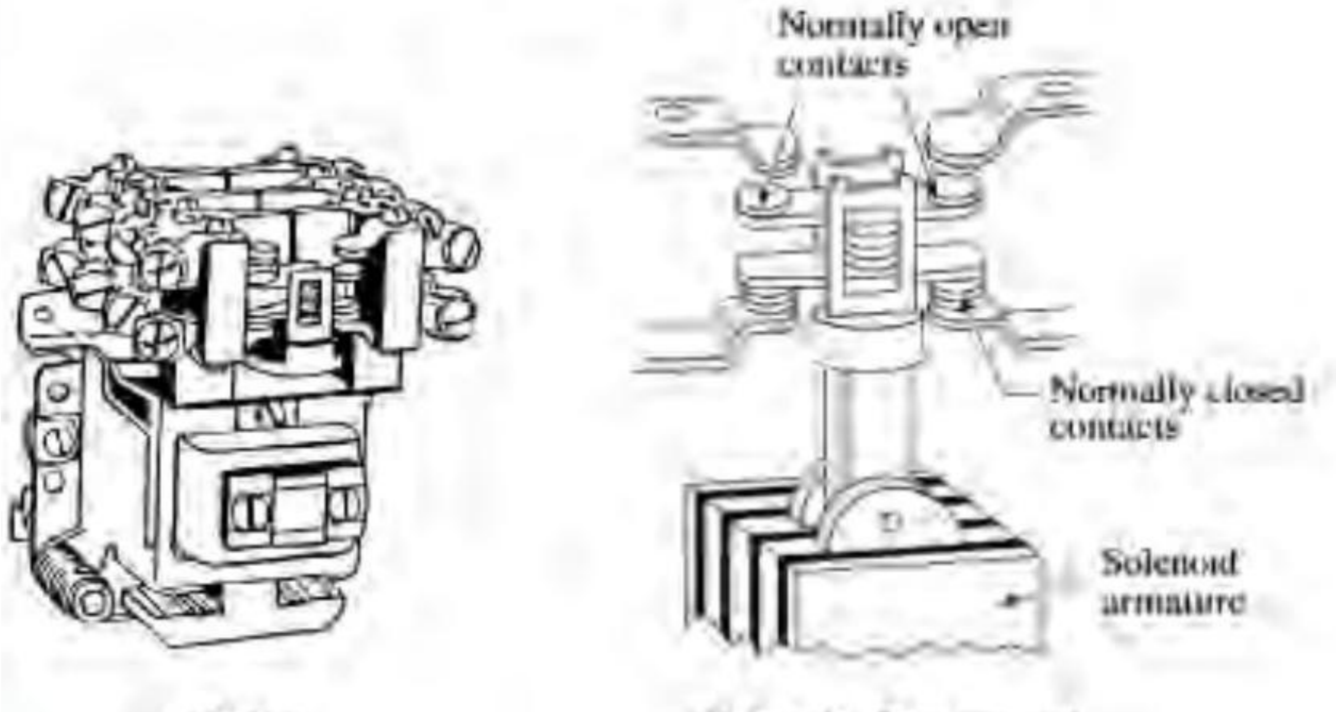
Magnetic Attraction

The magnetic field, which is stronger than the spring holding the movable armature away from the iron core, attracts the armature.

Contact Operation

In the "at rest" position, the movable contact connected to the armature is in contact with one of two stationary contacts. This set of contacts is normally closed. When the magnetic field pulls the armature towards the iron core, the armature breaks contact with one stationary contact and makes contact with the other.

Control Relays



(a) Relay (b) Detail of the contacts

Control relays are electrically operated switches that use electromagnets or solenoids to open and/or close several different circuits at the same time. The contacts are rated for light duty and usually carry only very small amounts of current as is usually the case for the components of control circuits.

Primary Use

These switches are primarily used to isolate control voltage from line voltage.

Control relays are not suited for controlling even single-phase motors of any size because of the high inductance and low resistance that cause high-starting currents when starting and high back-currents when contacts are opened for stopping.

Relay Construction

The T-bar of the armature is seen at the bottom in Figure 4-16(a). The bottom sets of contacts are normally closed, as shown in detail in Figure 4-16(b).

When the solenoid is activated, the armature moves upward, opening the bottom contacts and closing the upper contacts. The armature is insulated from the electrical contacts.

Contactors

The term relay is often used to describe any type of magnetically operated switch. A relay is actually a control device that contains small contacts designed to operate only low-current loads.

A contactor is very similar to a relay, except that a contactor contains heavy duty contacts designed to control larger amounts of current. This heavier contactor allows for a low voltage to control a component with a higher voltage and current draw. In some cases, it may even be a separate circuit being supplied to the component.

Contactor Applications

Heating Applications

In the heating and air-conditioning field, contactors are often used to connect power to resistance heater banks.

Contact Types

Contactors may contain auxiliary contacts as well as load contacts.

Motor Starters

Motor starters are basically contactors with the addition of overload relays.

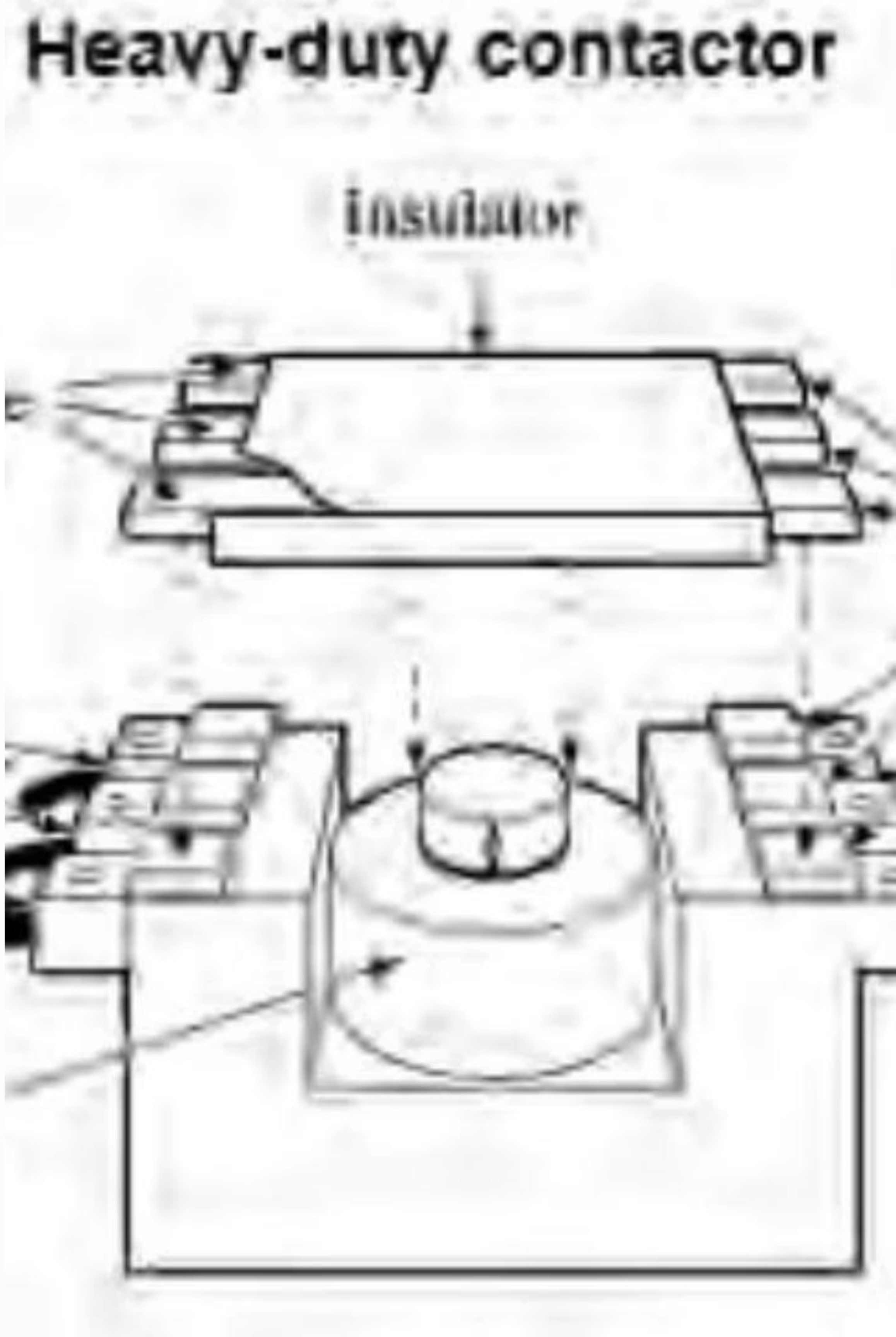
Motor Starter Components

Motor starters generally contain auxiliary contacts, which are used as part of the control circuit, and load contacts, which are used to connect the motor to the line.

Heavy-Duty Contactors

Heavy-duty contactors are solenoid/armature operators for switching heavy-duty electrical contacts. They are used to control the large amounts of current and high voltages required by industrial equipment. The figure shows a contactor that might be used to turn on a three-phase motor on a large boiler.

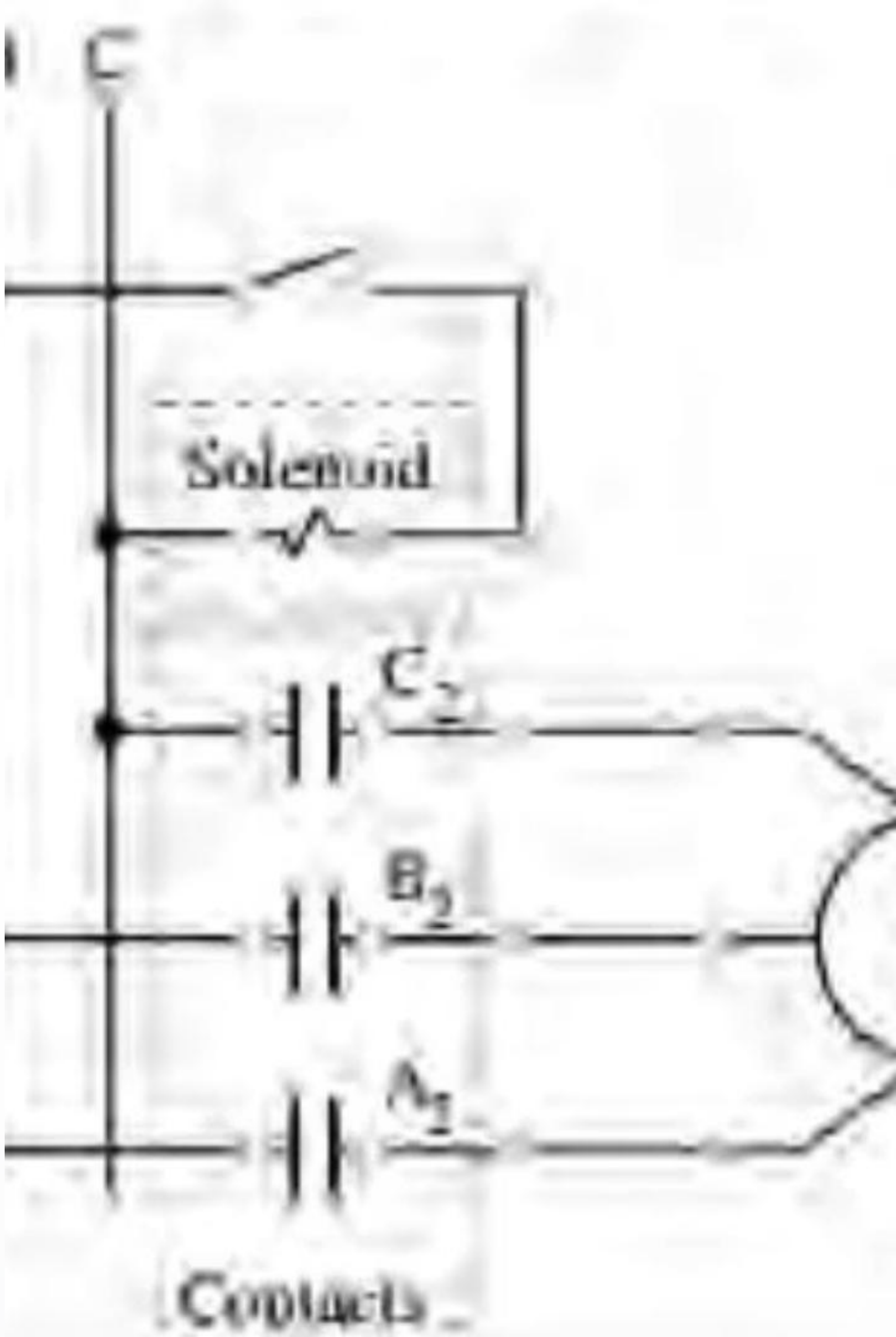
Note that the insulators that hold the conductive crossbars are attached to the T-bar armature that closes several sets of contacts at once.

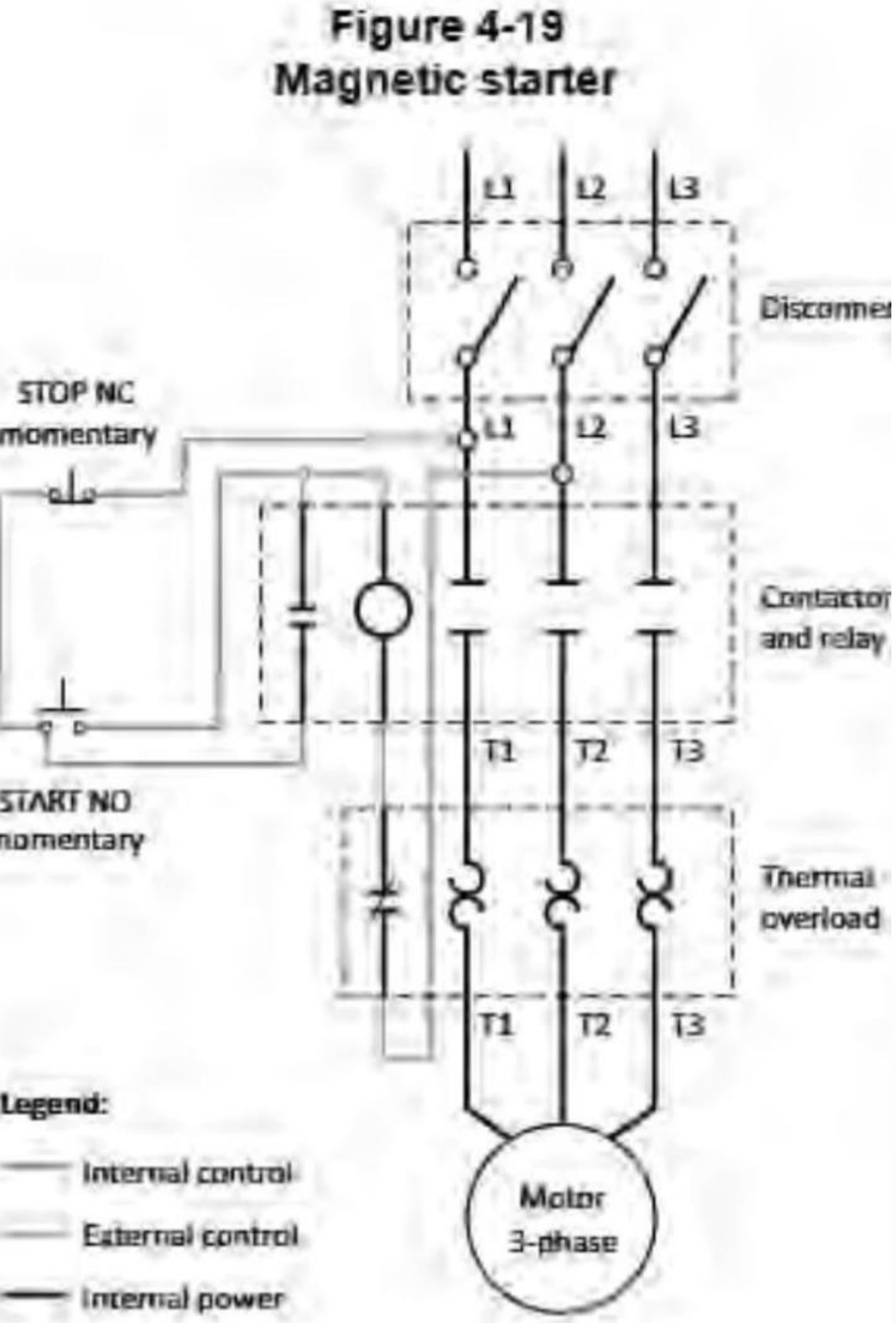


Heavy-Duty Contactor Schematic

The schematic shows the switch in the 110 V coil circuit, which simultaneously activates the 208 V three-phase circuit to the motor.

Most three-phase heavy duty motors require an overload sensing circuit to protect the motor from single-phase conditions and excessive current draw due to high load demands. This requires the use of a motor starter, usually a magnetic motor starter. However, more electronic versions are becoming common in addition to variable frequency drive controllers.





Three-Phase Magnetic Starter

The figure shows a typical three-phase magnetic starter. These starters combine contactor functionality with overload protection specifically designed for three-phase motor applications.

Understanding these components is important for gas technicians working on equipment with three-phase motors, such as large commercial boilers or industrial heating systems.

Electrical Boxes Overview

Many types and sizes of electrical boxes are available to meet the requirements of various applications. Variations include different depths, widths, heights, capacities, mounting bracket, and cable clamp arrangements.

Section 12 of the CE Code prescribes the requirements for the use and installation of electrical boxes and their accessories. The two boxes commonly used in the installation of gas appliances and equipment are device boxes and junction boxes.

Boxes must always have the covers installed after wiring.

Device Boxes

Device boxes can be used to support switches and other devices. There are two basic types: gangable type and non-gangable type.

Non-Gangable Type

These boxes have fixed sides and cannot be combined with other boxes.

The figure shows a non-gangable device box (2-gang).

Gangable Type

One side of a gangable device box can be removed to allow one or more additional boxes to be added or ganged to it.

This allows for flexibility in creating multi-gang boxes for multiple switches or devices.

Sectional Gangable Box

The CE Code requires any gas appliance that is connected to an electrical circuit to have an electrical disconnect switch. The switch, which must be mounted near the appliance in an approved electrical switch box, is used to shut off electrical power during emergencies or when the appliance is being serviced.

Take care when placing a switch box that you will use for disconnecting the furnace from the circuit. The CE Code requires that the switch for disconnection be located between the furnace and the point of entry to the room containing the furnace if the switch is a branch circuit breaker in the distribution panel board.

Disconnect Switch Requirements

Proper Placement

You must not have to pass close to the furnace to reach the switch, and it must not be placed on the furnace itself.

Clear Marking

The switch must be clearly marked with the circuit it controls.

Safety Purpose

Allows for quick power disconnection during emergencies or maintenance.

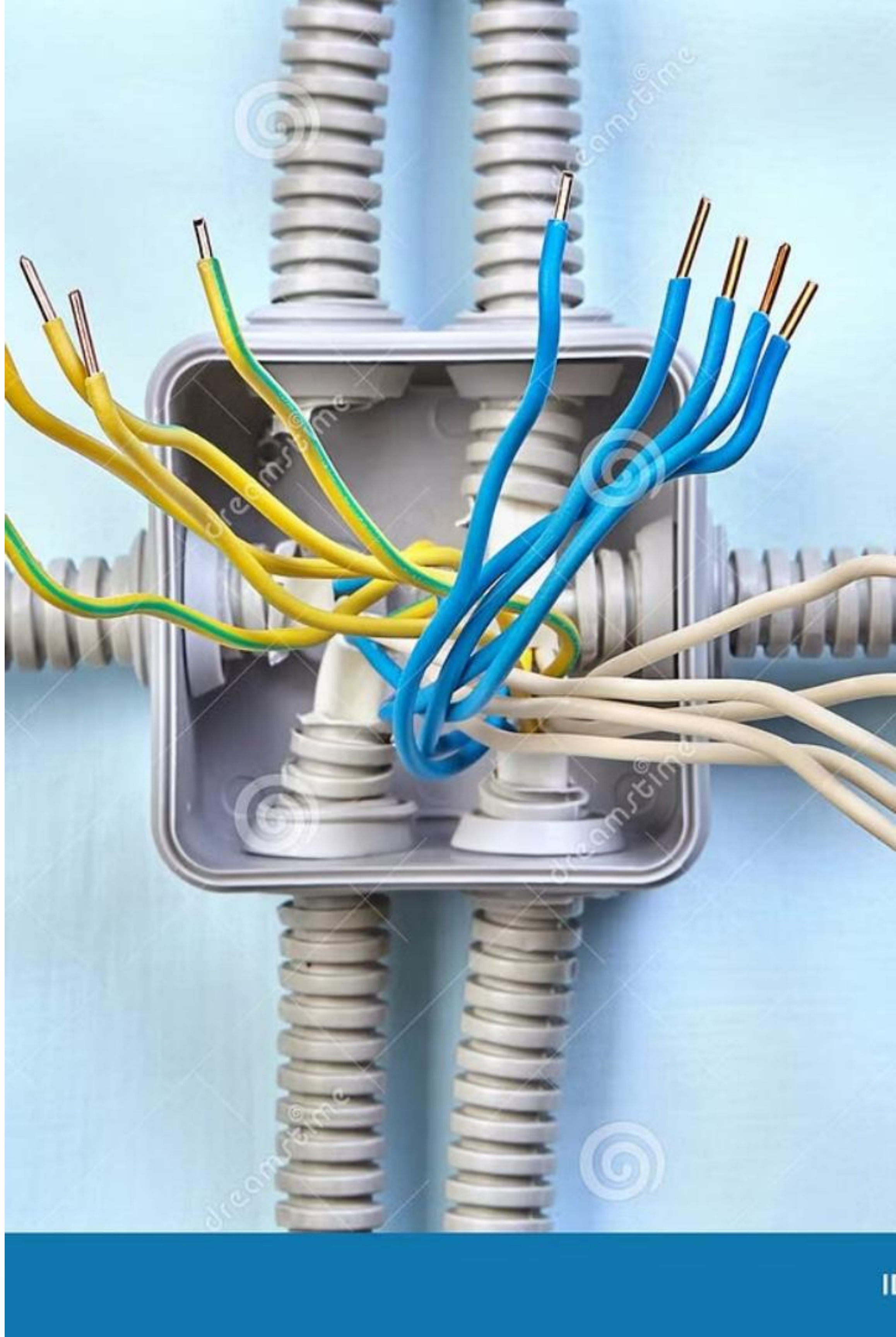
Code Compliance

Must meet all requirements of the Canadian Electrical Code.

Junction Boxes

There are two types of electrical boxes commonly used as junction boxes: octagon boxes and square boxes.

A junction box is often mounted directly on a gas appliance. In most installations, the connections between the branch circuit supplying the appliance and the appliance control system are made in the junction box. This is done to meet CE Code requirements and prevent short circuits and electric shock hazards.

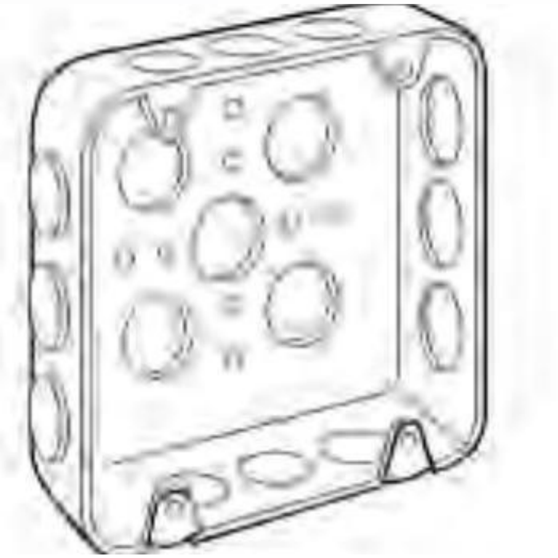


Octagon Boxes

Octagon boxes are usually used to support lighting fixtures or as junction points for wiring connections. They may also be used as switch or outlet boxes when equipped with special cover plates.

These boxes provide a secure enclosure for electrical connections and help prevent electrical hazards when properly installed and covered.

Square Boxes



Square boxes are used primarily as junction boxes for surface-run and concealed wiring circuits. Square boxes are available in two sizes.

4 Inch Wide Box

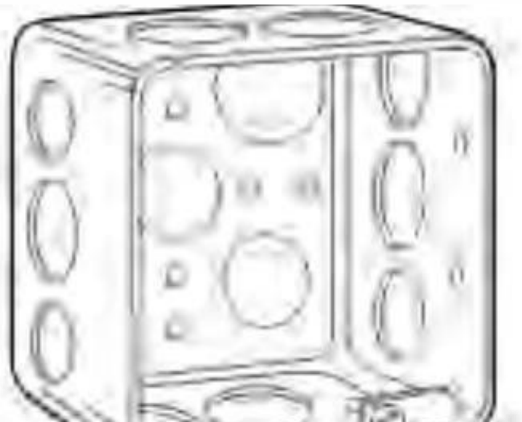
Most commonly used

Can be fitted with special covers that permit its use for switches, receptacles and pilot lights

4-11/16 Inch Square Box

Generally used for range or dryer receptacles

Provides more space for larger conductors and connections

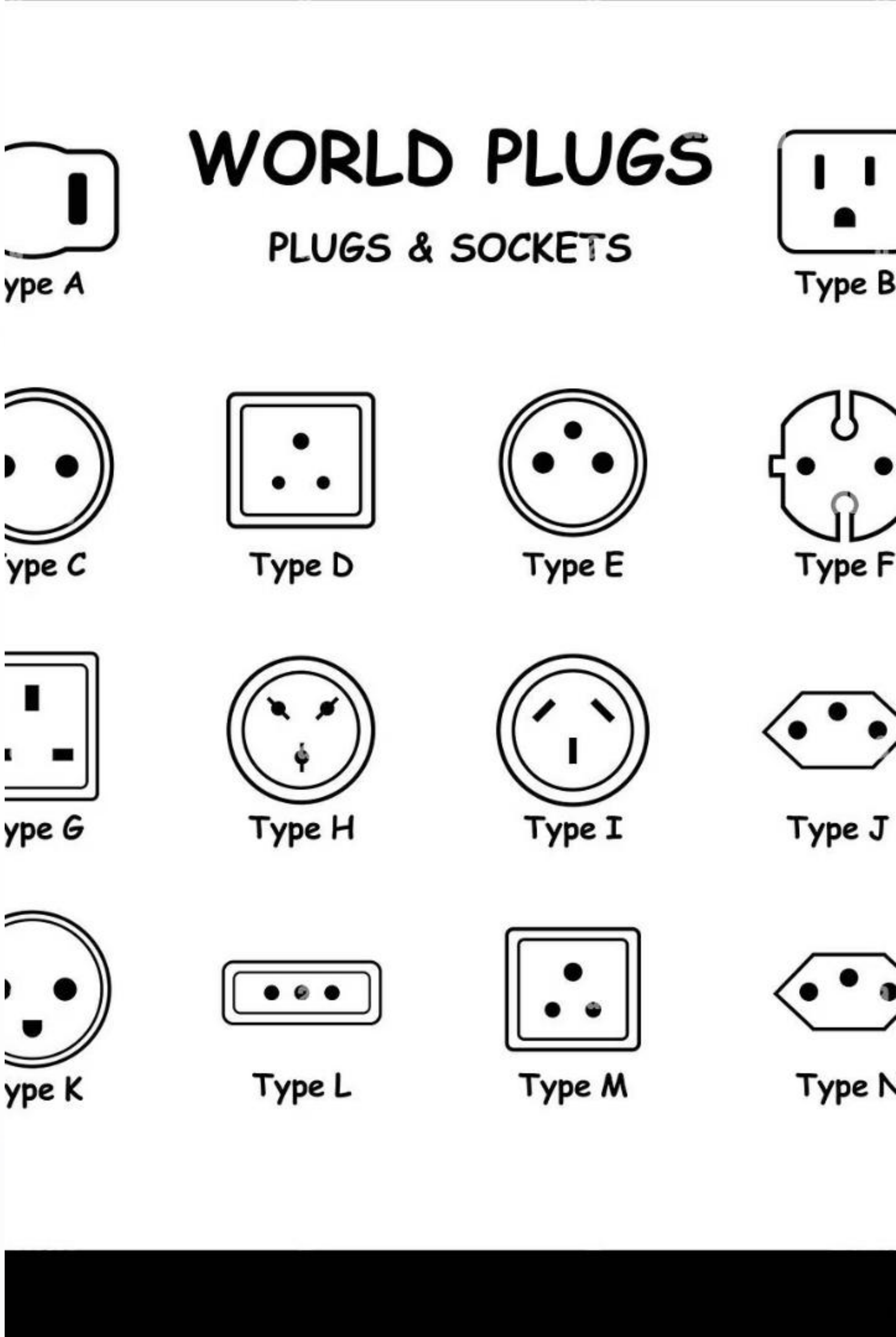


Sockets and Plugs

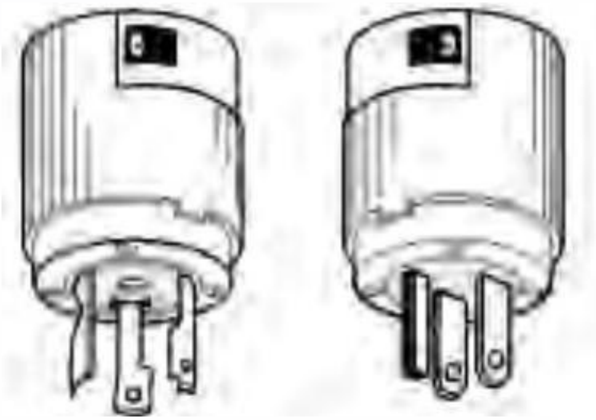
Some gas appliances and equipment installations require the use of special sockets (receptacles) and plugs. Occasionally, a gas appliance may be supplied with the necessary cable and plug, and the gas technician/fitter will only be required to select the appropriate receptacle assembly.

In some cases, it may be necessary for the technician/fitter to determine the equipment requirements and specifications from the manufacturer's installation instructions and select the appropriate cable, plug, and socket.

Be sure to check with the electrical AHJ regarding requirements on cable and cord end installations.



Locking and Non-Locking Plugs



Specialty plugs and sockets can be either locking or non-locking.

Non-Locking Plug

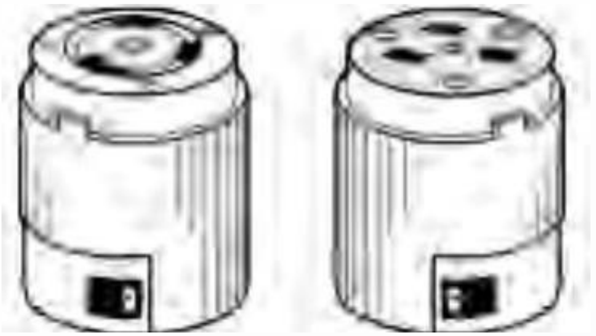
Is inserted straight into its socket, relying on contact friction to keep it securely in place

Can be withdrawn by pulling it straight out of the socket

Locking Plug

Is inserted straight into its socket, then rotated clockwise a short distance to lock it into the socket

Cannot be withdrawn from the socket unless it is first rotated counter-clockwise

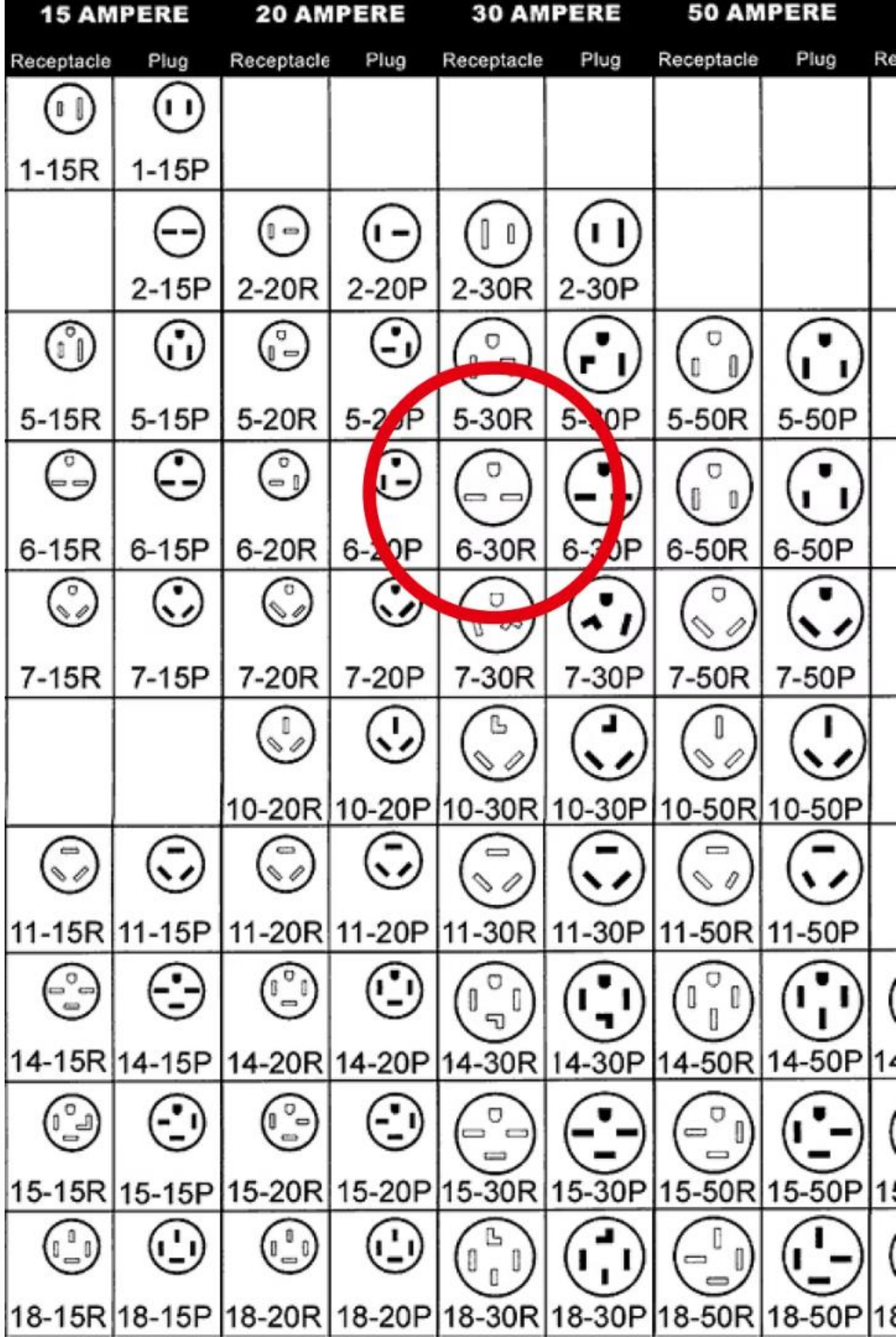


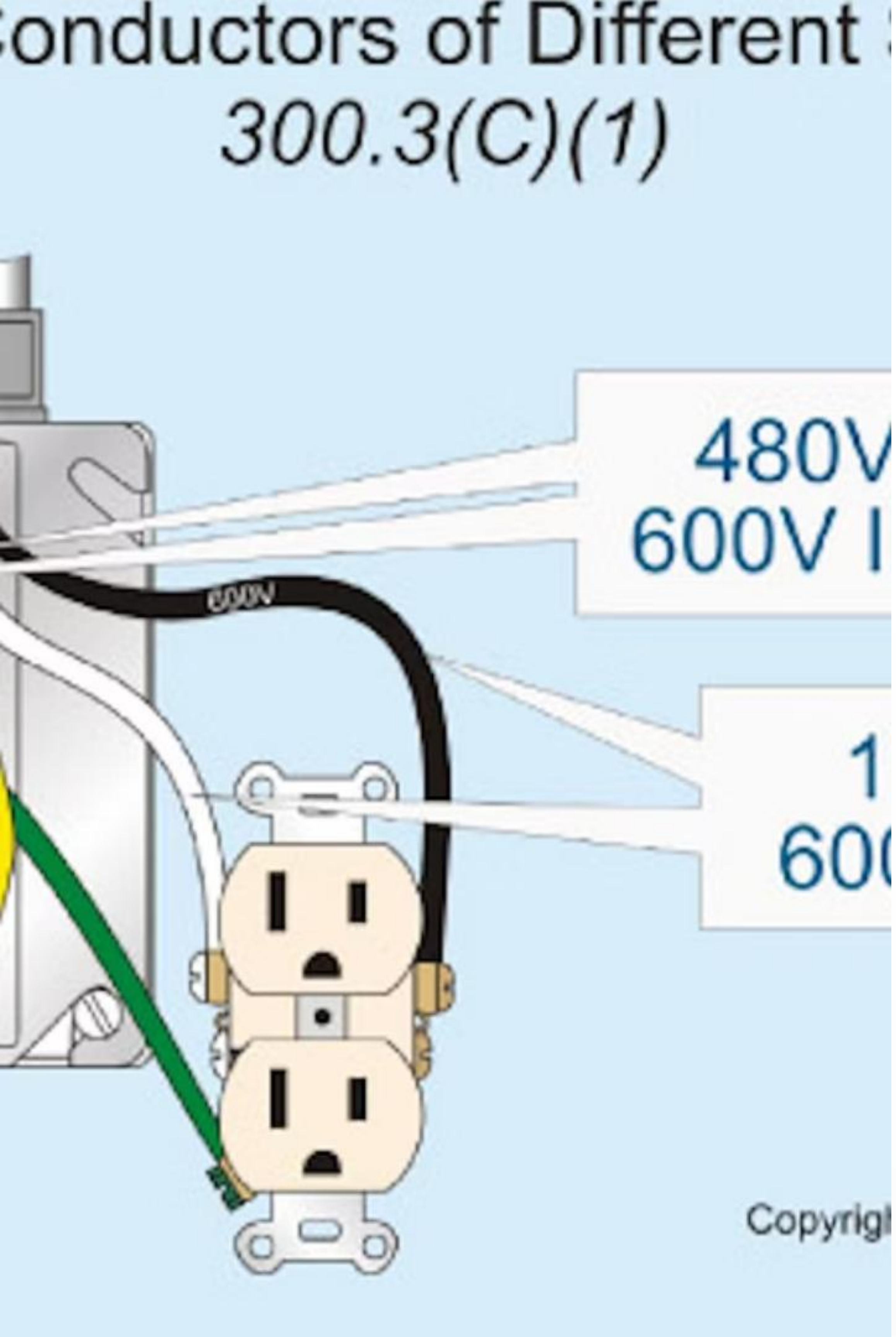
Plug and Socket Configurations

Each type of plug and socket assembly has different socket and terminal blade configurations and voltage and current ratings based on the intended application.

The configuration chart shows various receptacle socket configurations for different voltage and amperage ratings. These configurations are standardized to prevent connecting equipment to incompatible power sources.

For configurations 6-15R, 6-20R, 6-20RA, 6-30R, and 6-50R, Y denotes the identified terminal when used on circuits derived from three-phase, 4-wire 416V circuits.





Receptacle Terminal Designations

G Terminal

Represents the terminal for bonding to ground

W Terminal

Represents the identified terminal

X, Y, and Z Terminals

Represent the terminals for ungrounded conductors

Configuration Purpose

These standardized configurations ensure proper connections and prevent equipment damage from incorrect power connections

Electrical Fasteners

Electrical cable and conduit must be secured to building framing and wall and ceiling surfaces in accordance with CE Code requirements. The figure shows some of the fasteners commonly used for this purpose.

Proper fastening of electrical components is essential for safety and code compliance. Gas technicians should be familiar with these fasteners when installing or servicing gas equipment with electrical connections.

Conduit and Tubing Overview

Electrical conduit and tubing are used to contain and protect the electrical conductors of a circuit. Conduit and tubing are classified by wall thickness, mechanical stiffness, and material they are made from. The CE Code, Part 1 covers the requirements for the installation of electrical conduit and tubing depending on the type of equipment, location, or hazard.

Types of Conduit and Tubing

Examples of electrical conduit and tubing

Conduit Selection Factors

Environment

Consider whether the installation location is dry, wet, or corrosive when selecting conduit type.

Mechanical Protection

Rigid conduit provides better protection against physical damage than flexible types.

Flexibility Requirements

Use flexible conduit for connections to equipment that vibrates or requires occasional movement.

Code Compliance

Always check the CE Code for specific requirements based on the installation location and type of equipment.

Conduit Installation Best Practices

Proper Support

Secure conduit at regular intervals as specified by the CE Code.

Appropriate Fittings

Use the correct connectors and fittings designed for the specific type of conduit.

Proper Bending

When bending conduit, use appropriate tools to prevent kinking or flattening.

Conductor Fill

Do not exceed the maximum number of conductors allowed in a conduit based on its size.

Electrical Safety for Gas Technicians

Verify Power Off

Always confirm power is disconnected before working on electrical components

Use Proper Tools

Only use insulated tools designed for electrical work

Personal Protection

Wear appropriate PPE when working with electrical components

Follow Codes

Adhere to all CE Code requirements for electrical installations

Jurisdictional Considerations

Authority Having Jurisdiction (AHJ)

Always check with the local electrical authority having jurisdiction for specific requirements regarding electrical work.

Permit Requirements

Electricians are required to perform electrical work under a permit in all jurisdictions in Canada.

Scope of Work

Gas technicians/fitters should understand what electrical work they are permitted to perform in their jurisdiction.

Elementary Electrical Work

Gas and mechanical trades are permitted to perform elementary electrical work in some Canadian jurisdictions.

Summary of Circuits and Hardware

Electrical Panels

Understanding residential electrical service, branch circuits, and proper bonding requirements

Transformers

Knowledge of step-down transformers for control circuits, their ratings, and proper installation

Electrical Hardware

Familiarity with connection devices, switches, relays, contactors, boxes, sockets, plugs, fasteners, and conduit

Safety and Compliance

Following proper safety procedures and code requirements for all electrical work related to gas equipment installation

CSA Unit 12

Chapter 5
Millivolt Systems

Many gas-fired appliances are considered self-contained or self-powered. It is very common to encounter appliances equipped with devices that generate electricity and that have components that operate on direct current millivolt. This voltage is generated using heat from the gas flame and is used to operate minor control and safety circuits and extended systems, especially in offgrid applications.

Purpose of Millivolt Systems

Self-Contained Power

The gas technician/fitter must have complete knowledge of how this voltage is generated as well as the amount of voltage that is generated. The gas technician/fitter must also know how this voltage is distributed through the circuit and the test procedures used to isolate problems when they arise.

Specialized Applications

The electrical principles remain the same, but millivolt systems have very specific applications and restrictions. These systems are particularly valuable in off-grid applications where external power sources are unavailable.

Millivolt systems allow gas appliances to operate independently without requiring connection to household electrical systems.

Learning Objectives

Explain the generation of DC millivolt systems

Understand how heat from a flame creates electrical current through thermocouples and thermopiles

Explain the procedure used to test control circuits

Learn proper testing methods for troubleshooting millivolt system components

Describe millivolt thermostats

Understand the specialized thermostats used with self-powered heating control systems

Key Terminology

Term	Abbreviation (Symbol)	Definition
Millivolts	mV	A millivolt is 1/1000 of a volt
Powerpile		Consists of multiple thermocouples joined together at one end and connected in series to generate more voltage than a single
Thermocouple		Sensor used to measure temperature
Thermopile		See Powerpile.

Generation of Small-Value DC Voltages

Direct Current Basics

Unlike alternating current (AC), direct current flows in one direction only. Direct current (DC) is used in many different applications in North America.

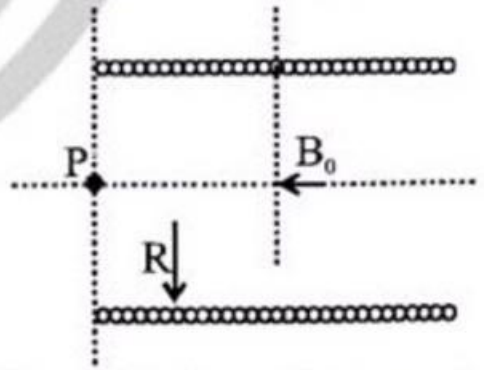
Common DC Applications

It is normally used to power electronic devices, control relays on most building automation systems, small appliances, automotive electrical systems, and, recently, solar panels.

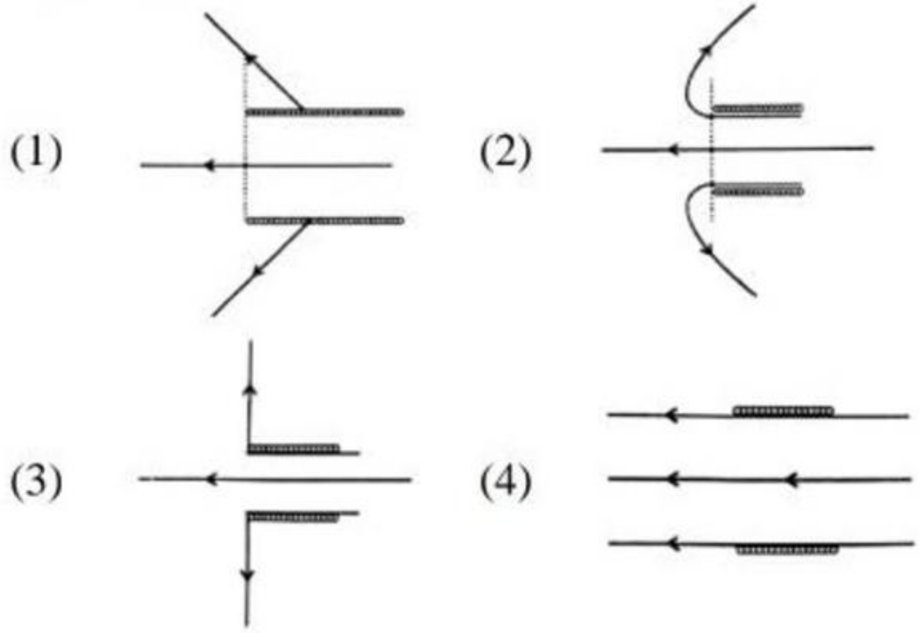
DC Generation Methods

DC is often supplied by some form of battery or power supply converter. However, other means, such as heating a bimetallic device called a thermocouple, can generate small DC voltages.

8. A direct current flows in a solenoid of length L and radius $R, (L >> R)$, producing a magnetic field of magnitude B_0 inside the solenoid.



Which of the following diagrams best describes the magnetic field lines in the vicinity of P at the end of the coil



Thermocouple Basics

Thermocouple Structure

A simple thermocouple consists of two wires, made of dissimilar (different) metals joined together at one end. The end at which they are joined is called the hot junction, while the opposite end is the cold junction.

Some thermocouples consist of a wire located in the centre of a small, circular metal tube. The tube and wire, which are made of dissimilar (different) metals, are joined at one end to form the hot junction (the opposite end is the cold junction).

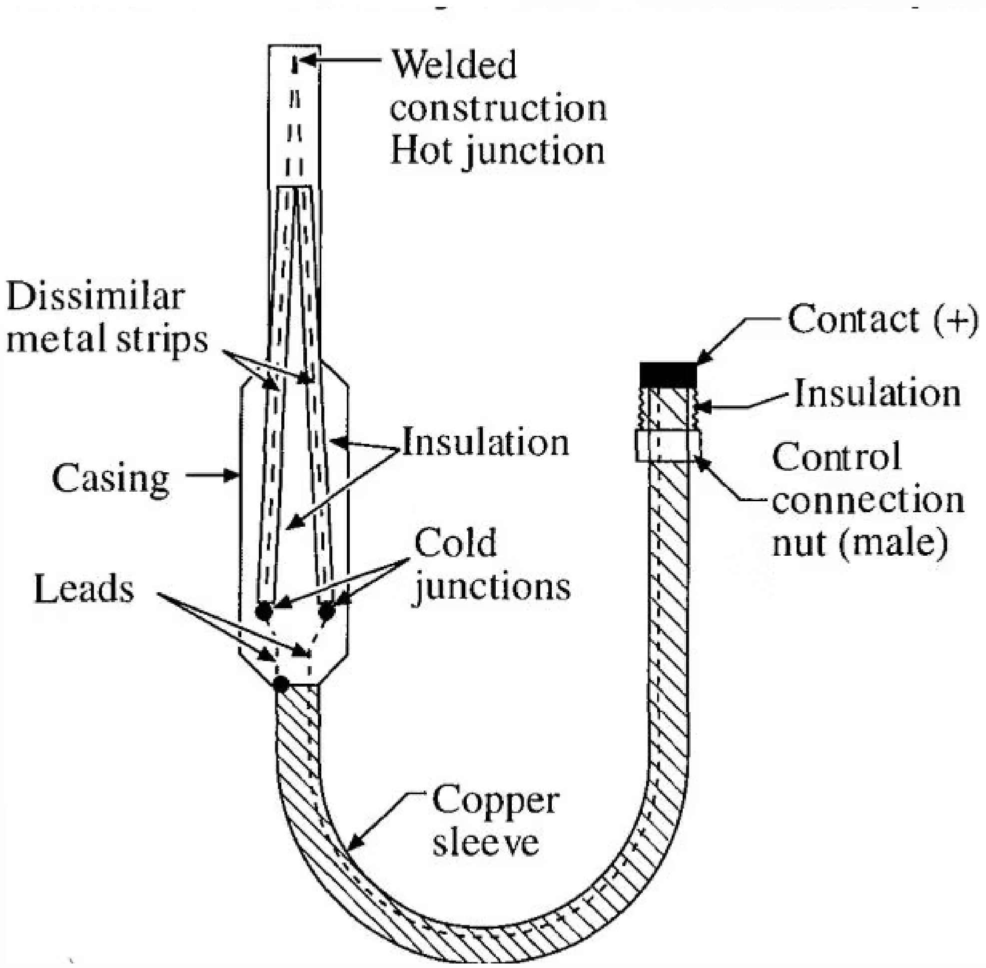


Figure 5-1 Combustion safety circuit thermocouple

How Thermocouples Generate Voltage

Heat Application

When sufficient heat is applied to the hot junction of a thermocouple

Voltage Generation

A small voltage is generated at the cold junction

Current Flow

Causing a positive-to-negative direct current flow

Measurement

The voltage generated is so small that it is measured in millivolts (mV)

If the cold junction is heated, current will flow in the opposite direction (negative-to-positive). A millivolt is 1/1000 of a volt. Thermocouples generate voltages in the 0-30 mV range.

Thermocouple Applications

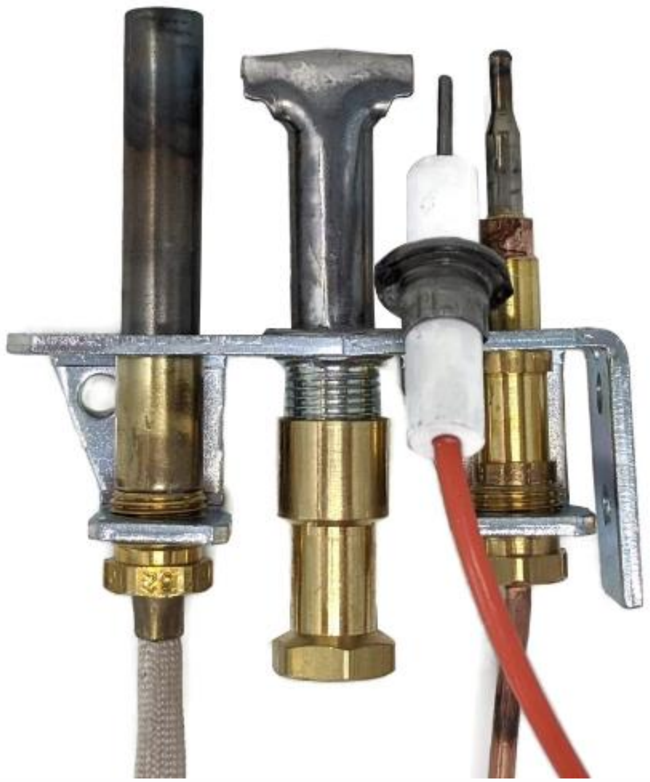
Safety Applications

Thermocouples are used as a flame detection device or flame safeguard on appliances that have constant pilots. They are also used on appliances with manual reset controls.

The thermocouple assembly is attached with a threaded male fitting, as shown in Figure 5-1.

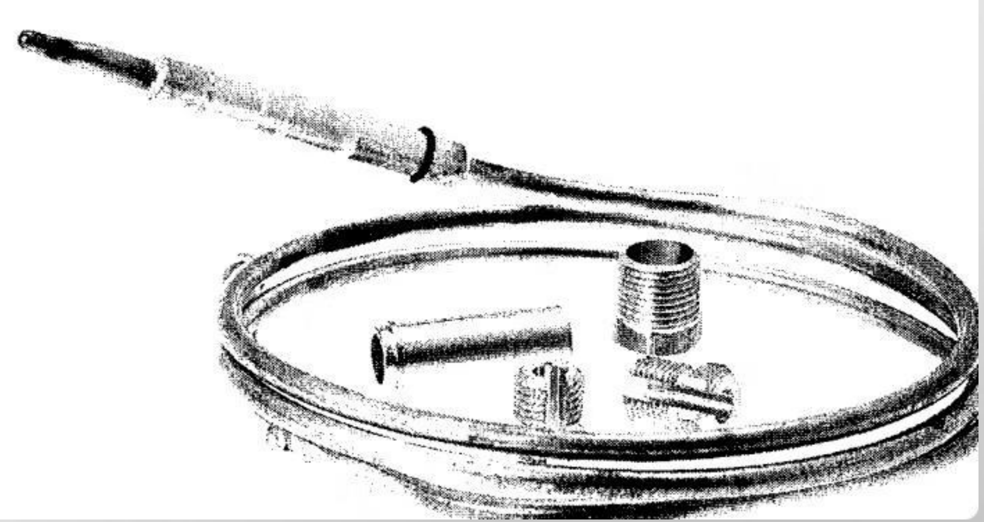
Operation Principle

When the pilot burner heats the hot junction, the thermocouple generates a voltage to power the electromagnet coil in the safety shut-off valve or safety switch. As long as the pilot remains lit, the spring-loaded solenoid shut-off valve or safety switch will remain open to allow the flow of gas to the main and pilot burners.



Most thermocouples supply only a small current in milliamps that is just enough to energize a very small electromagnetic solenoid.

Figure 5-2
Fast response thermocouple



Thermocouple Safety Requirements

90-Second Shutdown

In order to meet the requirements of CSA B149.1, when a pilot fails (goes out), the thermocouple must cool down and de-energize the safety shut-off valve or safety switch within 90 seconds.

Input Limitations

For this reason, thermocouples are only approved for use with gas appliances with inputs up to and including 400,000 British thermal units per hour (Btu/h) (117 kW).

Exception

A single thermocouple may be used to supervise inputs of natural gas appliances with inputs of up to 1,000,000 Btu/h (300 kW) if they have unrestricted vertical flue passes.

Propane Safety Requirements

20-Second Response Time

Appliances with a specific gravity greater than air (such as propane) shall have a maximum flame response time of 20 seconds.

Fast Response Thermocouples

These appliances will be equipped with fast response thermocouples.

Common Applications

As many of these appliances, such as fireplaces, are convertible for either fuel, this is the type of thermocouple that has become prevalent.

Hot Junction Requirements

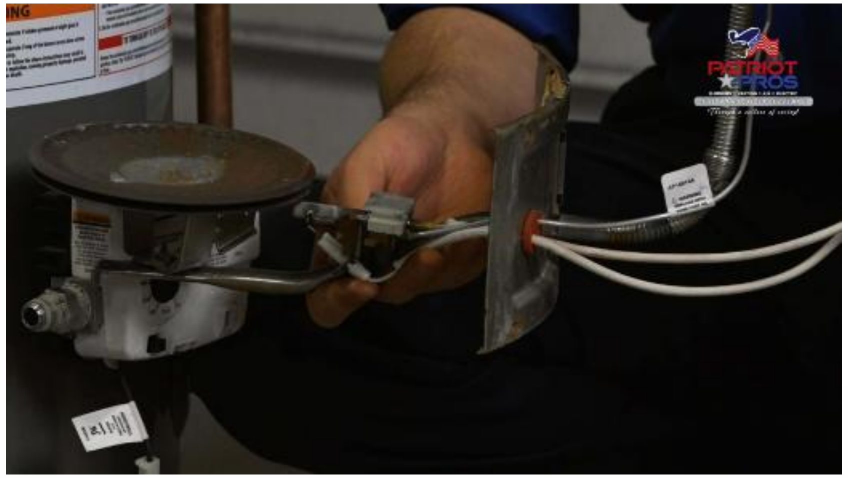
Temperature Difference

The thermocouple only generates a voltage if the temperature difference between the hot and cold junctions is at least 400°F (204°C).

The greater the temperature difference, the greater the voltage generated.

Proper Heating

For this reason, it is important that the pilot flame heat only the first 0.375 to 0.5 inch (10 mm to 13 mm) of the hot junction - no other part of the thermocouple should be heated.



Correct positioning of the thermocouple in the pilot flame is critical for proper operation.

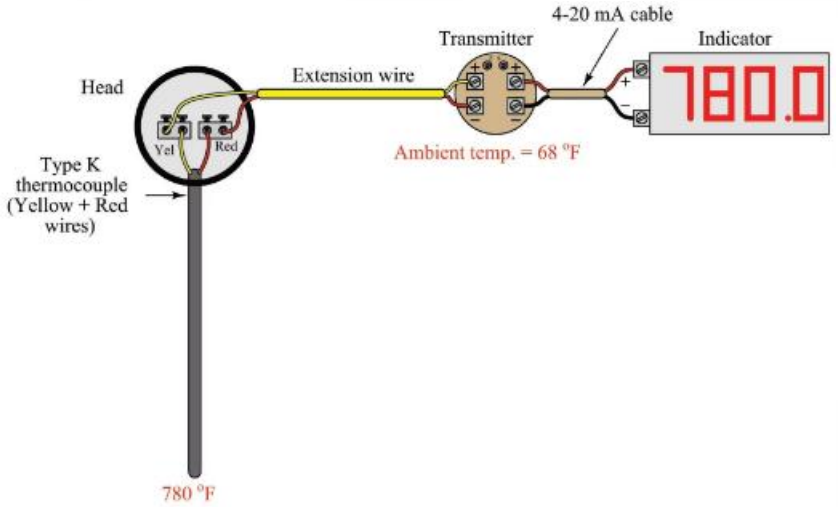
Cold Junction Connections

Connection Structure

One of the ends of the cold junction is connected to the copper outer sleeve of the thermocouple, creating one of the conductors of the supply circuit.

Wiring Configuration

While the other lead from the cold junction is connected to an insulated wire enclosed in the copper sleeve, which terminates at a coaxial connection that is connected to the safety switch or safety shut-off valve.



The cold junction connections complete the electrical circuit for the safety system.

Powerpile Generator

Definition

A powerpile, also known as a thermopile, consists of multiple thermocouples joined together at one end and connected in series to generate more voltage than a single thermocouple.

The total voltage generated by a thermopile is the sum of the voltages generated by each thermocouple it contains.

Powerpile schematic

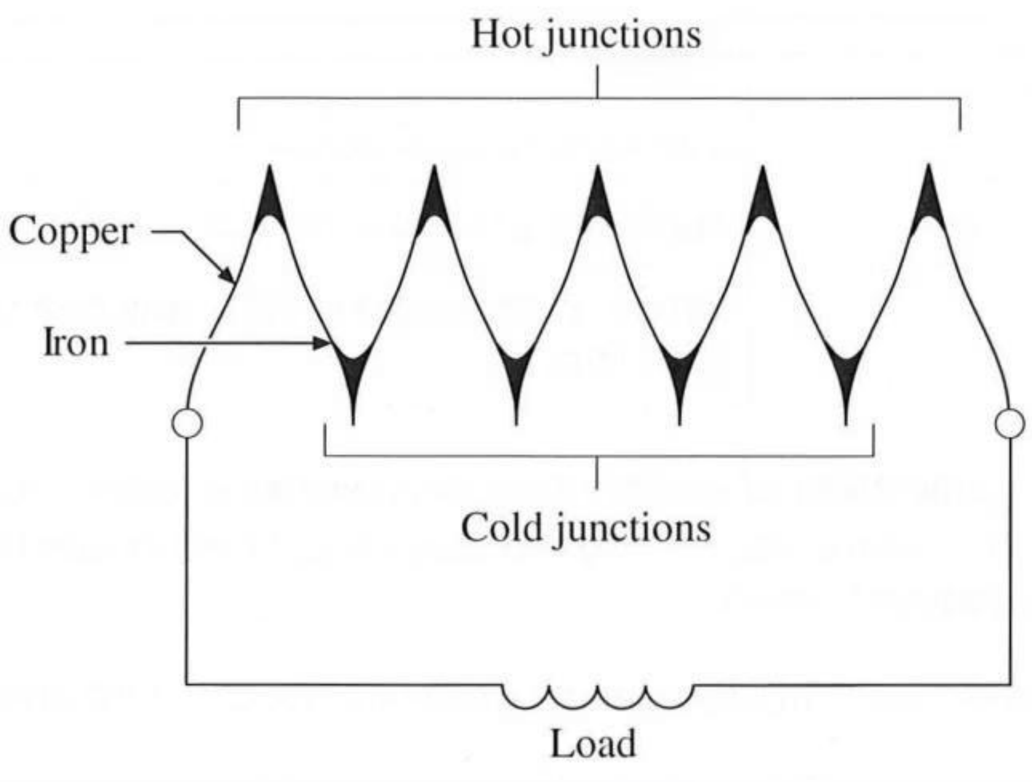
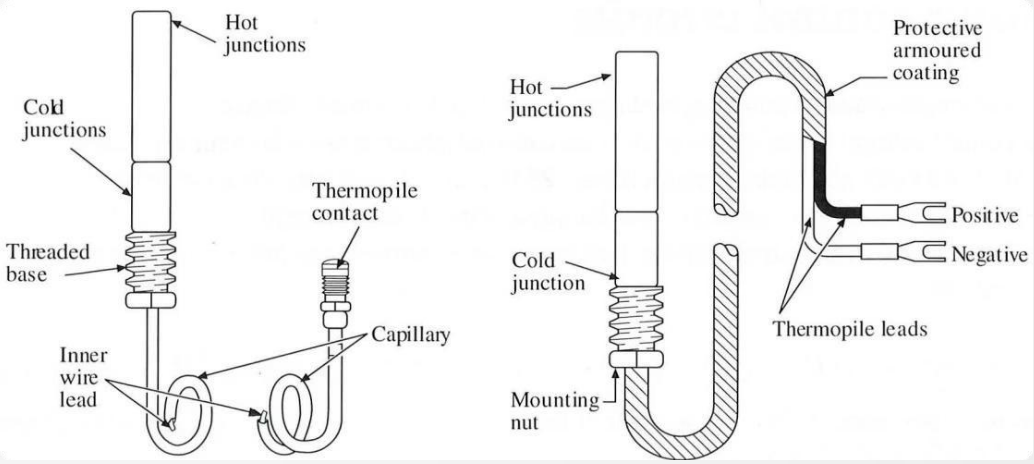


Figure 5-3



Powerpile Characteristics

Multiple Thermocouples

Most modern thermopiles consist of 10 to 30 thermocouples connected in series.

Higher Voltage Output

Powerpile output ranges from 250 to 750 mV, which allows the powerpile to power an appliance's combustion safety circuit and its control circuit.

Self-Sufficient Power

Powerpile generators are used on appliances with automatic-type controls. Pilot/powerpile generators, as they are called, generate electrical direct current power from the flame of a single pilot source. This makes the appliance self-sufficient for stand-alone applications.

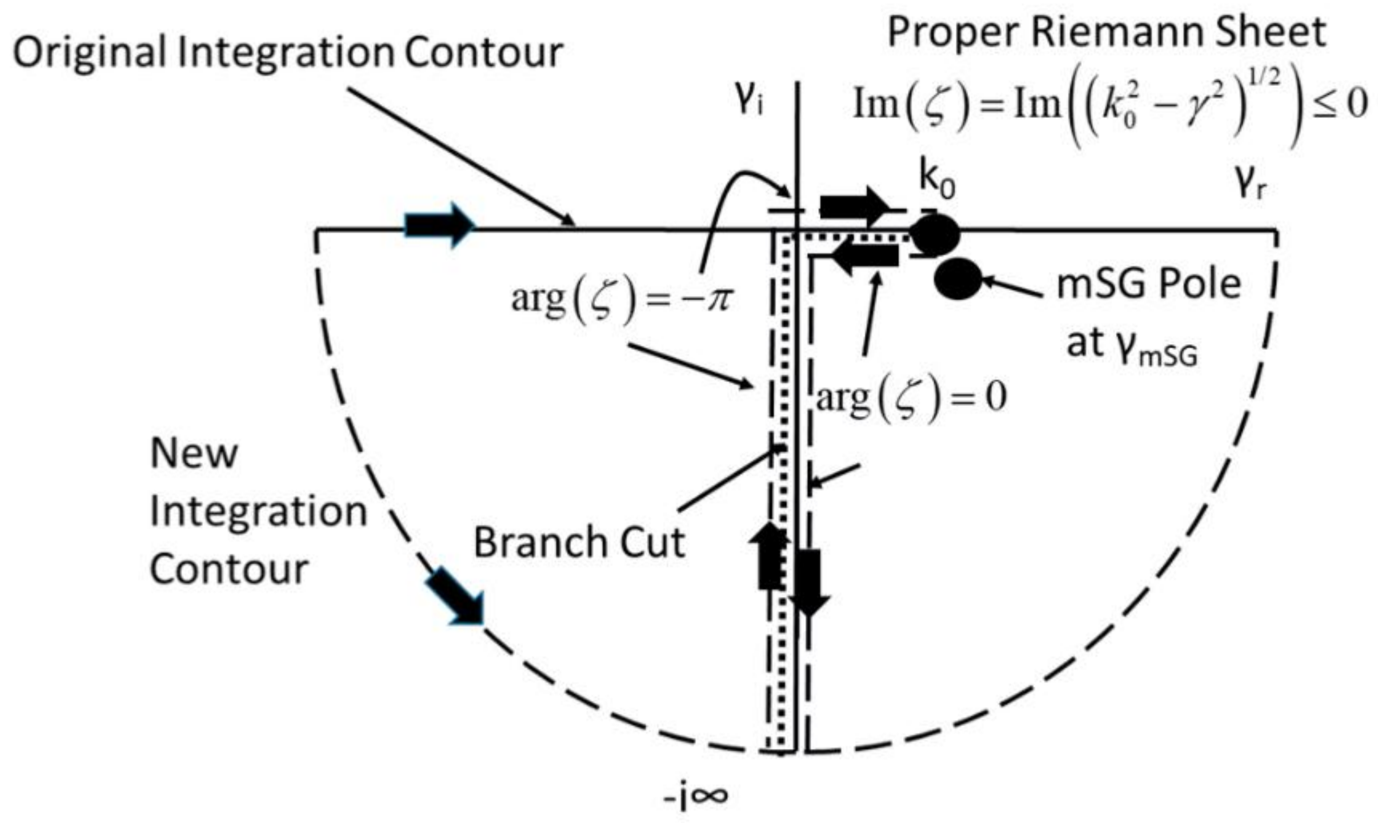
Powerpile Types

Coaxial Powerpile

A coaxial powerpile looks like a thermocouple; however, its hot junction and contact end are larger.

Two-Wire Powerpile

A two-wire powerpile has two cold junction leads that are covered with protective armour. Some have the same connecting nut as a thermocouple.



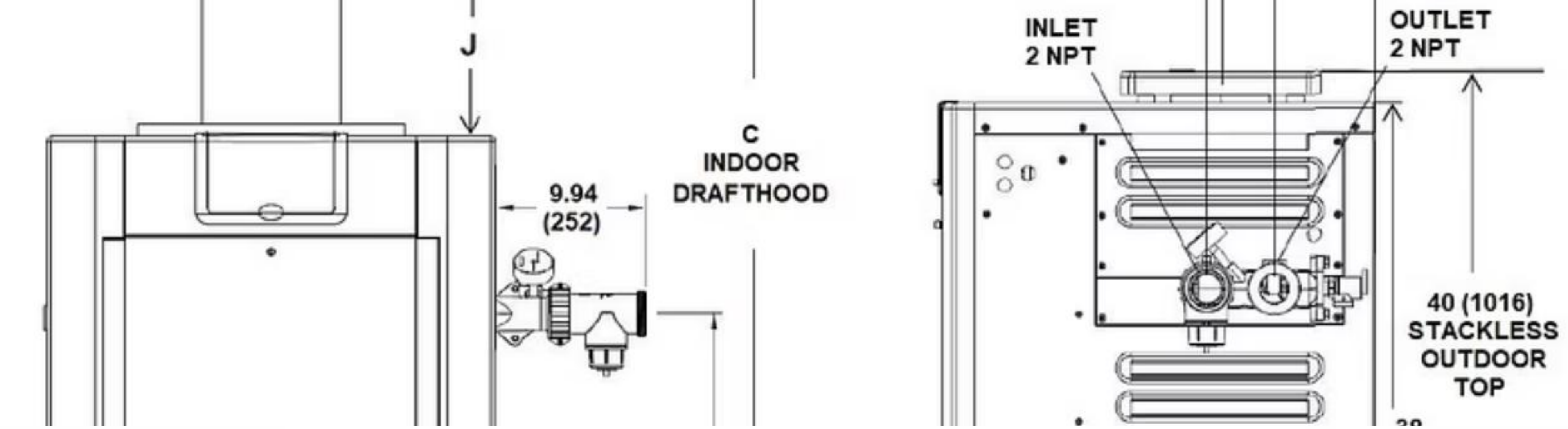
Pilot Flame Characteristics

Normal Pilot Flame

- Is mostly blue in color
- Burns steadily
- Envelops 0.375 to 0.5 inch of the powerpile tip

Undesirable Flame Characteristics

Characteristic	Cause
Hard, sharp flame	Too small a pilot orifice
Noisy, lifting, blowing flame	High gas pressure or excess primary air
Small, blue flame	Small or restricted orifice, low gas pressure, or a clogged pilot filter



Environmental Considerations

Outdoor Exposure

Because of the frequent application of self-contained/powered equipment, appliances can be subject to more outdoor environments, posing a greater risk of exposure to spiders, rodents, or generally dirty and contaminated areas.

Pool Heater Applications

A large number of residential pool heaters incorporate a standing pilot and thermopile system.

Service Considerations

Outdoor portable appliances are often subject to service problems related to plugged or restricted pilots due to the surrounding conditions of the pilot burner. Gas technicians/fitters need to pay special attention to these conditions.

Advantages of Millivolt Control Circuits

Self-Generated Power

The control voltage is self-generated - no external power source is required. Some applications such as fireplace might have 120 V systems and operate a fan motor.

Power Outage Resilience

The heating system can function even during electrical utility outages.

Lightweight Components

The low-voltage system uses lighter, less expensive components and is ideal for mobile applications.

Isolating Millivolt Circuits

1

Physical Isolation

Millivolt circuits must be physically isolated from higher voltage circuits

2

Prevent Contact

Must not operate with or come in contact with 24V or 120V circuits

3

Avoid Damage

Higher voltage will short out and damage millivolt equipment

In order to install, accurately and safely operate, and test millivolt circuits, they must be physically isolated from 24 V and 120 V circuits. Voltage from the conductors of the higher potential circuits will supply excessive voltage in the millivolt circuit, shorting out and damaging the equipment. Millivoltage circuits must not be mixed with full voltage circuits.

Testing Millivolt Circuits

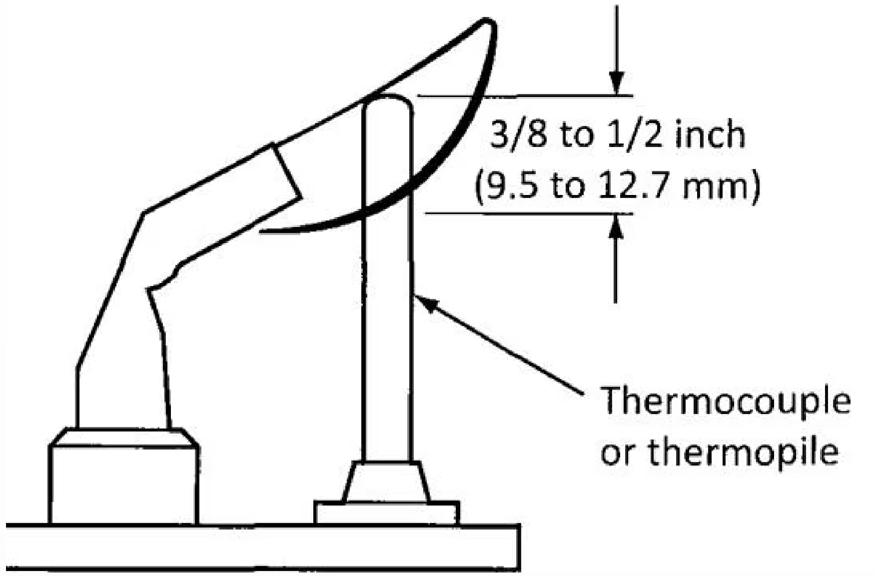
Required Equipment

Testing and troubleshooting circuits operating with a millivoltage power supply requires the use of a millivoltmeter.

Power Supply	Produces
Thermocouple	30 mV
Thermopile (also known as the powerpile)	up to 750 mV

Proper Positioning

To produce the correct voltage, position the thermocouple or thermopile correctly in a pilot flame with the proper flame characteristics, as shown in Figure 5-5.



Testing DC Power Supplies

Current Flow Direction

A thermocouple or thermopile produces DC current flow (in one direction). The direction of current flow determines the direction of needle movement.

Proper Connections

Be sure to connect the leads of the test meter correctly as some types of meters, especially analogue meters, are sensitive to polarity. Most digital meters will just give you a negative reading.

Flash Test

To avoid damage, connect one lead of the meter to the first test point and then momentarily touch the second lead to the second test point. Called a flash test, this test is performed to verify that the direction of needle movement is correct before you connect the second lead. If the needle moves backward, the polarity is reversed, so reverse the position of the test leads.

Digital Multimeters for Millivolt Testing

Advantages of Digital Multimeters

Most full functioning digital multimeters:

- will read a millivolt circuit; and
- are the most common testing device used with these systems.

Thermocouple Testing

A thermocouple:

- has an open circuit output of 30 mV; and
- can only be used to power a pilotstat device in a combustion safety circuit.

A thermocouple can be tested with:

- an open-circuit test; and
- a closed-circuit test.

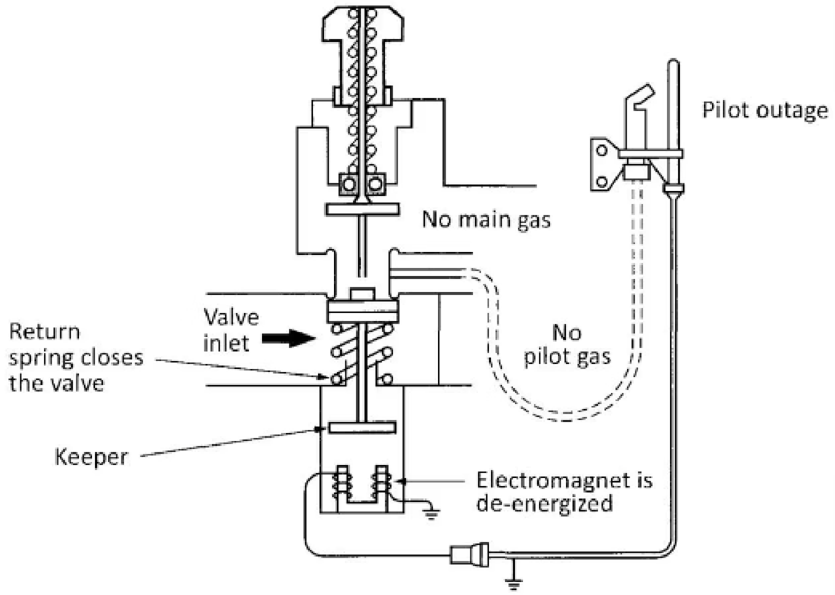


Figure 5-6 Thermocouple combustion safety system

Open-Circuit Test

Test Purpose

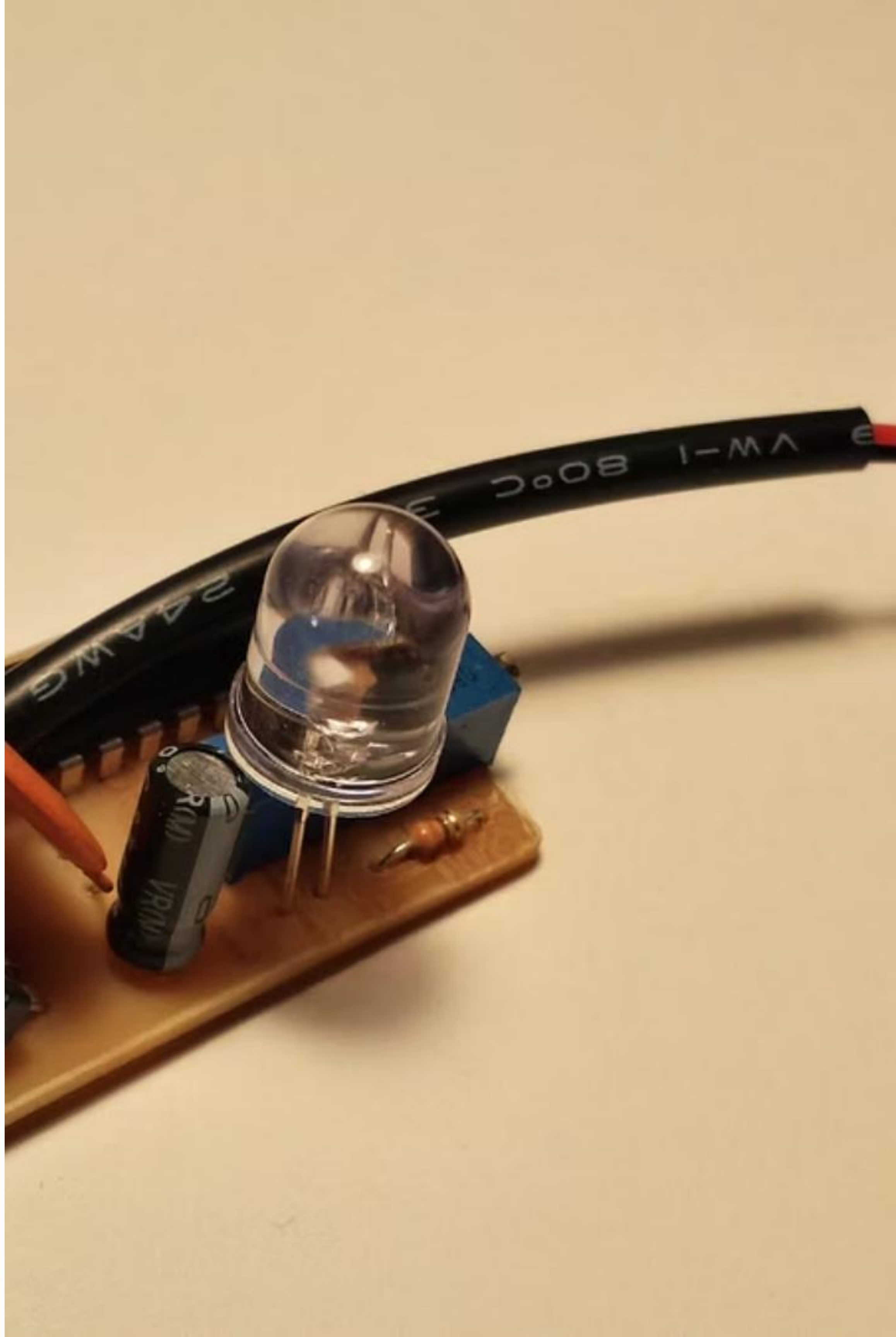
An open-circuit test shows the potential millivoltage that a thermocouple can produce when it is not under load.

Equipment Requirements

To perform this test, use a high-resistance meter. Most digital meters meet this requirement; however, only special analogue meters are suitable for this application. Always ensure that the proper meter is used for this test.

Test Preparation

Perform the open circuit test when the thermocouple is not under load. Therefore, before starting the test, disconnect the thermocouple from the pilotstat.



Open-Circuit Test Procedure

Select Meter Scale

Select a scale on the millivoltmeter suitable for reading a maximum 30 mV.

Connect Meter

Connect one lead of the meter to the outer copper conductor of the thermocouple and the other lead to the end of the inner conductor (watch polarity of meter).

Heat Thermocouple

With a pilot flame heating the hot junction of the thermocouple, it should read approximately 30 mV.

Evaluate Results

Replace the thermocouple if it produces less than 20 mV. Inspect the heated end for excessive wear and burned casing.

If it appears questionable, the best action is to replace the thermocouple.

Closed-Circuit Test

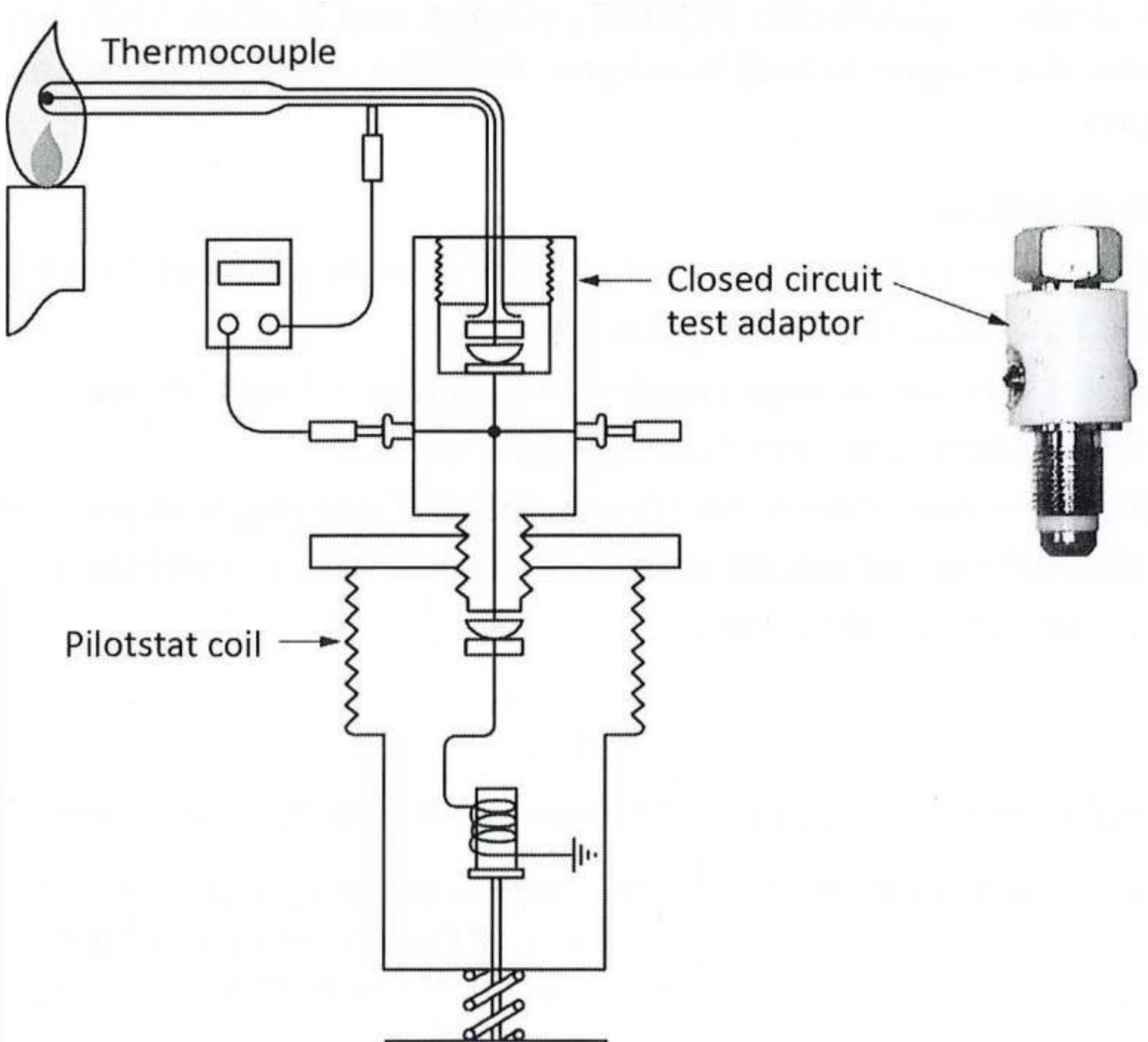
Test Purpose

A closed-circuit test shows the millivoltage that can be maintained when the thermocouple is powering a coil, usually the magnetic coil of a pilotstat device.

Perform the closed-circuit test when the thermocouple is connected to the coil in a pilotstat device. In order to connect the meter in parallel with the load/coil, use a thermocouple test adapter.

Test Benefits

This will test the performance of the thermocouple and show the millivoltage level that can be maintained under load. At the same time, you can test the pilotstat coil to determine its condition.



Closed-Circuit Test Procedure

Install Test Adapter

Disconnect the thermocouple from the pilotstat and install the test adapter.

Reconnect and Light

Reconnect the thermocouple to the top of the test adapter and relight the pilot burner.

Connect Test Leads

Connect one test lead to the outer conductor of the thermocouple and the other test lead to the side terminal on the test adaptor (watch polarity).

Read Meter

The meter should read 15 mV if the thermocouple is in good condition. Notice that this is approximately one-half of the open circuit voltage.

The thermocouple can produce a potential of 30 mV when not under load but can only maintain 15 mV while under load. If the closed-circuit voltage should drop to below 8 mV, replace the thermocouple.

Testing the Pilotstat Coil

Test Setup

It is easy to test the condition of the pilotstat coil with the test adaptor in place. You need a small current to develop the magnetic field required to hold the pilotstat valve open. Because the current flow is so small, it is easier to measure voltage.

Remember, there is a direct relationship between voltage and current. With a pilotstat coil, as the voltage becomes less, the magnetic field weakens. At some point, the pilotstat drops out and shut off the flow of gas.

Test Procedure

1. Connect one lead of the millivoltmeter to the copper conductor and the other to the terminal on the side of the test adaptor (check polarity). Under normal operation, the voltage reading is between 10 and 15 mV.
2. Blow out the pilot gas and allow the thermocouple to cool. As it cools, watch the millivoltmeter and notice that the reading is slowly decreasing.
3. The coil of the pilotstat should create enough magnetic field to hold the valve open until the millivoltage drops between 5 and 2 mV.

Interpreting Pilotstat Coil Test Results

Weak Coil

If the coil drops out with more than 5 mV, it is weak and should be replaced.

Sticking Valve

If the coil holds the valve open with less than 2 mV, the valve is sticking and should be replaced.

Safety Requirement

This drop out of the coil should take place within 90 seconds from flame failure to meet the requirements of CSA B149.1.

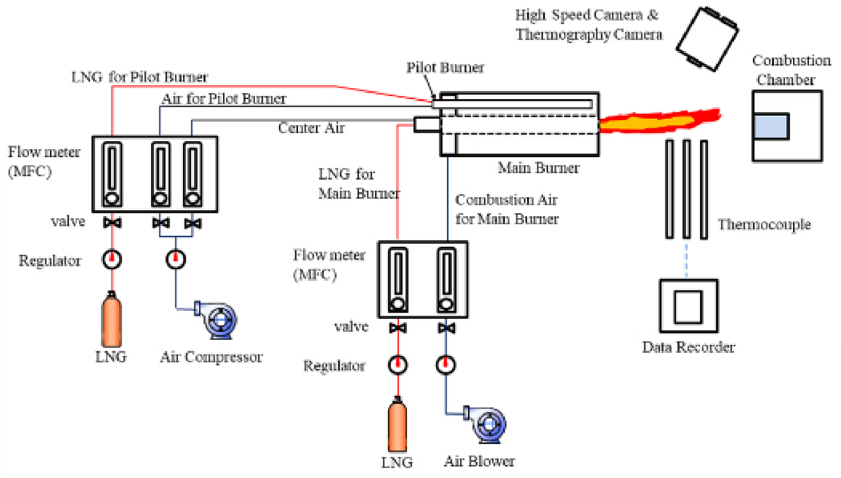
Checking for Pilot Flame Failure

Common Service Problem

Loss of pilot flame is a common service problem that you can check with a millivoltmeter and test adaptor.

Comprehensive Testing

You should check the thermocouple, pilotstat coil, and dropout time to make sure all problems are identified, then conduct an open circuit test as discussed previously.



Proper testing helps identify the root cause of pilot flame failures.

Thermopile Testing

Common Problems

Most of the problems in millivoltage circuits result from increases in resistance that reduce the current flow to a point where the gas valve coils do not operate.

The following are the causes of these resistances:

- loose wiring connections;
- corrosion to terminals and connectors;
- poor wire splices; and
- excessive wire lengths.

Testing Approach

The easiest way to identify where increases in resistance have developed is to measure the millivoltage drop across each component in the electrical circuit.

The key to successful troubleshooting and testing of thermopiles is to know the normal millivoltage readings to expect across each component of the circuit and to recognize excessive readings. Excessive millivoltage drops indicate excessive resistance.

Thermopile Output Types

250 mV Output

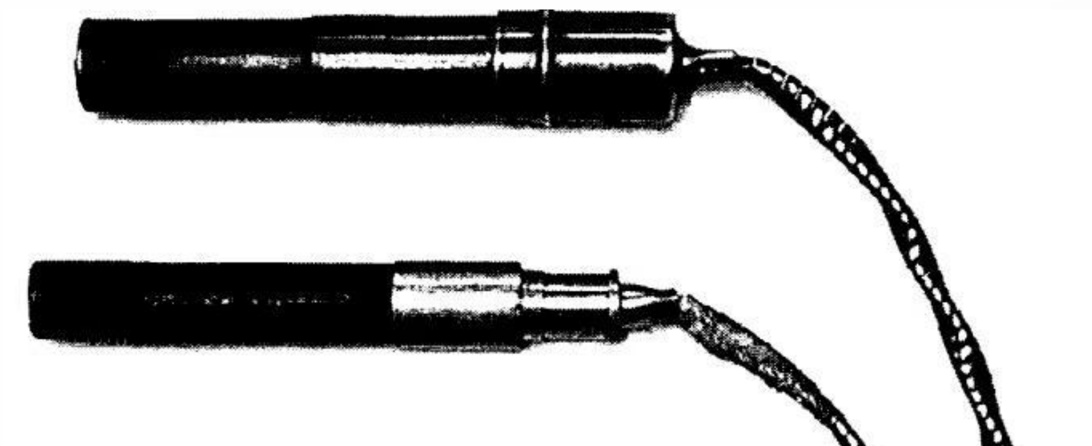
Used for simple control circuit consisting of a switch and a gas valve

500 mV Output

Has enough electrical power to operate control circuits with a gas valve, limit switch, and thermostat with long wire leads (maximum 30 ft or 9 m)

750 mV Output

Is always used when it is necessary to power the control circuit and the combustion safety circuit in parallel



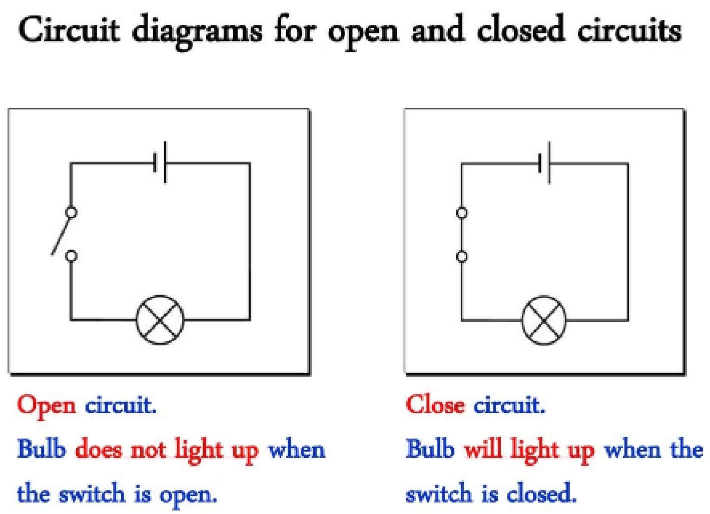
Understanding Circuit Voltage

Open Circuit Voltage

The output voltages listed above are approximate maximum voltages that the devices produce during an open-circuit test. Without a completed circuit, the voltage is static and at its maximum level, just as the pressure in a water pipe is static and maximum when there is no flow.

Closed Circuit Voltage

When a circuit is closed and current begins to flow throughout the circuit, a new voltage drop reading will occur related only to the voltage loss across the parallel circuit components.



The difference between open and closed circuit voltage is critical for understanding millivolt system operation.

Source Resistance Series Circuit

Internal Resistance

All DC voltage sources have an internal or source resistance that can be observed but not directly measured. To observe the source resistance, a second resistance (load) must be connected through a completed circuit.

Voltage Drop Laws

To understand the change in readings between the open and closed-circuit tests and how they relate to the source resistance, it is important to remember the voltage drop laws. The sum of all the voltage losses will be equal to the voltage output.

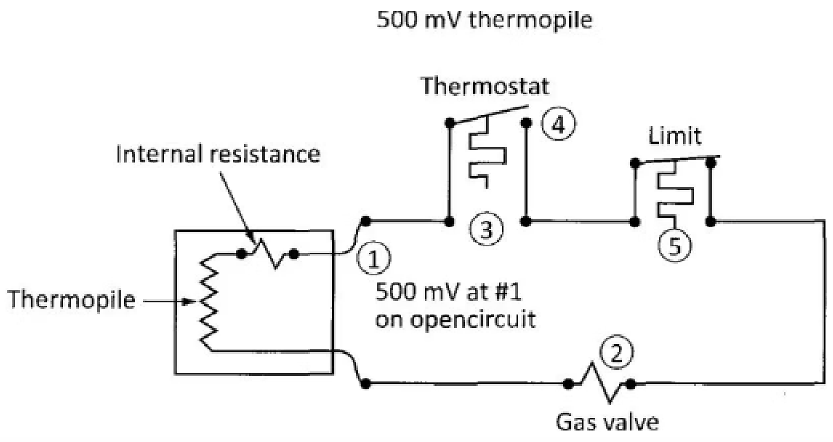


Figure 5-10 500 mV open control circuit

Thermopile Test Points

1 **Thermopile Output**

Measures the total available voltage from the thermopile

2 **Across Gas Valve**

Measures voltage drop across the gas valve coil

3 **Across Thermostat and Wire**

Measures combined voltage drop of thermostat and connecting wires

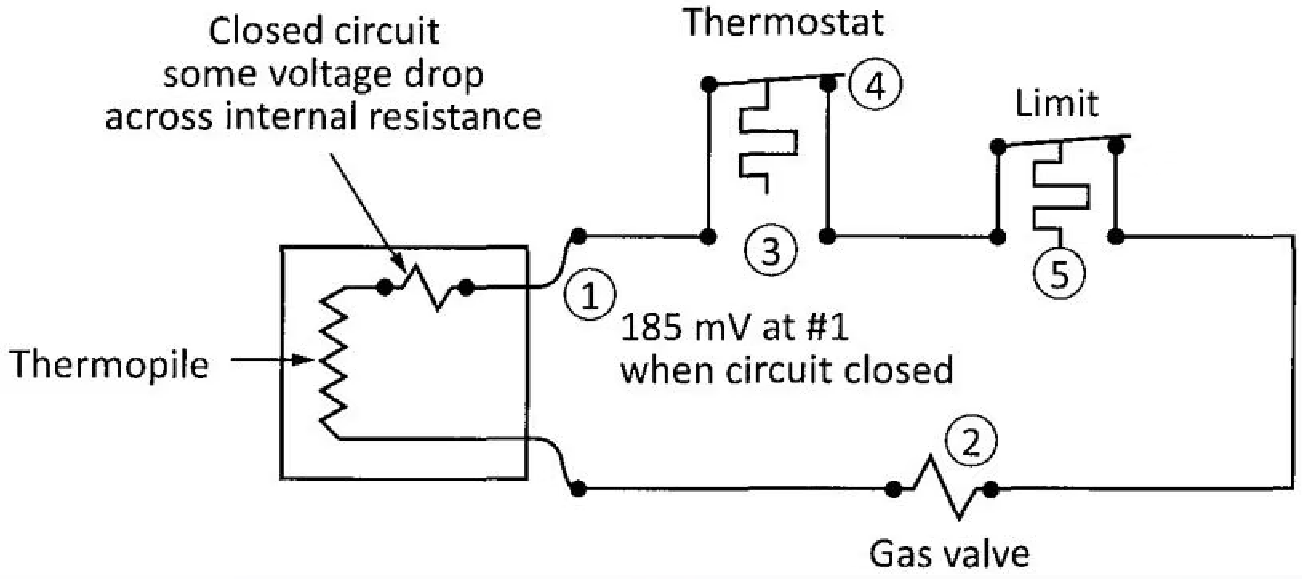
4 **Across Thermostat**

Measures voltage drop of just the thermostat

5 **Across Limit Switch**

Measures voltage drop across the limit switch

Figure 5-11
500 mV closed control circuit



Closed Circuit Voltage Example

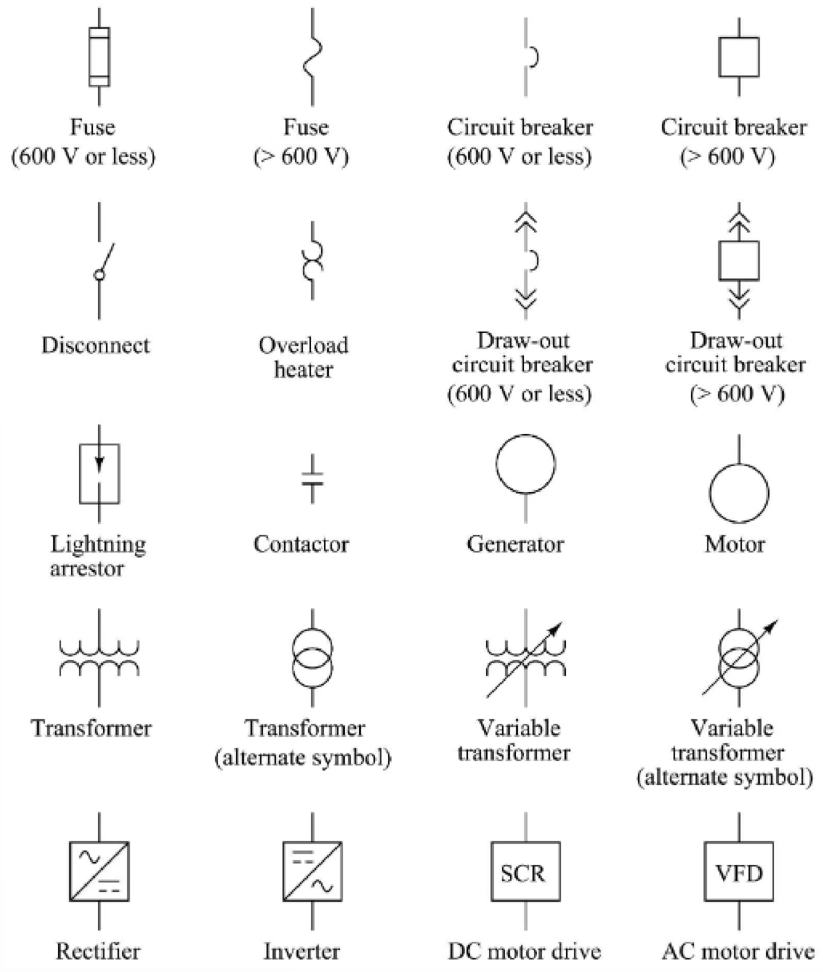
Voltage Distribution

When the circuit is closed, the meter reading at location #1 might show a 185 mV, which would be the voltage drop across all the external resistances. Therefore, the internal resistance of the source, which cannot be measured, would be 315 mV.

We can conclude that 315 mV is the voltage drop caused by the internal resistance at this particular amperage.

Voltage Calculation

500mV	185mV	315mV
(open test)	(closed test)	(internal resistance)



Understanding voltage distribution helps diagnose system problems.

Effect of Component Resistance

Resistance Changes

Suppose that one of the components, such as the thermostat, was to have a higher resistance. This would increase the resistance in the control circuit as a whole, causing the current flow to be reduced.

Impact on Readings

This reduced circuit amperage would result in a lower voltage drop created by the internal resistance of the thermopile, and the closed-circuit meter reading at location #1 would increase.

Example with Heat Anticipator

For example, the circuit, which included a thermostat with a heat anticipator, might have the following readings:

500mV (open test)	240mV (closed test)	260mV (internal resistance)

Reading Voltage with a Millivoltmeter

Test Procedure

All readings are taken in parallel across the components and with the thermostat calling for heat.

A typical reading for Figure 5-12 would be:

Meter position	Test location	Reading
Meter position 1	Thermopile output	253 mV
Meter position 2	Gas valve coil	140 mV
Meter position 3	Thermostat and wire	110 mV
Meter position 4	Thermostat	80 mV
Meter position 5	High limit	3 mV
Total losses (2 + 3 + 5)		253 mV

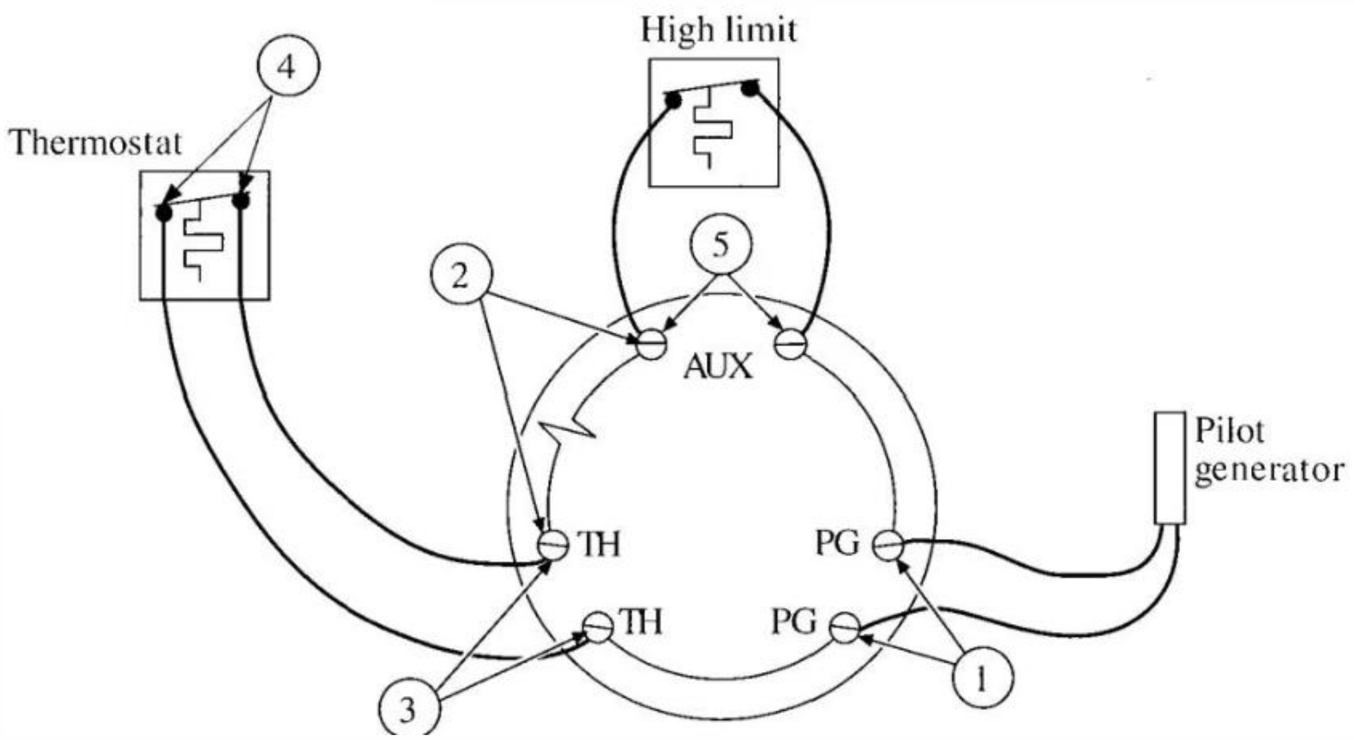


Figure 5-12 Reading voltage with a millivoltmeter

Characteristics of 500 mV Thermopiles

Simple Control Circuit

Figure 5-13 displays a simple control circuit consisting of a thermostat, limit switch, gas valve, and a 500 mV thermopile. Since there is no pilotstat coil, a loss of flame does not cause interruption to the pilot gas flow.

Voltage Distribution

The voltage of the source distributes itself across the resistive components that make up the load. The sum of all the voltage drops throughout the system must be equal to the output of the source.

Figure 5-13 provides an explanation of the maximum millivoltage readings that should be expected on a 500 mV circuit.

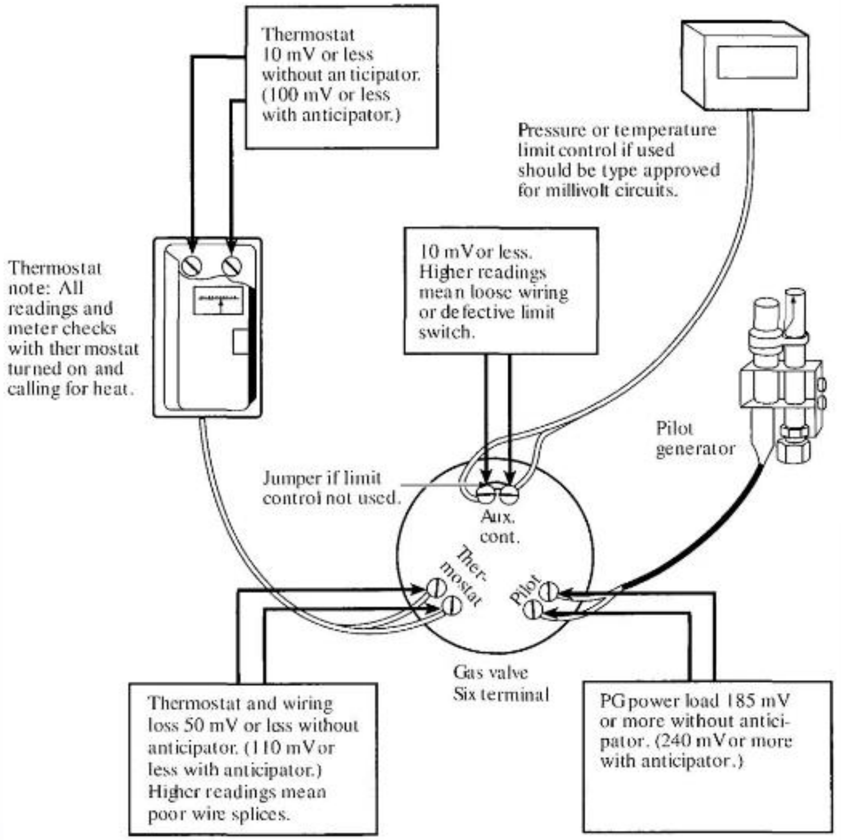
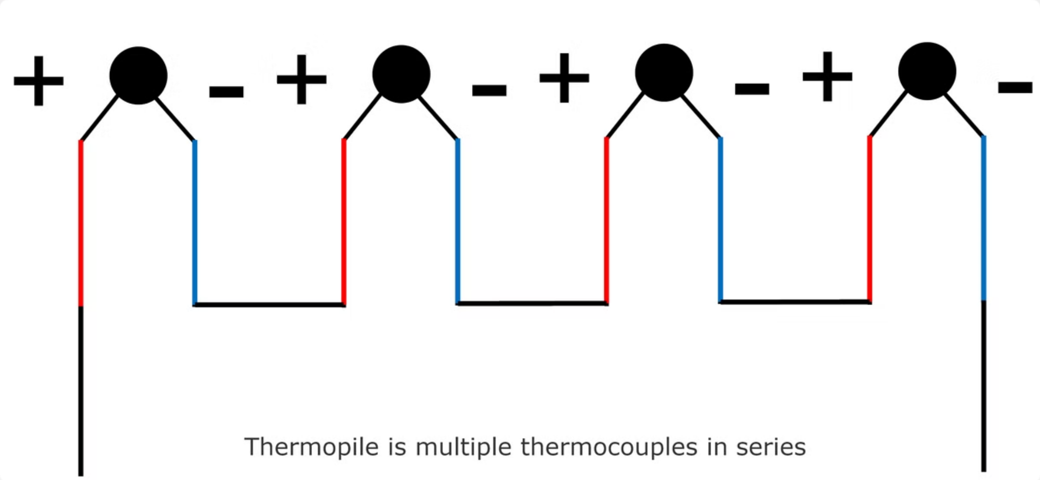


Figure 5-13 Typical voltage readings on a simple millivoltage control

Testing 500 mV Circuits



Preparation

Turn off the gas and clean the thermopile and pilot burner before starting the test.

Determine Valve Opening Voltage

Connect the test leads to position 2, light the pilot burner, and watch the meter to determine the valve open (V.O.) reading. A typical reading would be 60 mV.

Measure Maximum Output

Allow the thermopile to reach maximum output and record at position 1. A typical output value would be 253 mV. This may take approximately four minutes.

Check Valve Coil Power

Check the power across the valve coil (position 2). A typical reading would be 140 mV.

Valve Operation Requirements

Safety Margin

For the valve to open consistently, some safety margin is required above the power needed to open the valve. This margin should be large enough to ensure a consistent opening, but small enough to allow the longest service out of the thermopile.

If 30 mV is considered a good safety margin, this example provides 140 - 60 = 80 mV over what is required to open the valve. Since some valves may require as much as 120 mV to open, the voltage across the valve coil must be 150 mV or more.

Valve Coil Issues

If the valve does not open by 150 mV, the valve coil is faulty and must be replaced.

The readings across the coil can be affected by:

- Low output from the thermopile; and
- Satisfactory output from the thermopile but a high mV drop in the rest of the system due to faulty splices, excessive length of thermostat wire, or faulty thermostat or limit switches.

Checking Wire and Component Losses

1

Check Total Wire Loss

This includes the wire and thermostat loss. A typical value would be 112 mV. This reading can be 50 mV or less with no heat anticipator or 110 mV or less with a heat anticipator.

2

Check Thermostat Loss

A typical value would be 80 mV. These readings are 8 mV or less with no heat anticipator or 100 mV or less with a heat anticipator.

3

Determine Thermostat Wire Loss

Subtract the reading at position 4 from that at position 3. Position 3 - Position 4 = Thermostat wire loss. For example, 112 - 80 = 32 mV.

4

Check Limit Losses

This includes the limit and its wire. Usually the reading is close to zero (2 mV, for example).

If the wire loss is over 60 mV, check the visible line for poor splices which can cause over 100 mV losses.

Verifying Test Readings

Validation Formula

Ensure you have taken the correct readings:

Reading 2 + Reading 3 + Reading 5 = Reading 1

If there is a difference of more than 15 mV, recheck each reading.

Summary of Readings

Test location	Position	Reading
V.O.	2	60 mV
Thermopile output	1	254 mV
Valve coil	2	140 mV
TH and wire	3	112 mV
Thermostat	4	80 mV
Limit and wire	5	2 mV

Troubleshooting Example 1

Problem Description

The furnace does not always come on, but the gas valve opens when tapped. The thermostat is equipped with a heat anticipator.

Test Readings

Test location	Position	Reading
V.O.	2	75 mV
	1	269 mV
	2	77 mV
	3	190 mV
	4	30 mV
	5	2 mV

Diagnosis

The above readings indicate that the valve opens at 75 mV but only increases to 77 mV at full output. This is too low.

The reading at 3 across the wiring and thermostat is 190 mV, which is high.

Subtracting 30 mV from the 190 mV indicates a wire loss of 160 mV. This must be a result of bad wiring contacts or a poor splice in the wiring.

Solution

To correct this, clean the terminals and solder the splice.

Troubleshooting Example 2

Problem Description

The furnace will not come on. The thermostat has a heat anticipator.

Test Readings

Test location	Position	Reading
V.O.	2	80 mV
	1	260 mV
	2	75 mV
	3	110 mV
	4	70 mV
	5	75 mV

Diagnosis

The problem is that the reading at 2 is 5 mV below that required to open the gas valve. Examination of the above readings shows that the limit switch reading at 5 is very high, suggesting a faulty limit.

Solution

If this is corrected, there is sufficient voltage drop across the gas valve at 2.

Testing Tip

To obtain the V.O. reading when the power at 2 is too low, jumper the thermostat terminals. This makes the 110 mV in the thermostat and wire circuit available to help open the valve. Remove the jumper as soon as you get the V.O. reading.

When you jumper the thermostat terminals, the 110 mV drop in the thermostat and wire becomes zero, and the 110 mV becomes available to the rest of the system; therefore, the valve opens. You could mistakenly think the thermostat or wire is at fault.

Characteristics of 750 mV Thermopiles

Dual Circuit Applications

Use a 750 mV thermopile whenever there is a need to power two circuits such as a control and combustion safety circuit.

Figure 5-14 shows both types of circuits. The safety circuit consists only of a pilotstat coil, while the control circuit consists of a thermostat, limit switch, and gas valve coil.

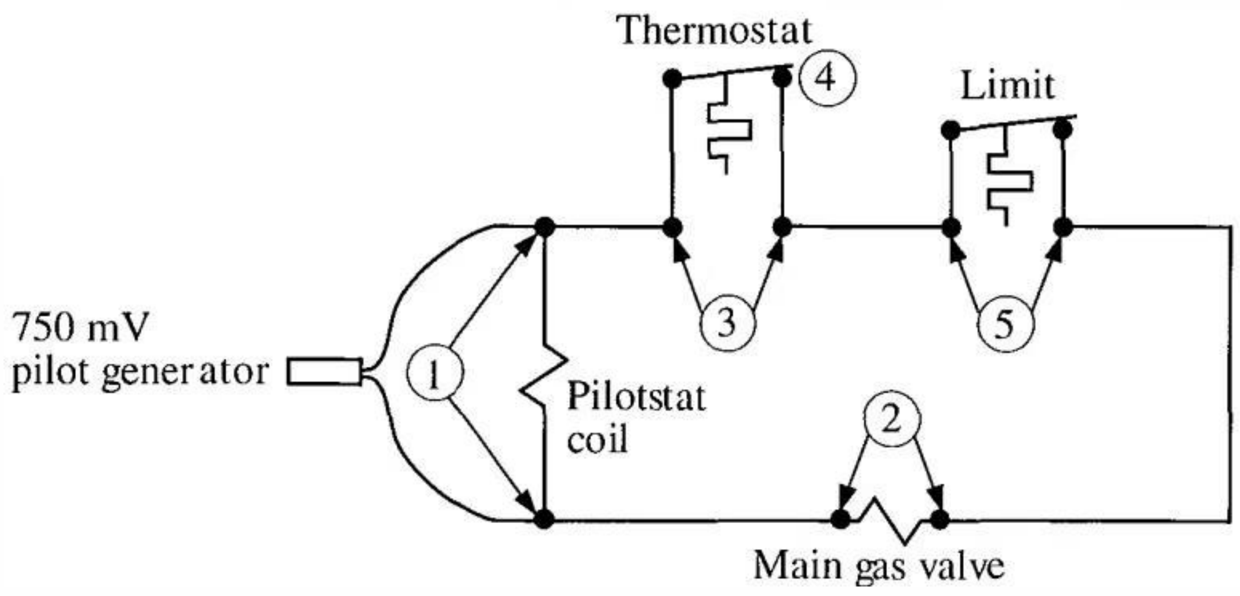


Figure 5-14 Testing millivoltage control systems with combustion safety and control circuits

Source Resistance in a Parallel Circuit

Parallel Circuit Operation

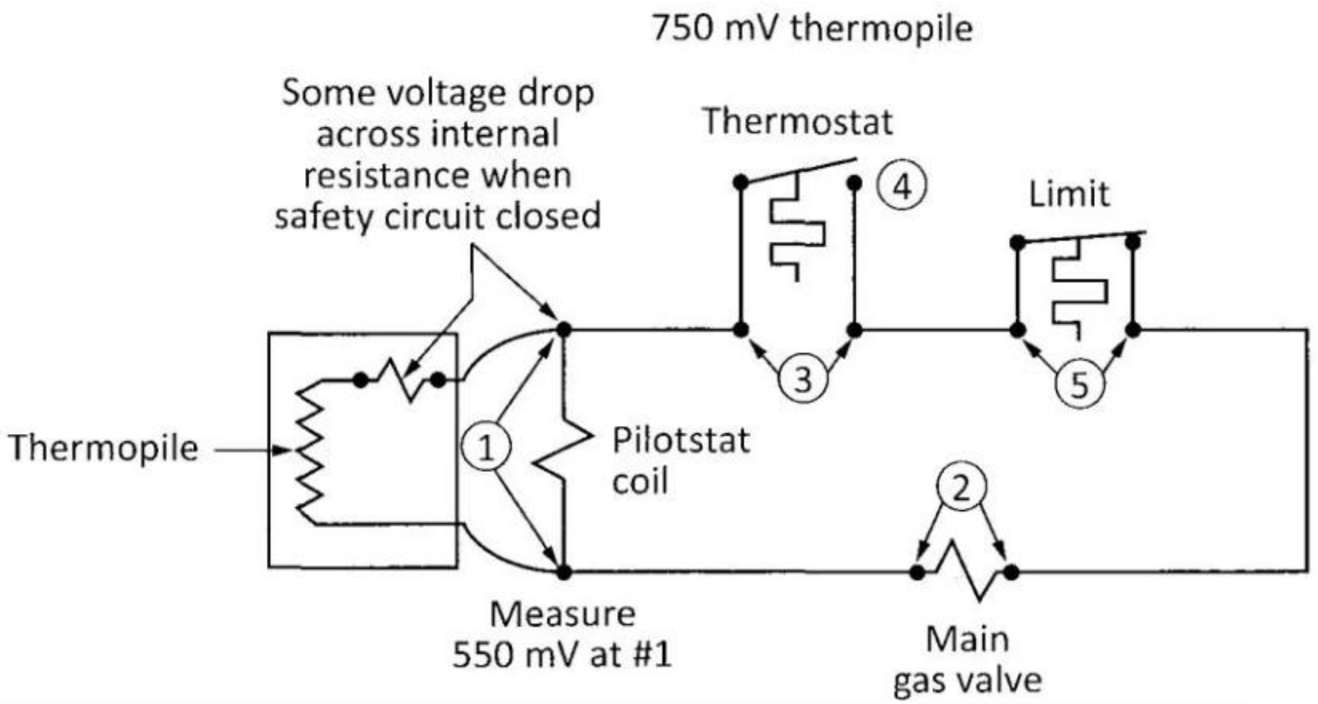
When the power pile energizes a safety circuit, the latter is wired in parallel to the control circuit so that it may be continuously energized.

Although the open circuit potential of the thermopile may be 750 mV when it is connected to the equipment, there will always be a closed pilotstat circuit, in which the internal resistance of the thermopile is again part of the equation.

Voltage Distribution

The voltage drop across the pilotstat coil measures approximately 550 mV; therefore, the internal resistance is causing a loss of approximately 200 mV. The internal resistance must be about 1/3 of the pilotstat resistance.

Figure 5-15
750 mV open control circuit



Parallel Circuit Effects

Resistance Changes

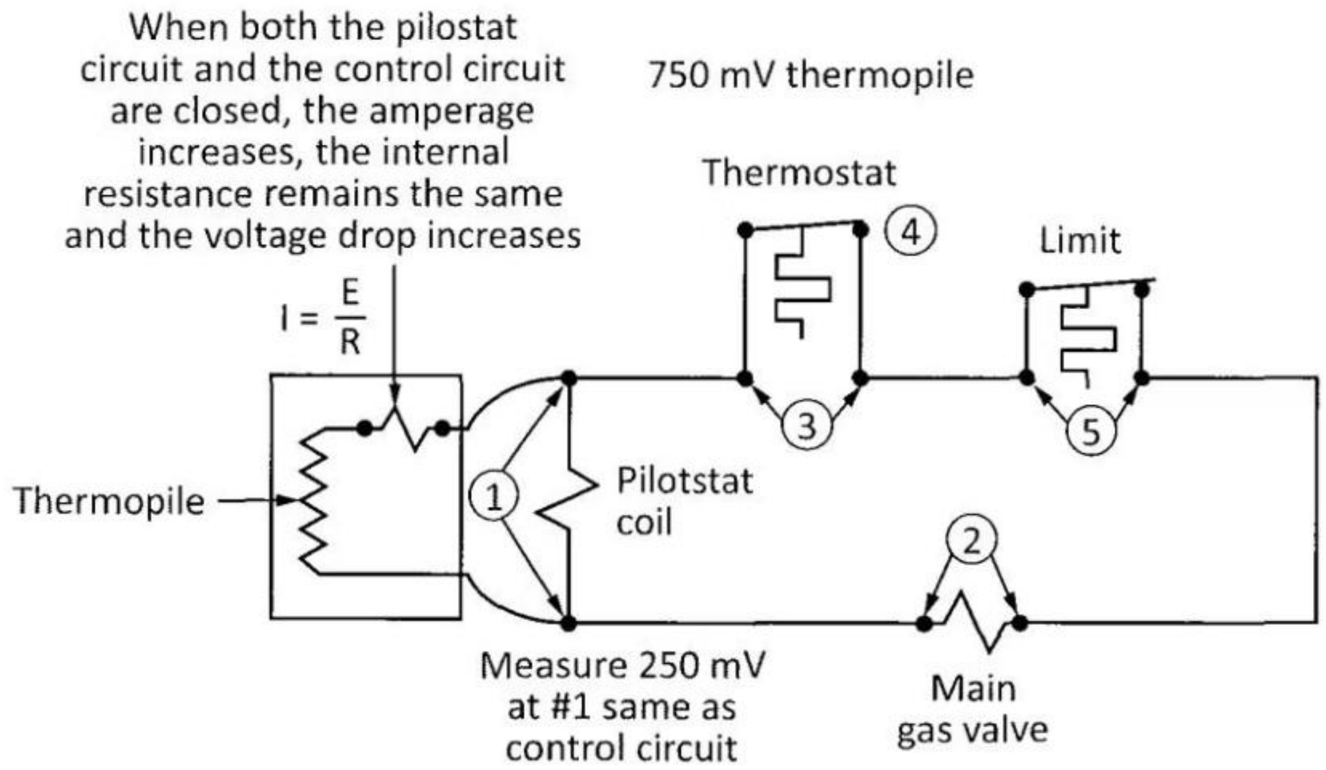
When the control circuit is closed and the main gas valve is energized, a parallel circuit from the thermopile connections is created.

Since parallel connected circuits create a lower total resistance, the total amperage in the overall circuit will increase. As the internal resistance of the thermopile does not change, the increased amperage will create an increase in the internal voltage drop.

Voltage Availability

Therefore, when the control circuit is made, the voltage drop across the internal resistance increases, and the voltage available to the control and safety circuits decreases.

Figure 5-16
750 mV closed control circuit



750 mV System Voltage Readings

Open Circuit Output

The open circuit output of the thermopile is 750 mV; however, when it is connected to the pilotstat, the millivoltage reading at 1 is reduced to approximately 550 mV.

Closed Circuit Output

When the thermostat contacts on the control circuit close, the millivoltage reading across 1 is reduced to approximately:

- 185 mV if the thermostat has no heat anticipator; or
- 240 mV if the thermostat has a heat anticipator.

Consistent Values

These are the same values as found on the control circuit of the 500 mV systems. The test values 1 to 5 are the same for both the 500 mV and the 750 mV systems.

Testing 750 mV Circuits

Test the Pilotstat Coil

With the thermostat calling for heat and the test meter leads across the thermopile terminals in position 1, depress the manual reset button on the pilotstat and light the pilot.

Observe the Pilot Flame

When the millivoltage reading is at 170 mV, release the manual reset button on the pilotstat and observe the pilot flame.

Evaluate Coil Performance

If the valve does not hold in and the pilot flame goes out, replace the coil. If the pilotstat holds in, blow out the pilot and watch the test meter. If the coil drops out over 140 mV, replace the coil.

Test Control Circuit

For testing of the control circuit readings 1 to 5, refer to the test procedures for the 500 mV control systems.

Millivolt Thermostats

Purpose and Application

Millivoltage thermostats are used with self-powered heating control systems. The heat of the pilot flame acting on the thermopile (pilot generator) produces the control system power. This type of thermostat often has a label indicating that it is only for use with millivolt systems.

Voltage Considerations

As detailed, thermopiles produce 250, 500, or 750 mV. 750 mV is about one-half the output of a 1.5 V D-size, dry-cell battery.

The gas technician/fitter must always ensure that the thermostat for a particular installation is sized according to the thermopile or power generator used. The voltage rating for a dedicated millivolt thermostat is usually 0 to 1.5 V DC.

Figure 5-17
Self-powered heating control system components

Millivolt thermostats are specifically designed for low-voltage applications.

Thermostat Compatibility

Compatibility Issues

If a 24 V thermostat is used on a millivolt system, it may have excessive resistance and cause too great of a voltage loss. Alternately, if a dedicated millivolt thermostat is used on a 24 V AC system, the thermostat will be damaged.

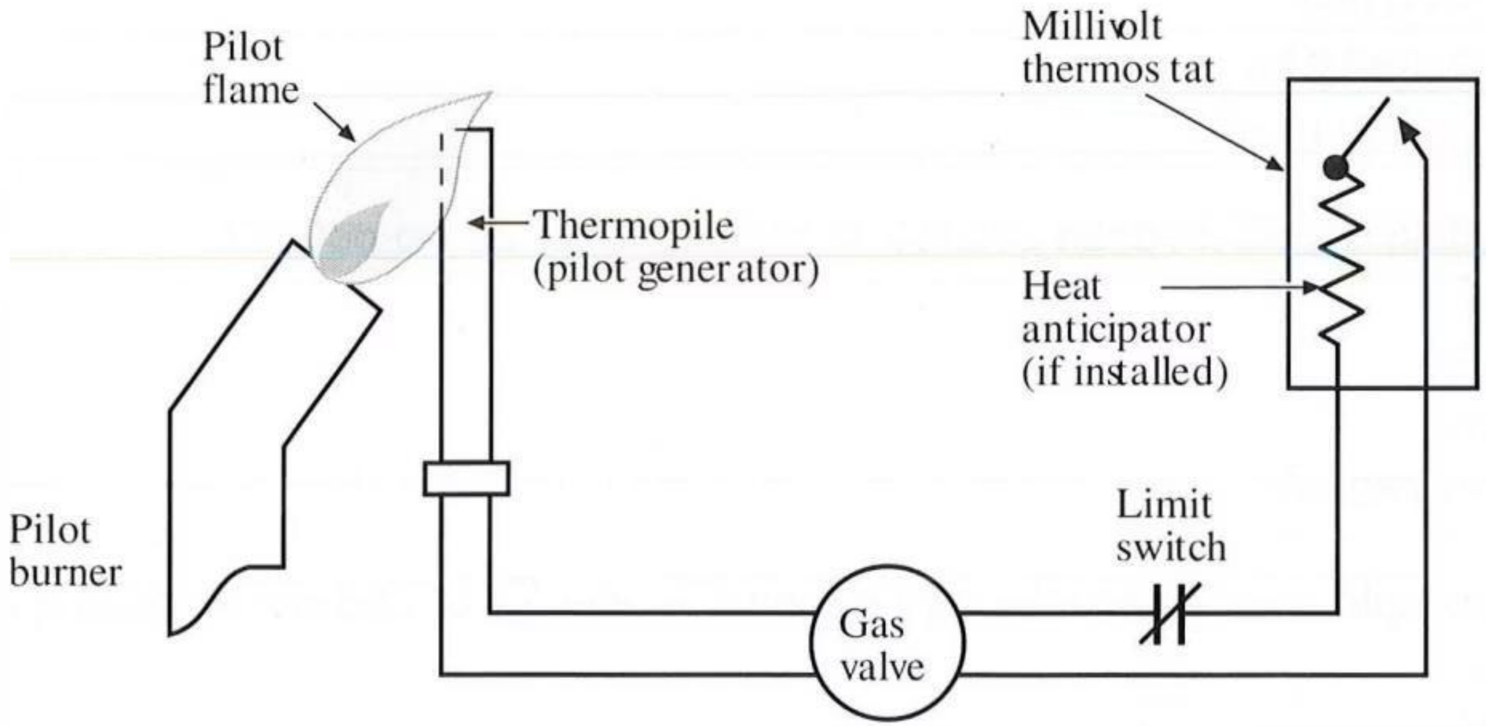
Digital Thermostats

Most digital thermostats are rated for use on 24 V AC or millivolt systems as the internal thermostat functions run off the backup batteries when wired for millivolt usage.

Power Requirements

The powerpile used must produce sufficient power to:

- operate the gas valve; and
- overcome total system electrical resistance, including the heat anticipator if one is installed in the thermostat.



Self-Powered Heating Control System Components

Pilot Burner

Provides the flame that heats the thermopile

Thermopile or Pilot Generator

Converts heat energy to electrical energy

Diaphragm Gas Valve

Includes a safety shut-off mechanism

Limit Switch

Provides temperature safety control

Millivolt Thermostat

May sometimes include a heat anticipator

Wire Runs

Connect the devices in the system

Wiring Requirements

Installation Guidelines

The gas technician/fitter must ensure that the correct type and gauge of wiring is used when installing self-powered control systems.

It is also important not to exceed the maximum recommended length for wiring runs specified by the manufacturer of the equipment in order to stay within system total resistance limits.

Wire Gauge Guidelines

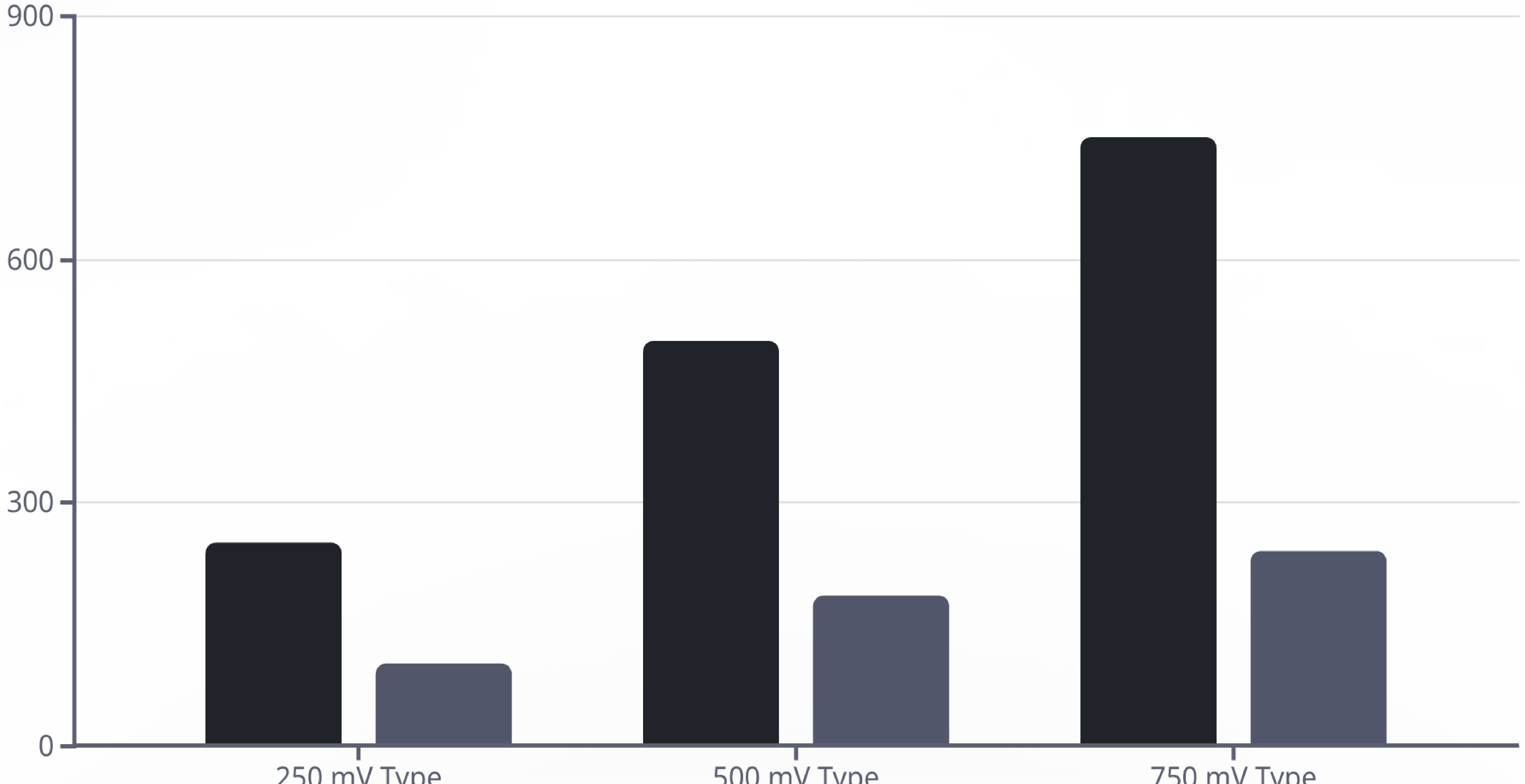
The following guidelines are for runs of 2-wire control system cables.

Note: Some manufacturers recommendations may differ, in which case their recommendations must be followed.

Runs up to	Use
30 ft (9 m)	No. 18 AWG minimum
50 ft (15 m)	No. 16 AWG minimum
80 ft (24 m)	No. 14 AWG minimum

Review: Thermocouple Basics

Review: Thermopile Voltage Outputs



Review: Pilot Flame Characteristics

Proper Pilot Flame

A normal pilot flame is mostly blue in color, burns steadily, and envelops 0.375 to 0.5 inch of the powerpile tip.

Improper Pilot Flame

Undesirable flame characteristics include hard sharp flames (too small orifice), noisy lifting flames (high pressure/excess air), or small blue flames (restricted orifice/low pressure).

Proper Positioning

The thermocouple or thermopile must be correctly positioned in the pilot flame for optimal voltage generation and system operation.

Review: Testing Equipment

Proper testing equipment is essential for diagnosing millivolt system issues. Digital multimeters, thermocouple test adapters, and specialized testing kits allow technicians to accurately measure voltage at various points in the system and identify problems.

Review: Common Troubleshooting Issues

160 mV

High Wire Loss

Indicates bad wiring contacts or poor splices

75 mV

High Limit Reading

Suggests a faulty limit switch

8 mV

Minimum Closed Circuit

Thermocouple replacement threshold

90 sec

Maximum Shutdown Time

Required safety response time

Understanding these key values helps technicians quickly identify and resolve common issues in millivolt systems. Regular testing and maintenance can prevent many of these problems before they cause system failure.

Summary of Millivolt Systems

Understanding Generation

Thermocouples and thermopiles convert heat to electrical energy

Testing Procedures

Proper testing methods ensure reliable system operation

Troubleshooting Skills

Identifying and resolving common issues in millivolt systems

System Maintenance

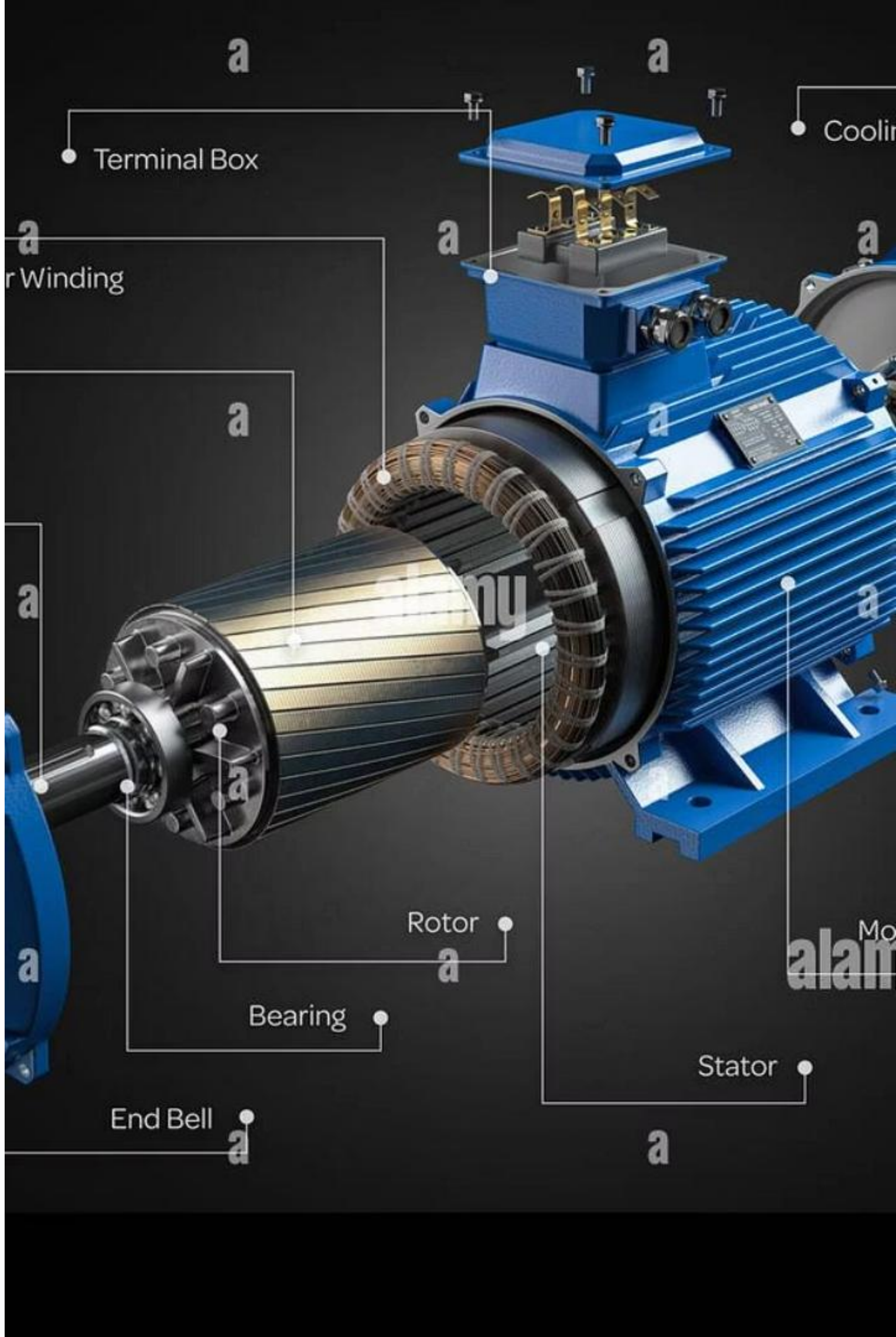
Regular maintenance ensures long-term reliability

Millivolt systems provide a reliable, self-powered solution for gas appliances, especially in off-grid applications. Understanding how these systems generate and use small DC voltages is essential for gas technicians and fitters. Proper testing, troubleshooting, and maintenance procedures ensure these systems operate safely and efficiently.

CSA Unit 12

Chapter 6
Electric Motors: Components, Operation, and Applications

Electric motors are essential components in various mechanical systems, converting electrical energy into mechanical energy. This presentation explores the construction, operation, and applications of different types of electric motors, with a focus on their components, nameplate information, and protection devices.



Key Motor Components

Stator

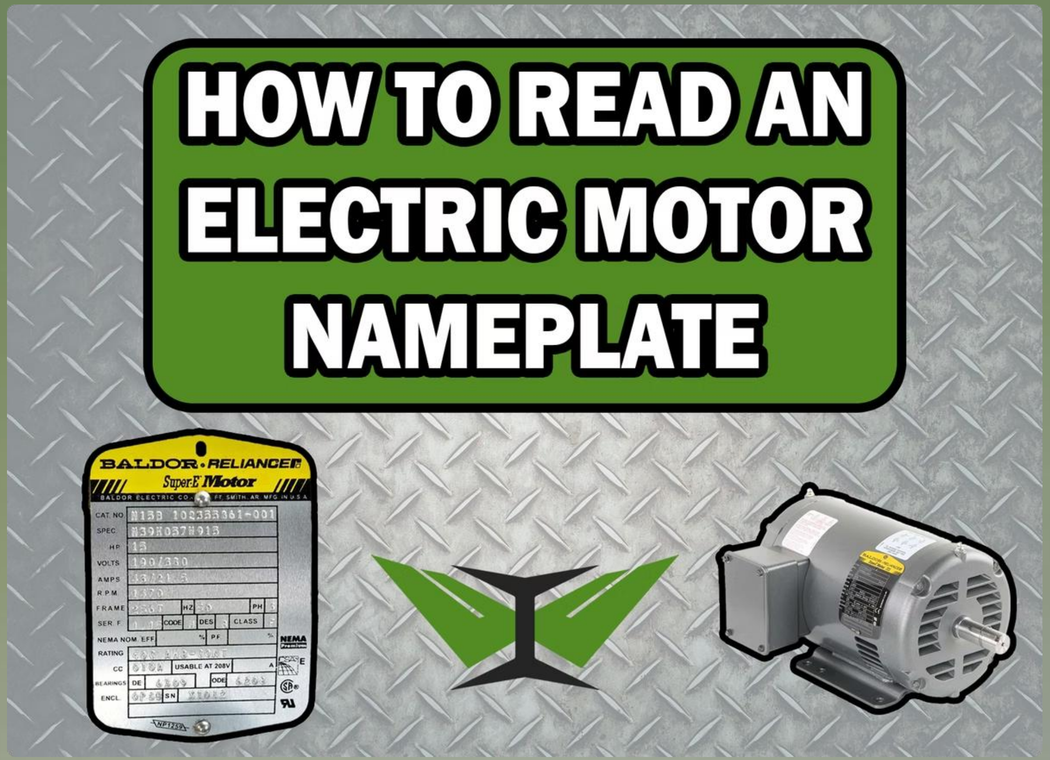
The stationary part of a rotary system, found in electric generators, electric motors, sirens, or biological rotors. It consists of two or more electromagnets and their windings, usually cylindrical in shape.

Temperature-sensing device

Also called motor thermostat, this component directly senses the motor winding temperature to protect the motor from overheating.

Rotor

The rotating part mounted on a shaft in the center of the stator. It has a laminated iron core containing aluminum or copper rods or bars along its outer surface.



Motor Nameplate Information

Electric motors have nameplates that provide gas technicians and fitters with valuable information for selecting and installing a motor.

Note: Do not remove or deface nameplates.

Thermal Protection

Describes the motor's over temperature protection. Many fractional horsepower motors have built-in thermal protection.

Type and Application

Indicates the motor type (e.g., split-phase) and its intended use (e.g., fan and blower).

Model Number

Set by the manufacturer for identification purposes.

More Nameplate Information

Horsepower (HP)

Rated power output of the motor (e.g., 1/3 for a fractional horsepower motor).

Speed (RPM)

Full-load speed in revolutions per minute (e.g., 1725 rev/min).

Voltage (V)

Operating voltage (e.g., 115V or sometimes dual voltage like 115/230V).

Full-Load Amperage (F.L.A)

Also known as RLA (rated-load amperage), refers to the approximate current drawn when developing rated horsepower.

Additional Nameplate Information

Frame Sizes (FR.)

Classified by diameter, used to obtain frame dimensions, mounting bolt distances, and shaft specifications.

Frequency: Designed to operate on a specific AC voltage frequency (typically 60 Hz).

PH: Specifies the phases of the motor (e.g., "1" indicates a single-phase motor).

LRA (Locked Rotor Amperage)

The amount of current the motor will draw at the moment of starting.

INS.CL: Indicates the class of insulation (e.g., B class is 130°C), representing the thermal breakdown resistance temperature of the windings.

MAX AMB: Maximum ambient temperature (e.g., 40°C) at which the motor can operate without overheating.

Service Factor (S.F)

The amount of excess short-term current (load) a motor can handle (e.g., 1.35).

Bearings (BRG.): Typically sleeve bearings or ball bearings for fractional and sub-fractional horsepower motors.

Date Code: Indicates when the motor was manufactured.

Motor Applications and Types

Application	Types of motors	Comments
Shaft-mounted fans and blowers	Single-phase, Split-phase, Permanent-split capacitor, Shaded pole, Three-phase squirrel-cage induction	Either totally enclosed or open. Designed for propeller fans or centrifugal blowers mounted on the motor. Generally not suitable for belted loads due to insufficient locked rotor torque.
Belted fans and blowers	Single-phase capacitor-start, Split-phase, Split-phase capacitor motors	Intended for operating belt-driven fans or blowers commonly used in heating and air-conditioning installations.
Air-conditioning condensers and evaporator fans	Shaded pole, Permanent-split capacitor	Very few shaded pole motors are used today.
Domestic oil burners	Split-phase	Motor operates mechanical-draft oil burners for domestic applications.

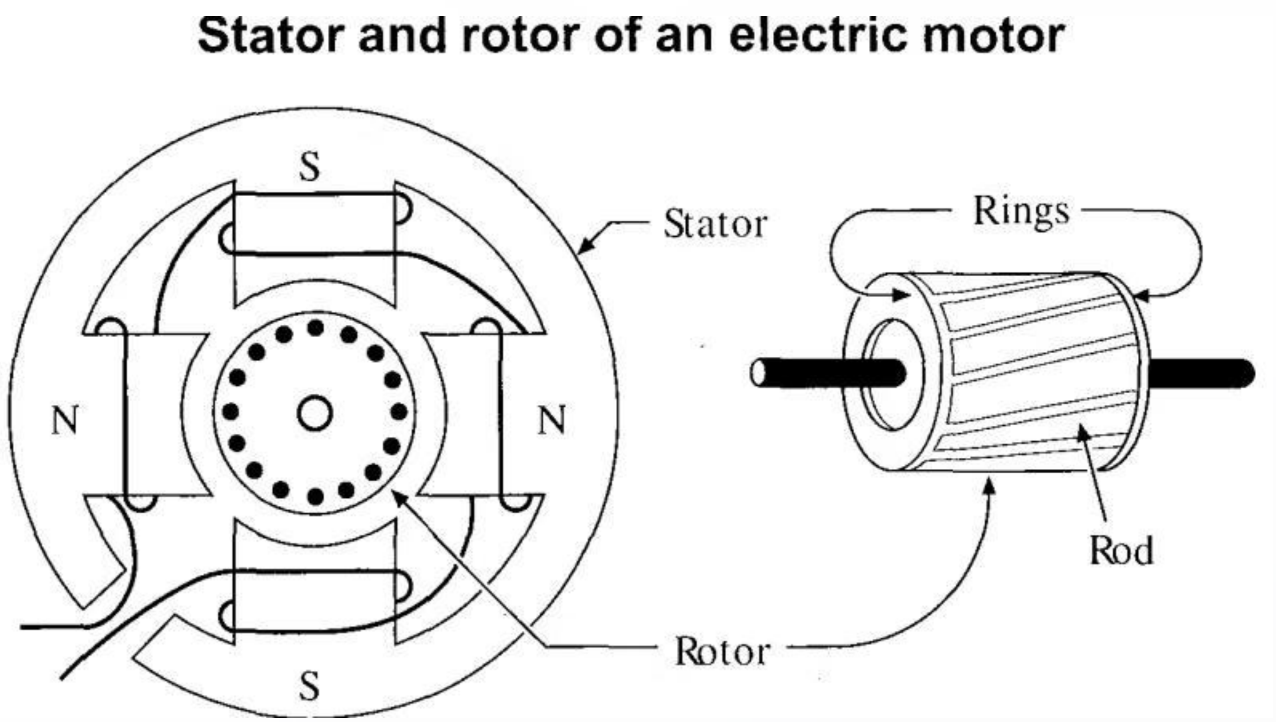
Basic Motor Construction

All electric motors have a similar basic structure with two main parts:

Stator (or frame)

The stator is stationary, consisting of two or more electromagnets and their windings. It is usually cylindrical in shape, with field poles facing and projecting their magnetic fields into the center space of the cylinder.

The windings are connected to a source of AC, which causes the poles to change polarity in step with the changing direction of the AC.

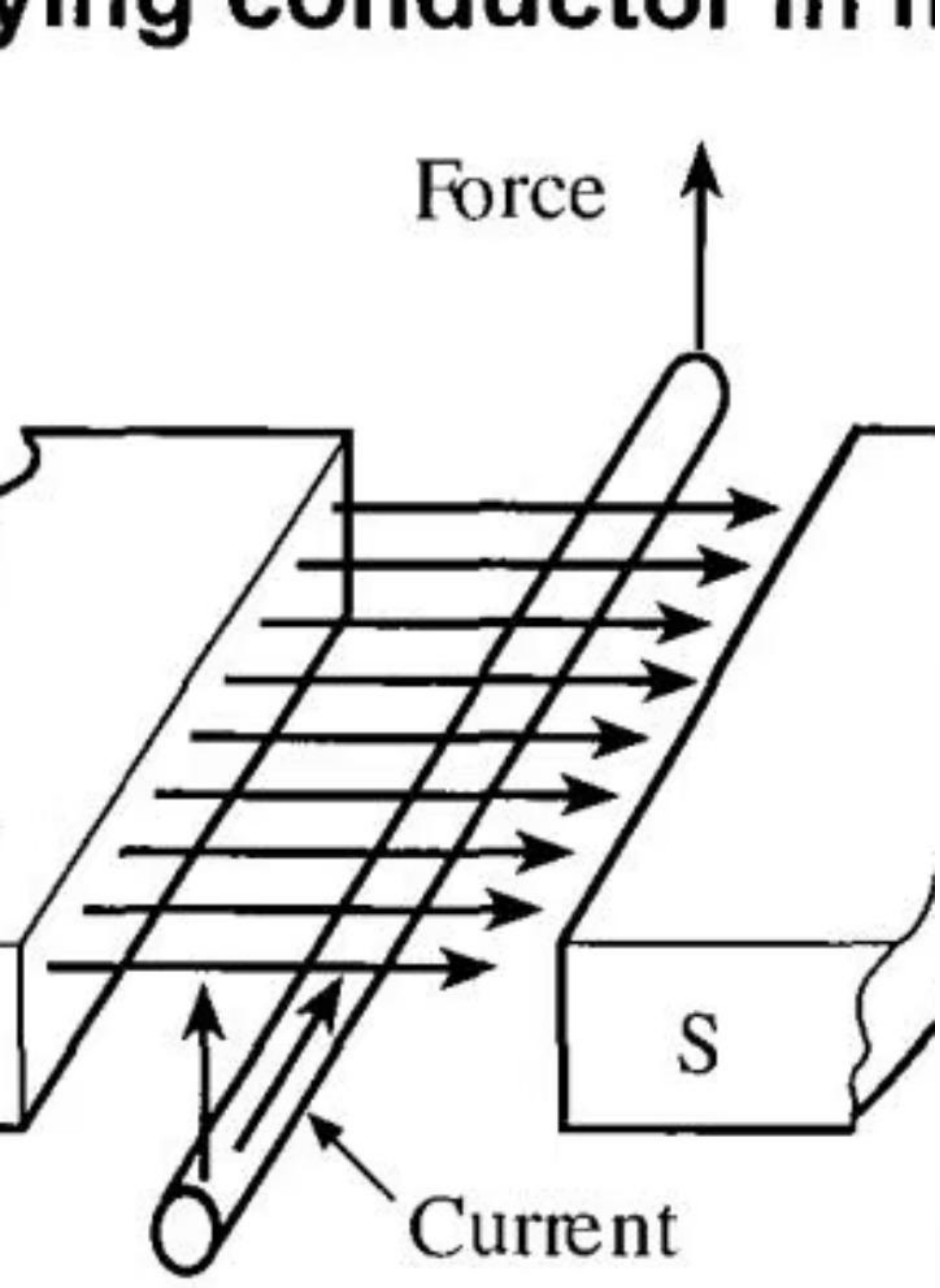


Rotor

The rotor is mounted on a rotating shaft in the center of the stator. It has a laminated iron core containing aluminum (sometimes copper) rods or bars along its outer surface.

The rods or bars are almost parallel to the rotor shaft and serve as conductors through which current flows. At the ends of the rotor are rings connecting the rods or bars together, completing the current paths.

The bars and rings look like a squirrel cage, giving this type of motor its name.



How Motors Generate Motion

Magnetic Field Interaction

As the rotor turns, the bars swing across magnetic fields created by the stator poles, inducing current in them.

Current Flow

The current in each rotor copper rod sets up a magnetic field that interacts with the magnetic field created by the stator poles.

Rotation Force

Since "like" magnetic lines repel each other, and "unlike" fields attract each other, the rotor starts to turn inside the stator.

Continuous Motion

The polarity changes when AC current is applied, constantly changing the attraction and repulsion forces causing continuous rotation.

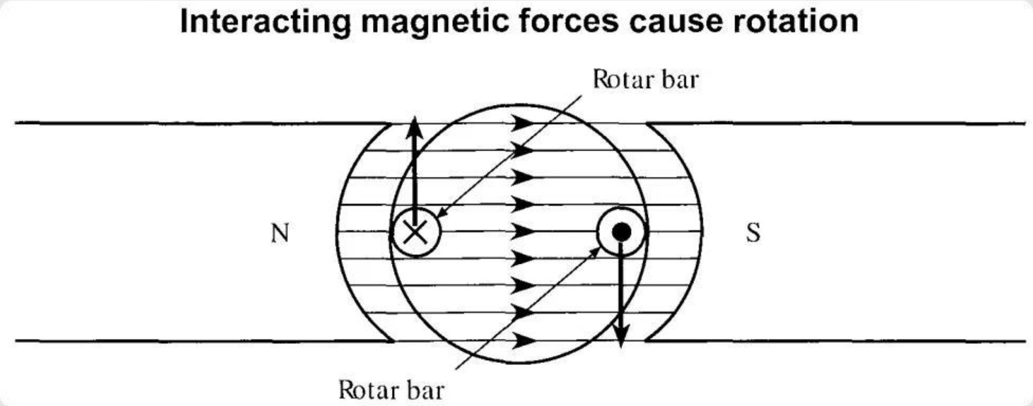
Motor Speed Calculation

The frequency of the current change determines the motor speed. Typical AC power is supplied at 60 hertz (Hz or cycles per second), so the rotor of a motor with two poles would turn 60 times every second, or 3600 revolutions per minute (RPM).

You can use the following formula to determine the synchronous speed (without load) of motors in RPM:

> RPM = (Frequency × 120) ÷ number of poles

This calculation gives theoretical motor speed. Internal motor friction and connected mechanisms add resistance, affecting actual speed. The difference between calculated and actual speed is called motor slip. Excessive slip can indicate problems like improper lubrication, defective bearings, tight belts, or an overloaded motor.



Three-Phase Motors Overview

Three-phase motors are efficient and economical. These motors are most widely used throughout industry and are known for their constant speed characteristics. They have various designs with a wide range of torque characteristics.

Squirrel Cage Induction

The simplest construction of AC motors with no physical connections between rotor and stator.

Wound Rotor

Features insulated winds with slip rings and brushes, providing very high starting torque.

Synchronous

Runs at a speed exactly proportional to the line frequency, used where constant speed is required.

Squirrel Cage Induction Motor

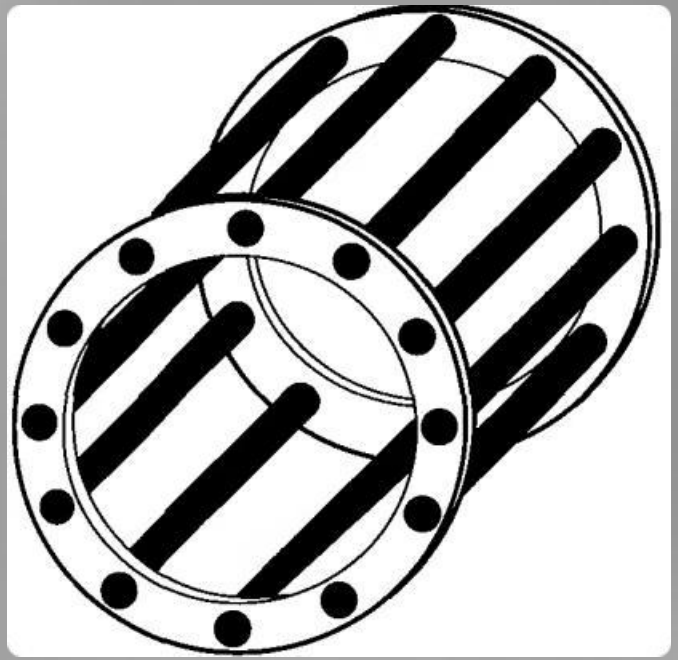
In a squirrel cage induction motor, no physical connections exist between the rotor and the stator. Hence, the magnetic field must be induced into the rotor. Its construction is the simplest of the AC motors.

Components

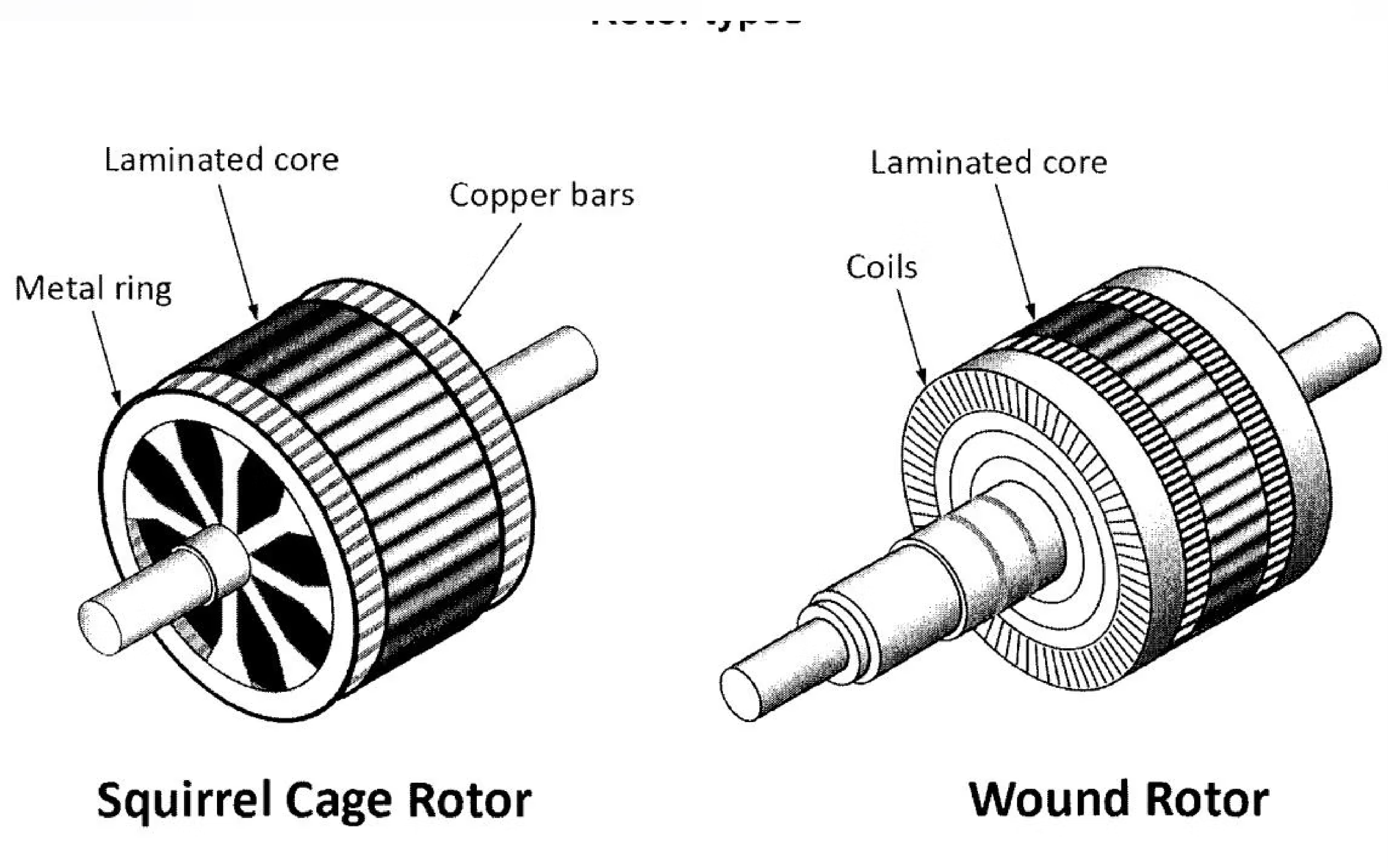
- A frame that provides a magnetic circuit and supports the stator windings
- Stator windings
- A squirrel cage rotor
- End bells

Characteristics

- Starting torque ranges from normal to very high depending on design
- Wide variations in applications due to torque range
- Efficient and economical operation
- Widely used in industry



Wound Rotor Motor



Design Differences

The difference between wound rotor motors and squirrel cage motors is in their rotor design. The wound rotor has insulated winds with slip rings and brushes.

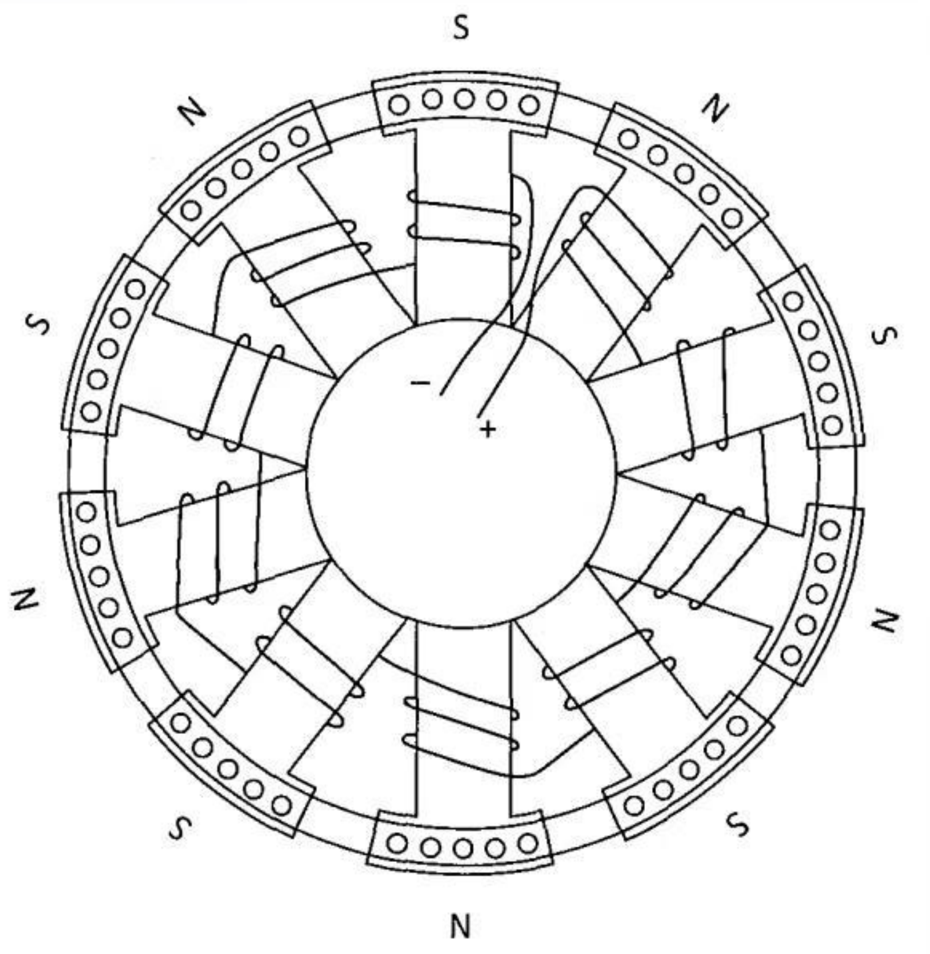
This design provides very high starting torque compared to standard squirrel cage motors.

Applications

Wound rotor motors are used widely throughout industry for:

- Cranes and hoists
- Elevators
- Machine tools

Synchronous Motor



Squirrel cage and wound rotors are asynchronous induction motors, meaning they always run at a speed which is less than the rotating magnetic field (synchronous speed). The synchronous motor operates differently.

Design

The rotor is essentially a DC electromagnet with the same number of poles as the stator. The poles in most types project out from the rotor.

The field poles are fed from a direct-current source, so their polarity remains constant and lock into step with the rotating magnetic field of the stator.

Starting

Synchronous motors usually require additional rotor windings such as a squirrel cage to allow them to start as an induction motor.

Once up to speed, they lock into synchronous operation with the line frequency.

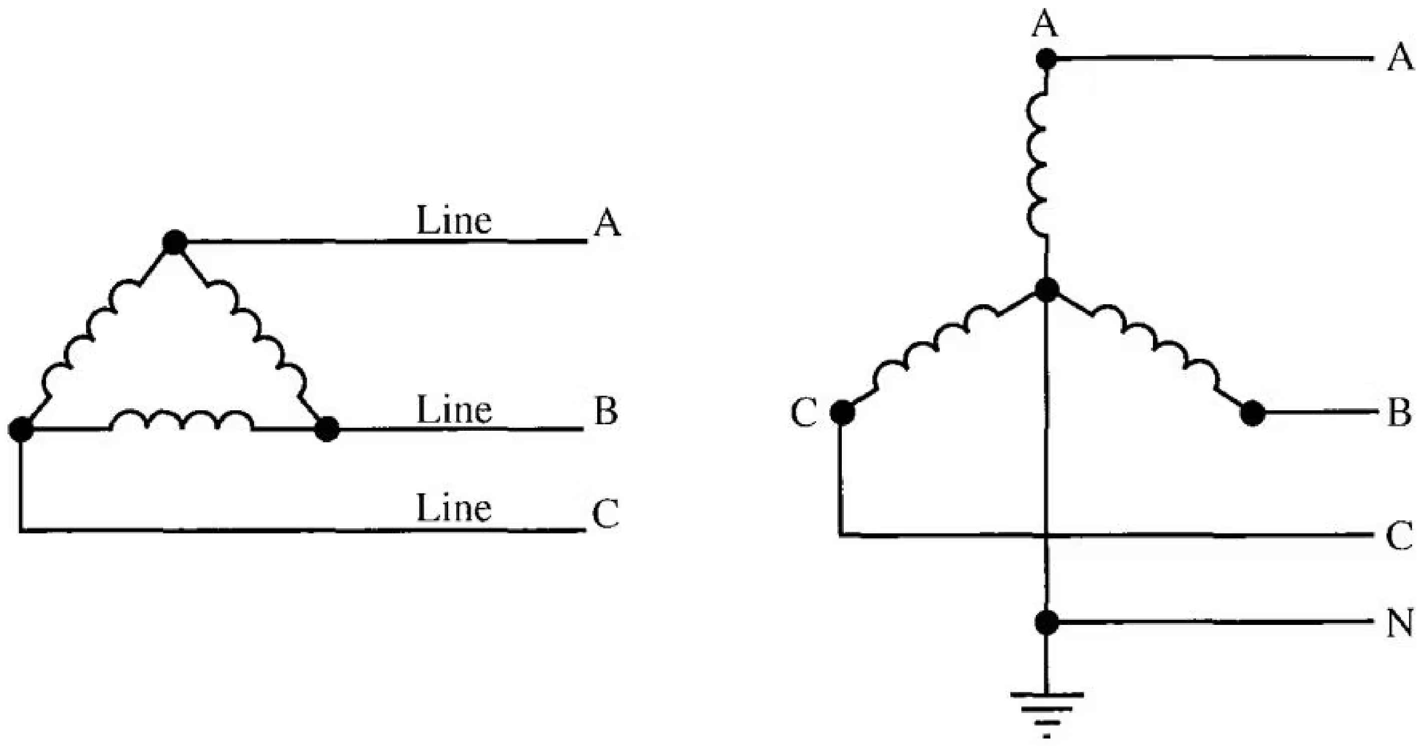
Applications

Used where very constant speed is required, exactly proportional to the line frequency.

Common in clocks, timing devices, and positioning motors.

Large synchronous motors with power ratings of several megawatts are used in industrial processes for high efficiency.

Three-Phase AC Circuits



Delta Connection (Δ)

In the delta connection, the winding insulation is normally subjected to a higher voltage than that of the wye connection.

The delta connection is usually not grounded so that a single ground on one phase will not affect the operation of the motor.

Two or more grounds, however, constitute a short circuit between the points of the grounds and will result in improper operation or failure of the motor.

Wye Connection (Y)

The wye connection is generally grounded at the common point.

While the winding insulation is usually subjected to a lower voltage (than the delta connection), a ground on any of the phases will adversely affect the operation of the motor.

The direction of rotation of a three-phase motor can be reversed by switching any two motor leads.

> Caution! After a three-phase induction motor has been disconnected for service, it is very important to reconnect the line conductors to the correct terminals. Failure to ensure this may result in the motor and the load that it drives rotating in the wrong direction. This can cause damage.

Single-Phase Motors Overview

Single-phase motors operate on the same induction principle as three-phase motors once they get up to speed. A single-phase motor, however, needs a supplementary device to make it self-starting.

Having no magnetic rotating field at start, it will have no starting torque as the magnetic fields are initially opposing each other. The solution is to incorporate separate start windings, which will produce out-of-phase magnetic fields in the rotor.

Split-Phase Induction

Uses separate run and start windings displaced by 90 electrical degrees.

Resistance-Start

A split-phase motor with an external resistor in series with the auxiliary winding.

Capacitor-Start

Uses a capacitor in series with the starter winding for greater torque.

Permanent-Split Capacitor

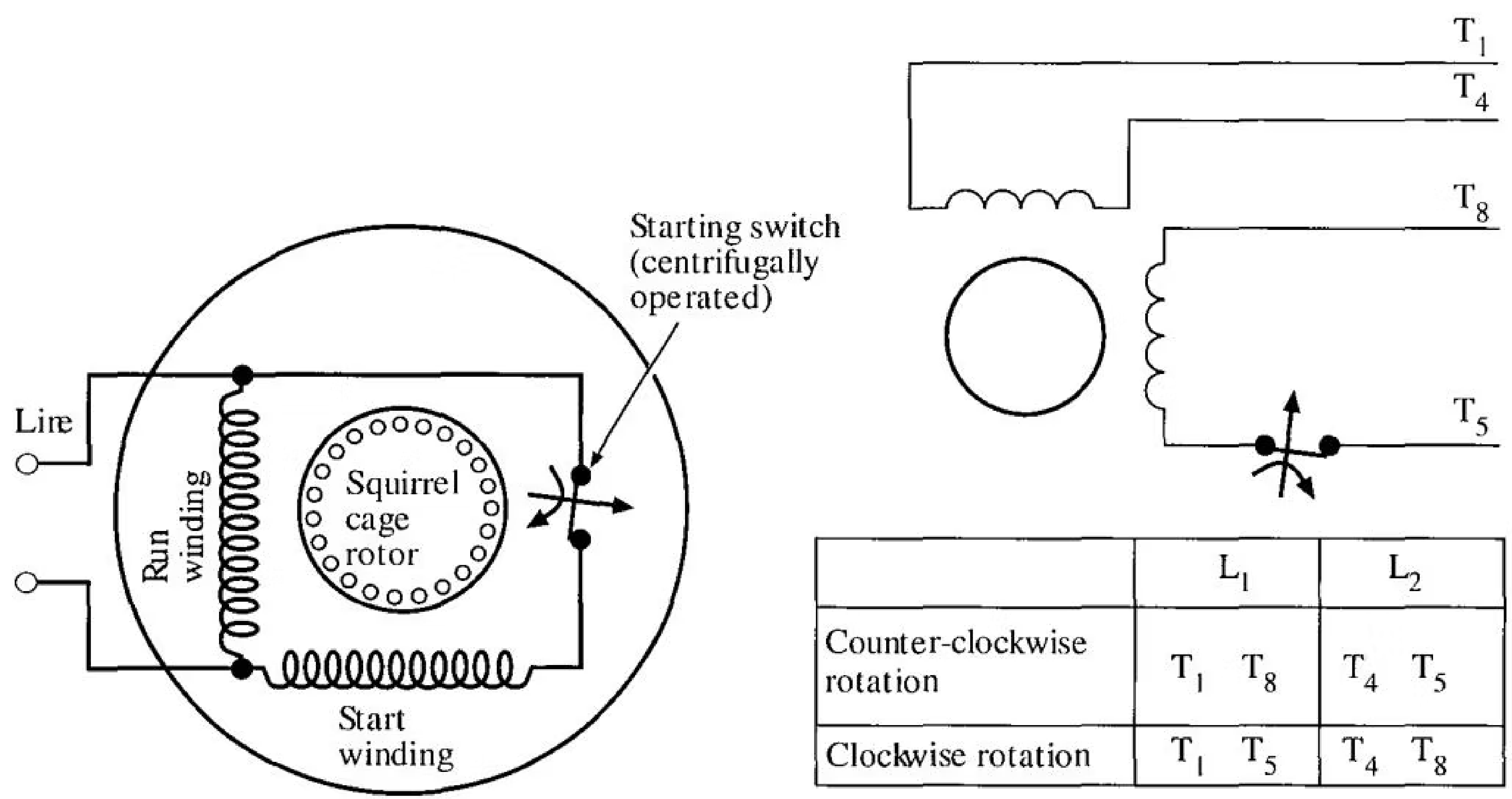
Uses its start winding and capacitor continuously without change in capacitance.

Shaded Pole

Uses a shading coil or low resistance loop as its starter winding.

Split-Phase Induction Motor

The split-phase motor and its connections



	L_1	L_2
Counter-clockwise rotation	T_1 T_8	T_4 T_5
Clockwise rotation	T_1 T_5	T_4 T_8

(a) (b)

Essential Components

The split-phase induction motor has two separate and distinct windings on the stator that are mutually displaced by 90 electrical degrees:

- The run winding
- The start winding

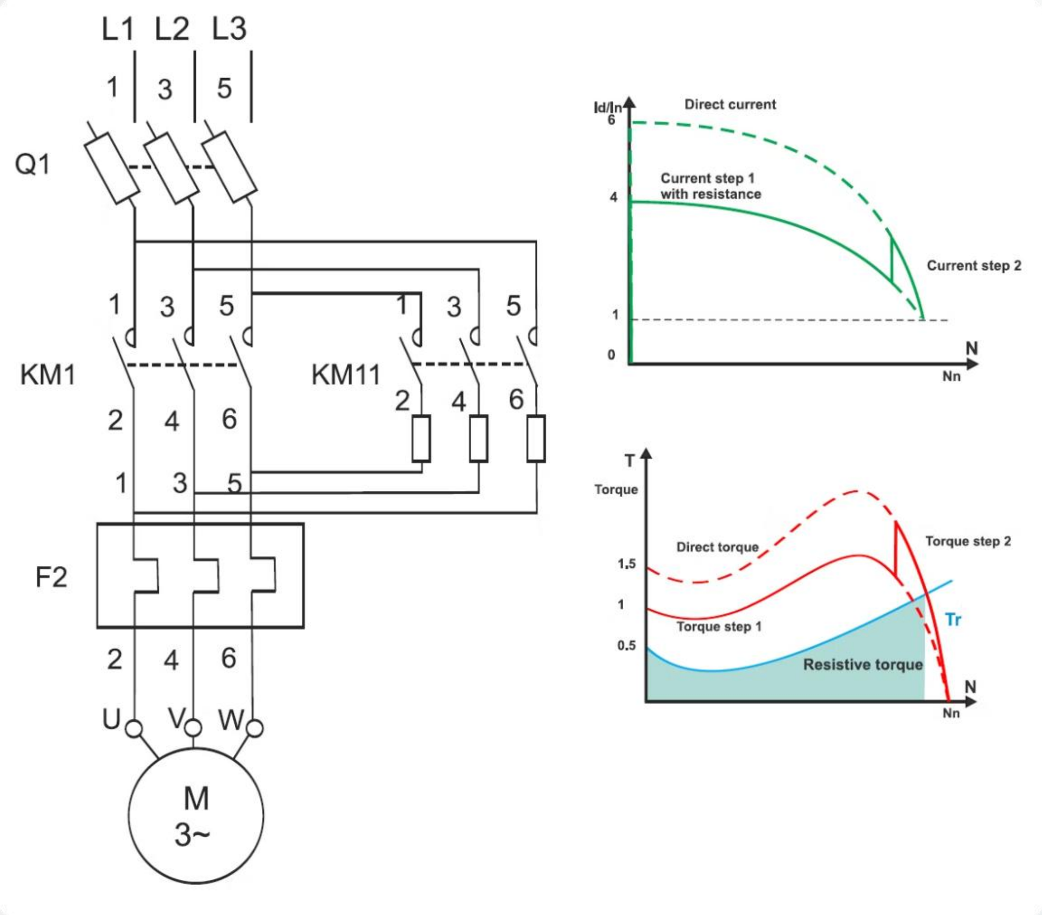
The direction of the current flow through the start windings determines the motor direction.

Operation

For starting purposes, both run and start windings are connected in parallel across the line. In series with the start winding is a starting switch (usually a centrifugal switch).

These motors are fractional horsepower units and are found in small pumps. They can use either wound or squirrel-cage rotors, although squirrel-cage is the most widely used.

In split-phase motors with four external line leads, the leads can be identified by tags, color, or by both for clockwise or counter-clockwise rotation.



Resistance-Start Motor

Design

A resistance-start induction motor is a split-phase motor in which an external resistor is connected in series with the auxiliary winding.

Operation

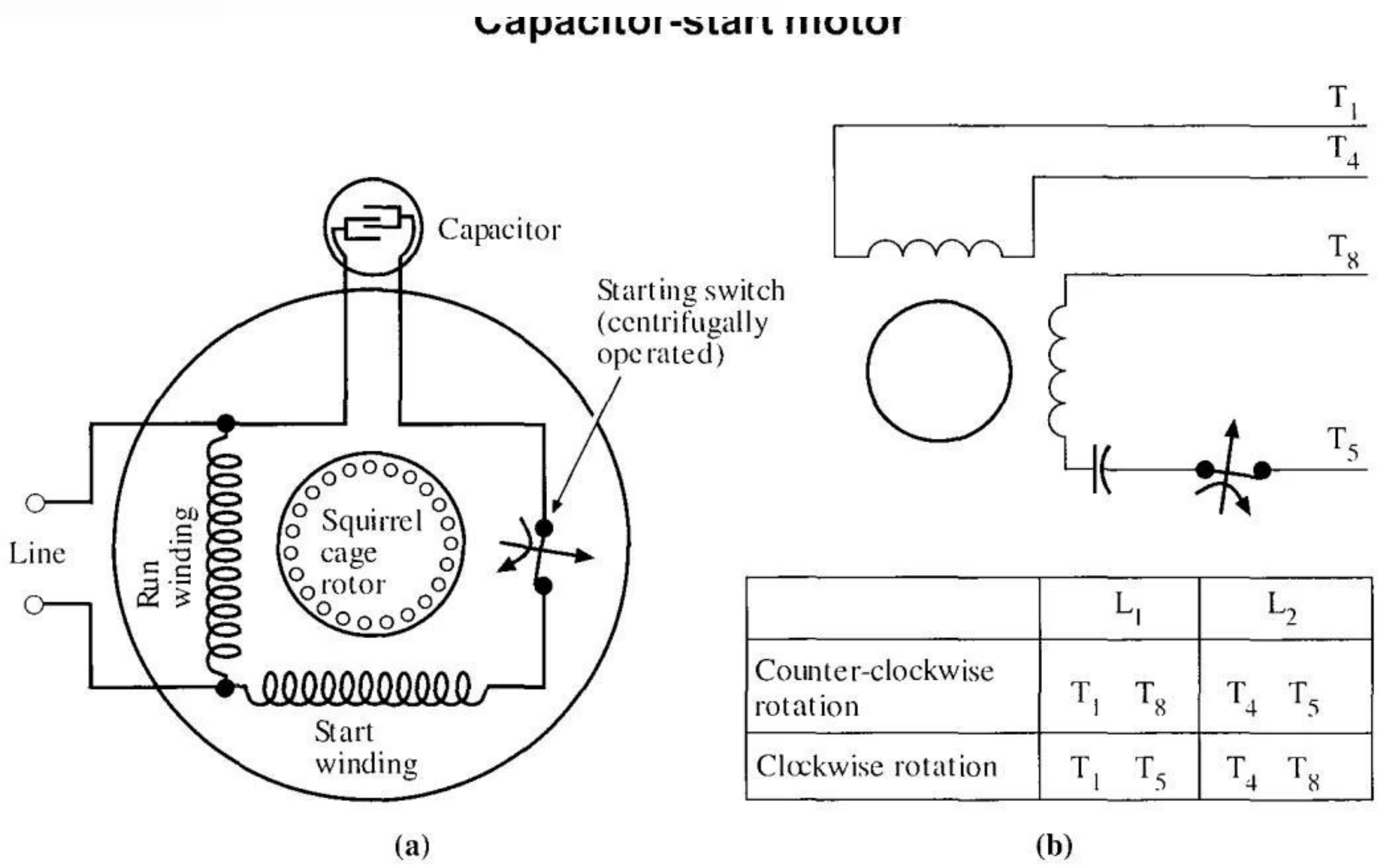
Because the start winding is highly resistive and the run winding highly inductive, the currents through the two windings are displaced by 30-50 electrical degrees.

This creates a pulsating magnetic field, which induces rotor currents resulting in development of torque.

Applications

Resistance-start motors have a low starting torque and are used for light load applications where high starting torque is not required.

Capacitor-Start Motor



Also known as a capacitor-start induction run (CSIR) motor, the capacitor-start motor is similar in construction to a split-phase motor, except that it has a capacitor in series with the starter winding.

Capacitor Function

The capacitor permits a greater time displacement between the two winding currents (approximately 90°), resulting in a smoother rotating field and greater torque development in the rotor.

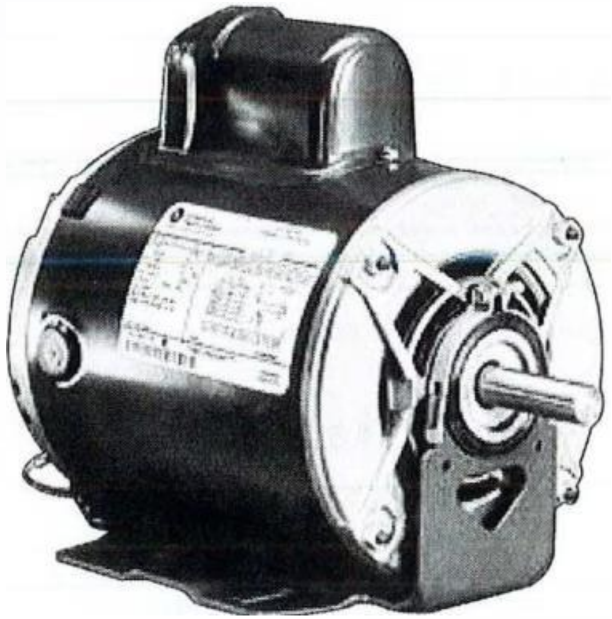
Starting Operation

Capacitor-start motors use the capacitor only while starting. It is disconnected once the motor reaches approximately three-quarter speed.

Centrifugal Switch

A centrifugal switch opens to bypass the capacitor in the circuit when the motor reaches sufficient speed.

Capacitor-Start Motor Construction



The capacitor-start induction run (CSIR) motor combines the benefits of split-phase motors with improved starting torque thanks to the capacitor in the start circuit.

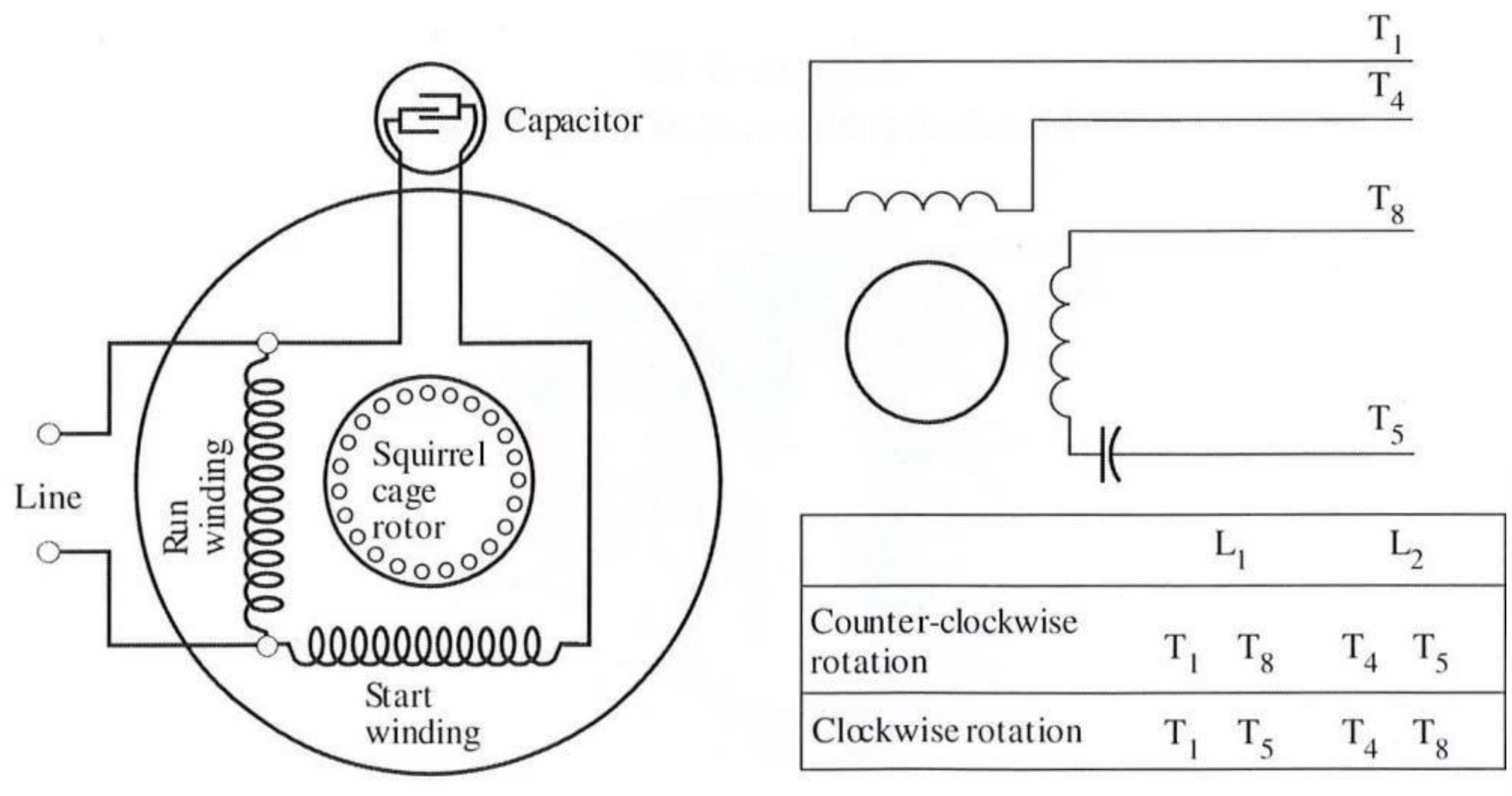
Key Components

- Run winding (main winding)
- Start winding with capacitor in series
- Centrifugal switch
- Squirrel cage rotor

Operation Sequence

1. When power is applied, both run and start windings are energized
2. The capacitor creates phase displacement between windings
3. This produces a rotating magnetic field with high starting torque
4. As motor reaches about 75% of rated speed, the centrifugal switch opens
5. This disconnects the start winding and capacitor
6. Motor continues running on the main winding only

Permanent-Split Capacitor Motor



	L_1		L_2	
Counter-clockwise rotation	T_1	T_8	T_4	T_5
Clockwise rotation	T_1	T_5	T_4	T_8

(a) (b)

Design Features

The permanent-split capacitor (PSC) motor is a capacitor motor that uses its start winding and capacitor continuously without change in capacitance.

The arrangement of windings and connections is exactly the same as the capacitor-start motor, except that the starting switch is omitted.

This design eliminates the need for a starting switch or relay, simplifying the motor construction.

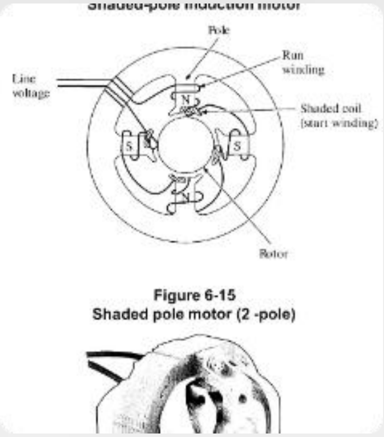
Applications and Characteristics

PSC motors are generally not suitable for belted applications or for any continuous-duty application requiring substantial locked-rotor torque.

These motors are ideal for light duty fans and direct drive applications.

The PSC motor starts up very slowly compared to split-phase motors, which is desirable for forced air fans as it reduces start-up noise.

In the connection diagram, the line leads are identified for clockwise rotation and counter-clockwise rotation.



Shaded-Pole Induction Motor

Definition

A shaded-pole motor may be defined as a single-phase induction motor that uses a shading coil or low resistance copper/aluminum loop as its starter winding.

Construction

This shaded coil is mounted on one side of each of the stator poles. This setup produces a moving magnetic field perpendicular to the field pole and starts the rotor turning.

Applications

These economical, reliable motors are used in a wide variety of very low torque applications such as small fans and humidifiers.

They are simple in construction with no starting switch, making them reliable but limited in torque capabilities.

Single-Phase Motor Protection

Single-phase motors draw a very heavy current upon start-up, but this current rapidly drops off once the motor begins to run. Overload devices ensure that the motor, if subjected to excessive torque during start-up or run time, does not overheat.

Temperature-Sensing Devices

Motor thermostats directly sense the motor winding temperature to prevent overheating.

Current-Sensing Devices

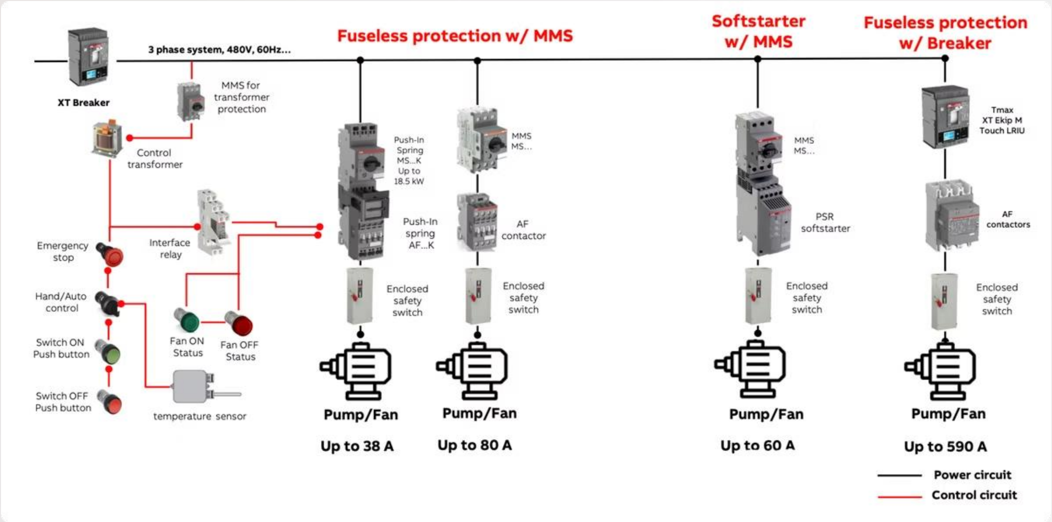
Measure current as an indication of motor temperature, shutting down the motor if excessive current is detected.

External Protection

Starters with calibrated overload devices that trip and disengage the circuit under excessive conditions.

Overheating is the primary factor for deterioration of insulation and motor failure. Protection devices are typically set by the motor manufacturer based on motor type, application, load requirements, operating temperature, and location.

Start-Up Devices for Single-Phase Motors



Single-phase motors (1/20 hp to 5 hp) need additional current to start up. Various devices help provide this initial inrush of current.

Built-in Devices

- Centrifugal switch
- Capacitor

External Devices (for hermetic motors)

- Current relay
- Potential relay
- Solid-state relay

Selection criteria for these devices include motor type, application requirements, load requirements, amperage draw, operating temperature, and installation location.

Centrifugal Switch

Initial Position

The split-phase motor contains a centrifugal switch with flyweights mounted on the rotor shaft.

Acceleration Phase

As the motor accelerates, centrifugal force moves the flyweights outward against the force of the spring.

Switch Opening

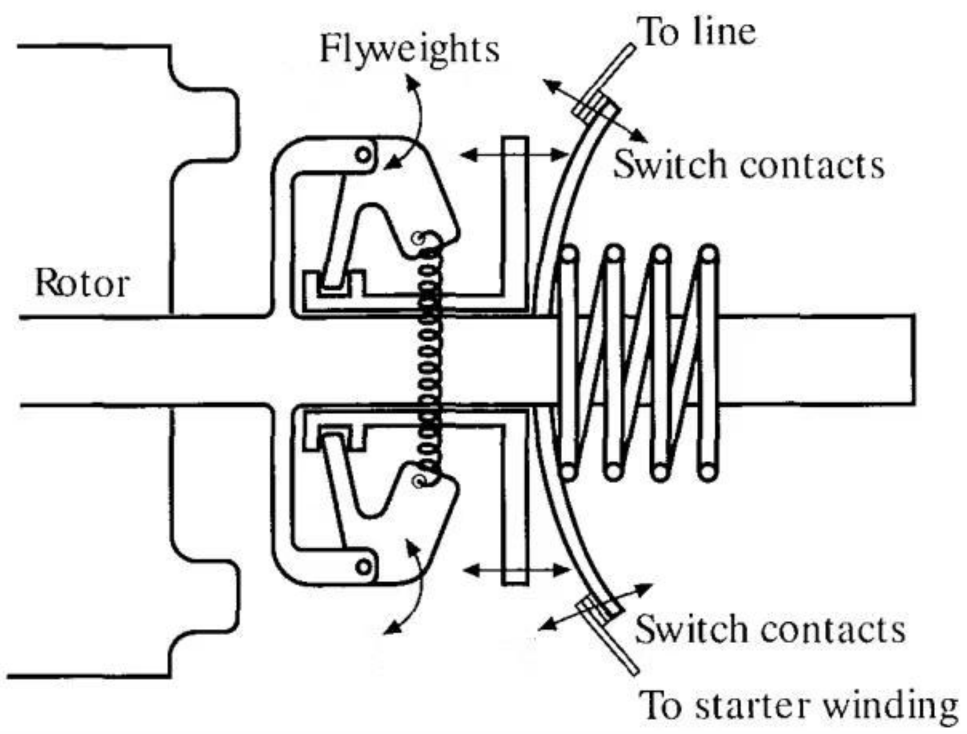
As the flyweights move out, they force a collar to move along the rotor shaft and push the switch open. This occurs when the motor reaches about 75% of its rated speed.

Deceleration Phase

As the motor slows down, the centrifugal force on the flyweights decreases and the spring forces them back in towards the rotor shaft. This permits the switch to close again.

Capacitors in Motor Circuits

Figure 6-16
Centrifugal switch



Start Winding Capacitors

If used in the start winding only, it is called a capacitor-start motor. Being used for a few seconds at a time, it should have no cooling problems.

However, if a motor is started too often or if the start winding is used for a longer period than it is designed for, the capacitor insulation will overheat, and the capacitor may fail.

> Note: Never use a starting capacitor in the run circuit.

Run Winding Capacitors

If the capacitor is used for the run winding, it is carefully designed to dissipate any heat generated during operation.

Run capacitors are designed for continuous duty and have different electrical characteristics than start capacitors.

> Caution! Never place fingers across the terminals of a capacitor. It may be charged and may give a shock. Always short out the terminals with a rated resistor before handling it.

Capacitor Testing and Replacement

Substitution Test

When a motor does not start or run properly, there is a good possibility that the trouble is in the capacitor. The simplest capacitor test is to substitute a good capacitor (of the same specifications) for the one being tested.

Verification

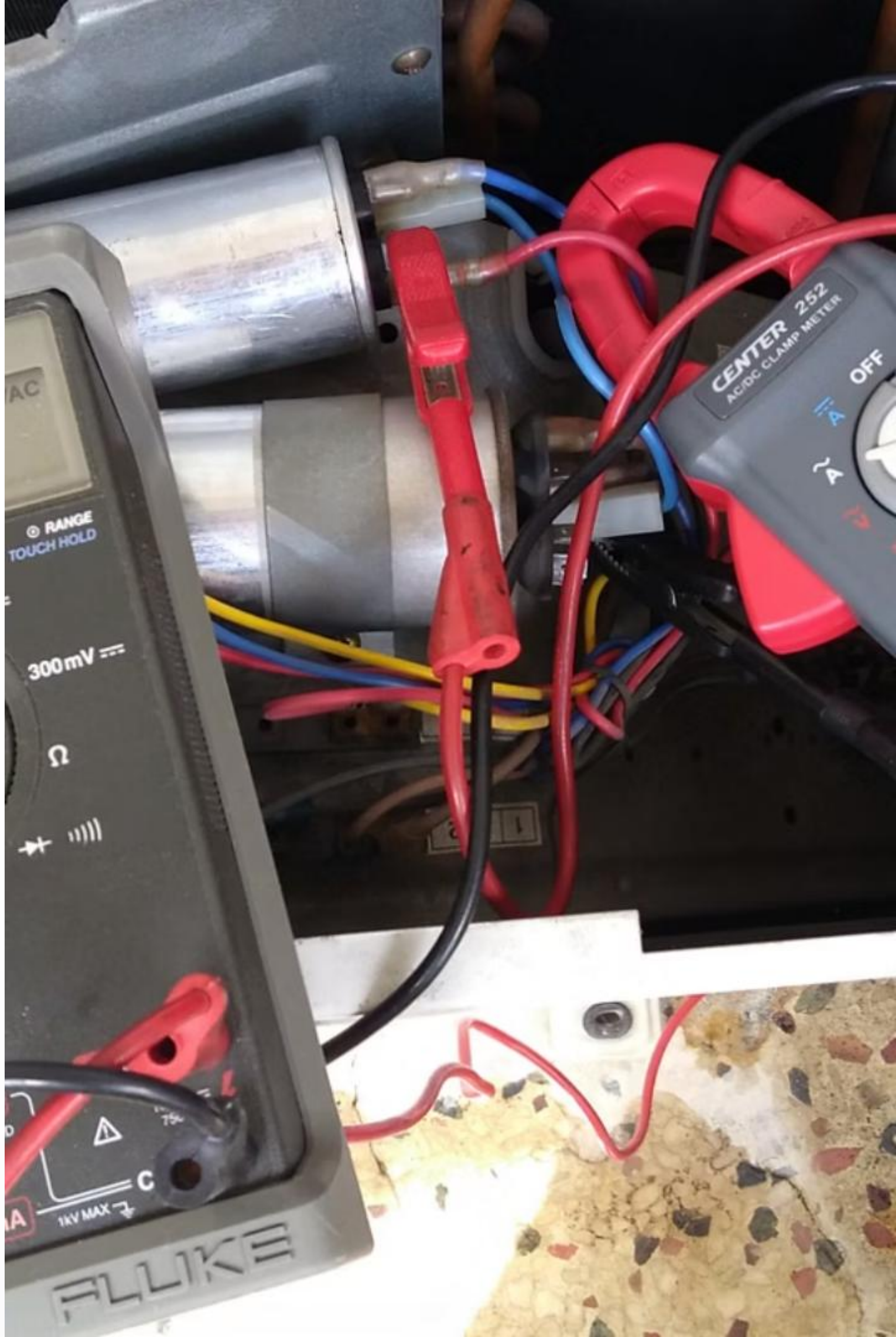
If the motor operates with the new capacitor, the old one is faulty. The replacement capacitor should be of the same voltage and capacity as the old capacitor.

Replacement Guidelines

If you must use a different capacitor, it should be 5% to 10% over capacity rather than under.

Common Failures

The most common cause for failure of a capacitor is a ground or open circuit condition. Most multimeters will check for these conditions.



External Start-Up Devices

External start-up devices are needed when it is not possible to include switches inside the motor, as in the case of a hermetic motor.

Starting Relays

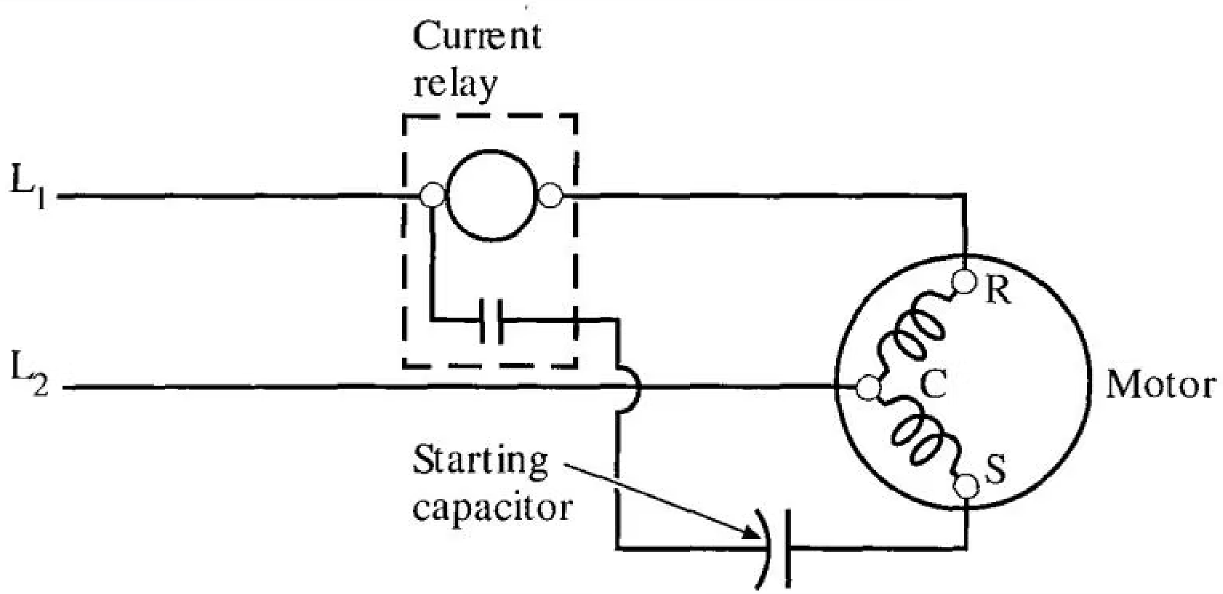
Starting relays are used to remove the starting winding from operation when the motor reaches approximately 75% of its normal running speed.

Types of Starting Relays

- Current relay (amperage relay)
- Potential relay (voltage relay)
- Solid-state relay

Each type of relay operates on different principles but serves the same purpose: to disconnect the start winding once the motor is up to speed.

Current Relay Operation



The current relay is sometimes called amperage relay since it is the amperage draw on the circuit that operates the relay. This electromagnetic relay is normally used on small capacitor-start induction-run motors.

Initial Connection

The relay coil is connected in series with the motor's run winding.

Starting Position

The magnetic relay is an electromagnet much like a solenoid. Either a weight or a spring holds the starting winding contact points open when the system is idle.

Start-Up Sequence

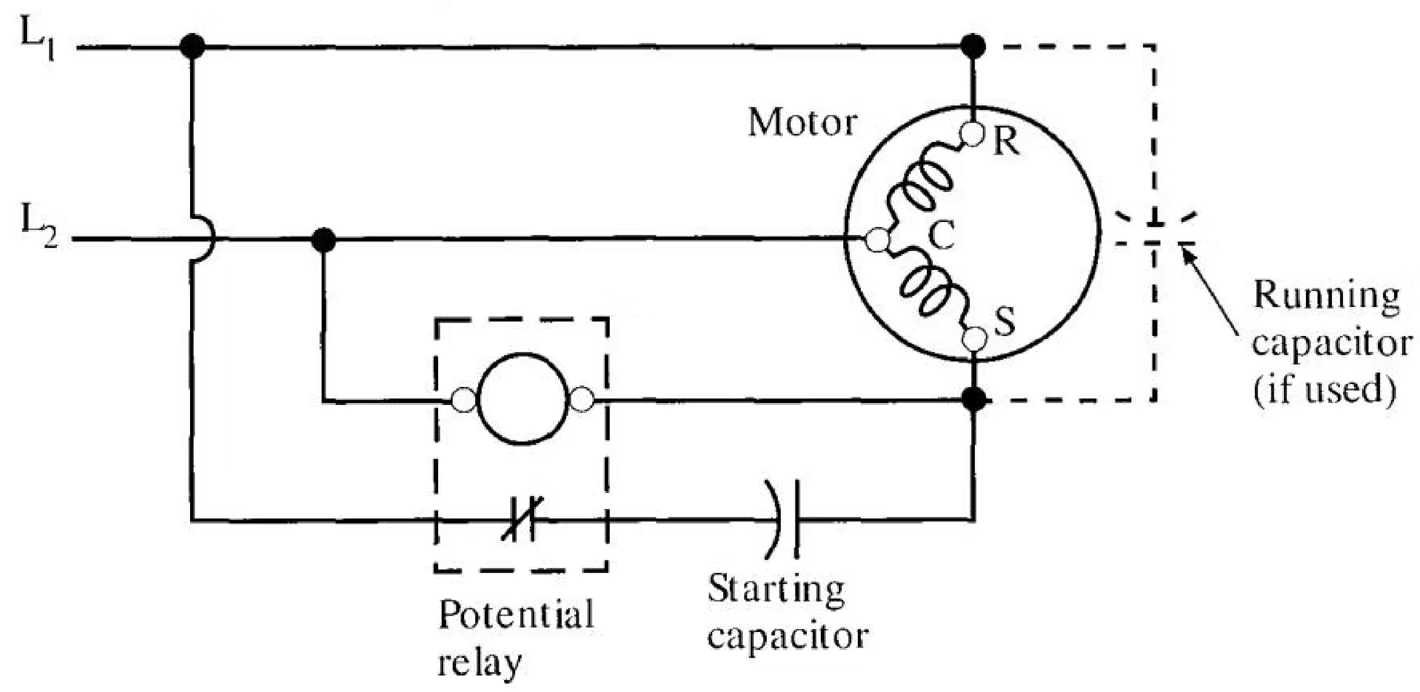
When the motor control contacts close and high current flows into the running winding, the magnetic current relay coil is heavily magnetized. It lifts the weight or overcomes the spring pressure and closes the contacts.

Running Operation

This action closes the starting winding circuit, and the motor quickly accelerates. As it reaches 2/3 or 3/4 of rated speed, the amperage draw decreases, reducing the magnetic strength enough to be overcome by the weight or spring, opening the contacts.

Potential Relay

Figure 6-18
Wiring diagram of potential relay



Definition and Use

Potential relay, sometimes called voltage relay, is usually used with larger sizes of capacitor-start induction-run motors.

Like the current relay, the potential relay has a magnetic coil that, when energized, operates a set of movable contacts.

Operation

The contacts in this relay are held closed by gravity or a spring and are open only when the coil is energized.

This normally closed feature is its biggest advantage since there is no arcing of the relay points when the circuit closes.

The relay responds to the back EMF (electromotive force) generated by the motor as it accelerates, opening the start circuit at the appropriate time.

Solid-State Relay

Components

Relays using solid-state transistors, diodes, and triacs are used to control starting of hermetic motors.

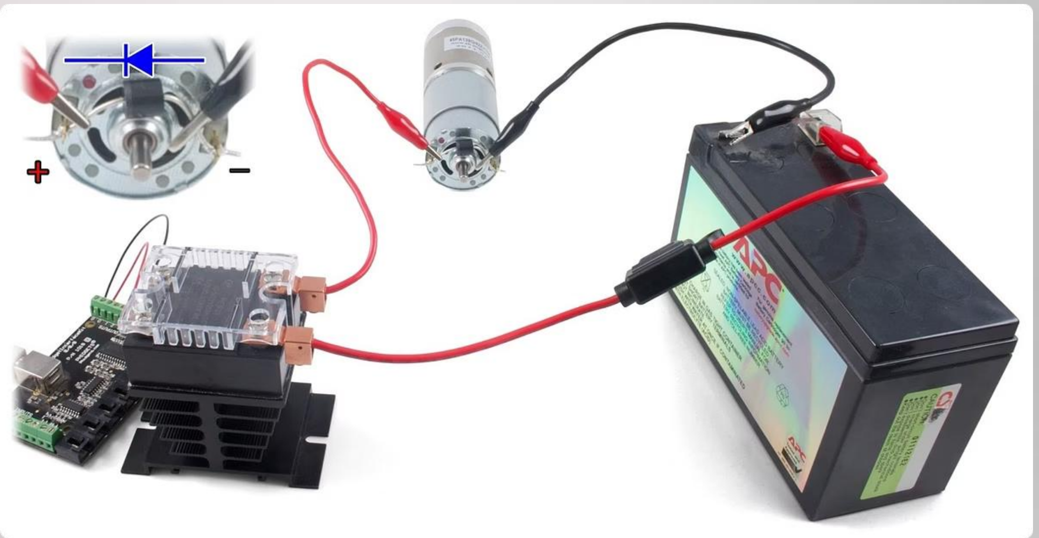
Operation

Changes in voltage in the motor as it starts and gathers speed are used to open the start winding circuit at the correct time.

Advantages

These relays are not as sensitive to the size of the motor as other relays. The same solid-state relay can be used for motors varying from 1/12 to 1/3 hp.

They have no moving parts, making them more reliable and longer-lasting than mechanical relays.



Overload Protection Devices

If a motor is overloaded, it heats up. This temperature rise is destructive to the motor and, if left unchecked, will burn out the motor. Motor overload protection devices are designed to sense the increase in motor current to temperature relationship and to shut it down if a damaging increase in temperature is detected.

Temperature-Sensing Device

Temperature-sensing devices (called motor thermostats) directly sense the motor winding temperature.

These devices do not carry current as they would heat up and give a false reading if they did.

Usually, these devices are automatic since they are located inside the housing and are inaccessible.

Reset time may take anywhere from 20 minutes to several hours, depending on motor size and how many trips have occurred.

Current-Sensing Device

One type is the temperature disc (Klixon disc). Current flows through the bi-metal disc and heats it.

A predetermined amount of current heats the disc enough to cause it to warp so that it opens a set of contacts.

After the contacts open to break the circuit, the disc cools down and automatically resets.

This type of current overload device, referred to as replica protection, is usually mounted inside the housing of small motors.

External Overload Protection

Magnetic Starter

Most external overload protection is provided by a starter with overload devices calibrated to the motor conditions of operation.

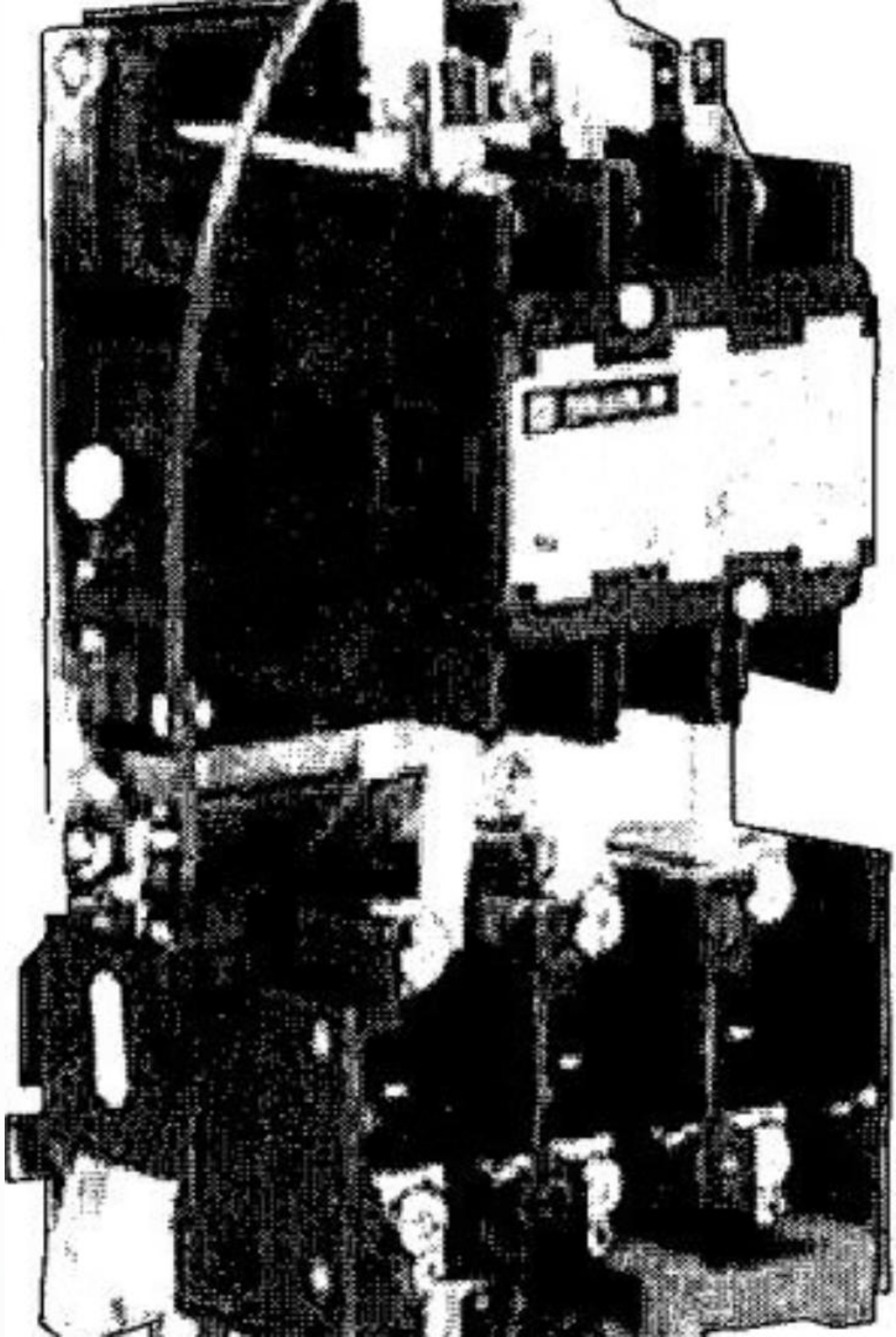
Operation Types

The starter can be manual or automatic and will have temperature-sensitive current devices that protect the motor within its full load current capacity.

Protection Mechanism

The thermal overload will trip the starter and disengage the circuit to the motor under excessive conditions, preventing damage from overheating.

External overload devices are more accessible for maintenance and replacement compared to internal protection devices. They can be adjusted or replaced without disassembling the motor.



Motor Insulation

Basic Functions

Motor insulation has two basic functions:

- To separate the various electrical components from one another and from the stator iron and all the structural parts
- To protect itself and the electrical components from contaminants and other destructive forces

Materials and Design

Coil windings are usually insulated with varnish-impregnated paper, fiberglass, or polymers.

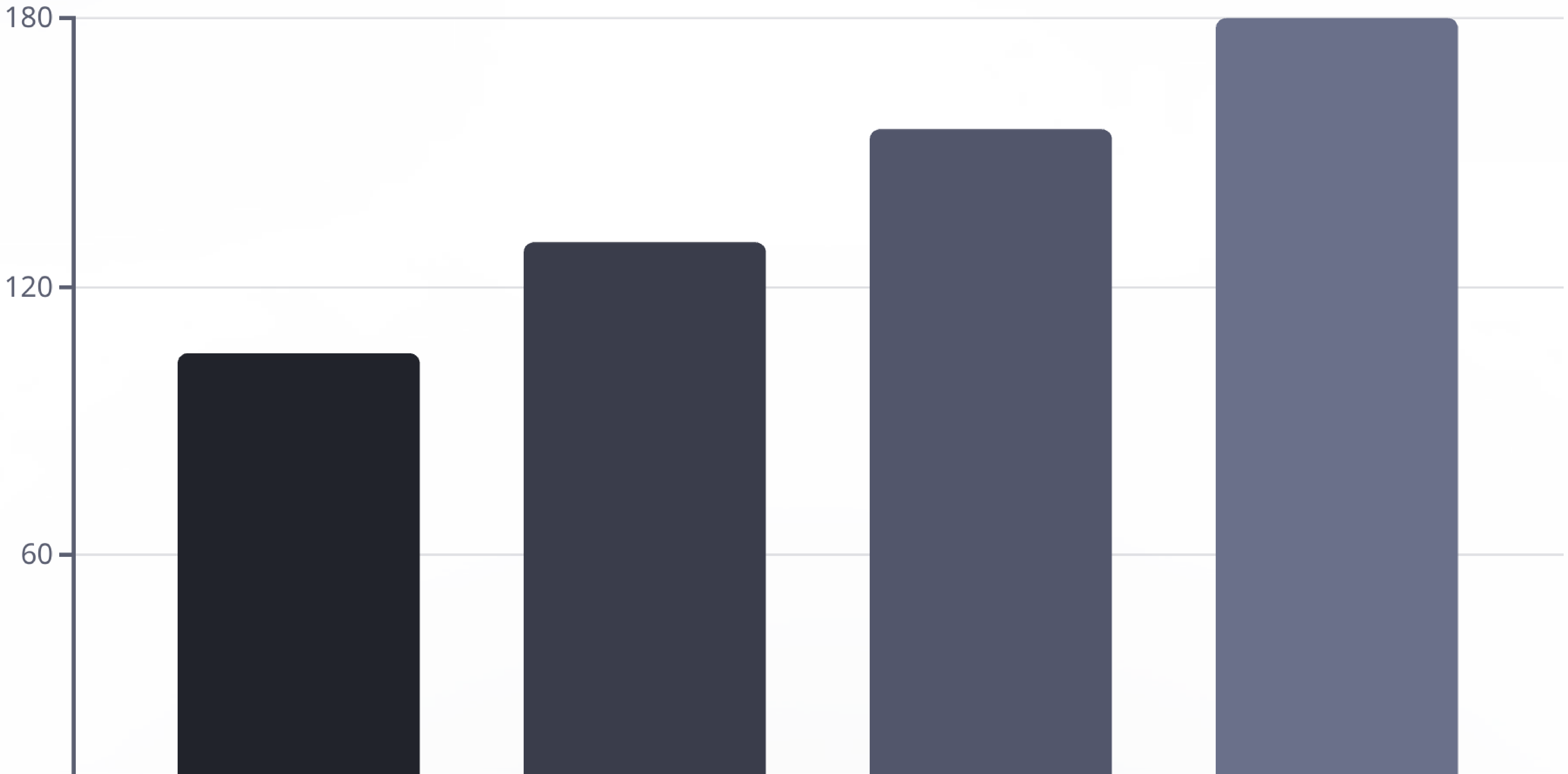
The insulation is designed not only to withstand the normal voltages to which they are exposed, but also to include a margin to handle voltage surges.

The insulation of the leads from such coils is usually deliberately made weaker so that, should failure occur, it may be more apt to take place outside the stator or rotor where it would be more easily repaired.

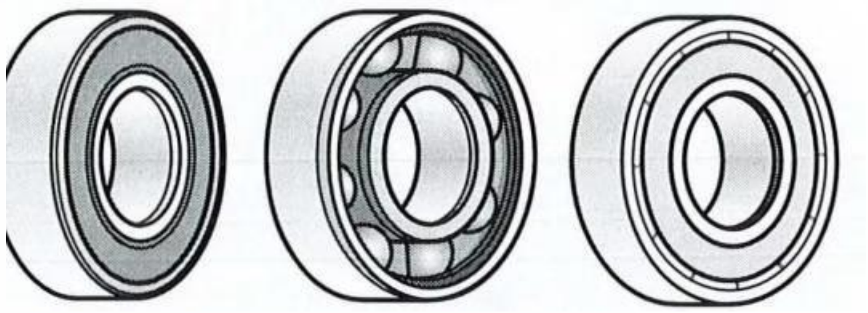
> Motor heating is the primary cause of motor insulation failure. Heat causes deterioration of the insulation, resulting in a breakdown in insulating quality, short circuits, and eventually motor failure.

Insulation Temperature Rating

The standard ambient temperature used for insulation rating purposes is 40°C (104°F), meaning the motor will begin to overheat when the air or other contacting medium is higher than 40°C.



Motor Bearings



Bearings are one of the most vital parts of the motor and, except for the starting switch, are the only wearing parts in most types of fractional horsepower electric motors. Three-phase motors have even fewer moving parts. With only two bearings, they are easily maintained.

Sleeve Bushings

Require periodic lubrication through grease fittings.

Used in smaller, lighter-duty applications.

Ball Bearings

Most designs are sealed and self-lubricating.

Provide better support for heavier loads and higher speeds.

Roller Bearings

Used in larger motors and heavy-duty applications.

Can handle greater radial loads than ball bearings.

When motors are repaired and/or serviced, the bearings may be replaced with sealed-for-life bearings and, as such, should have the grease fittings removed and holes plugged.

Motor Speed Control

Speed control is often desirable in a large number of fan and blower applications in heating and air-conditioning installations.

Direct Drive Motors

The PSC direct drive fan motor is directly linked to the fan wheel.

Multi-Speed Motors

A multi-speed PSC motor can be identified by a number of wires at the motor electrical connections.

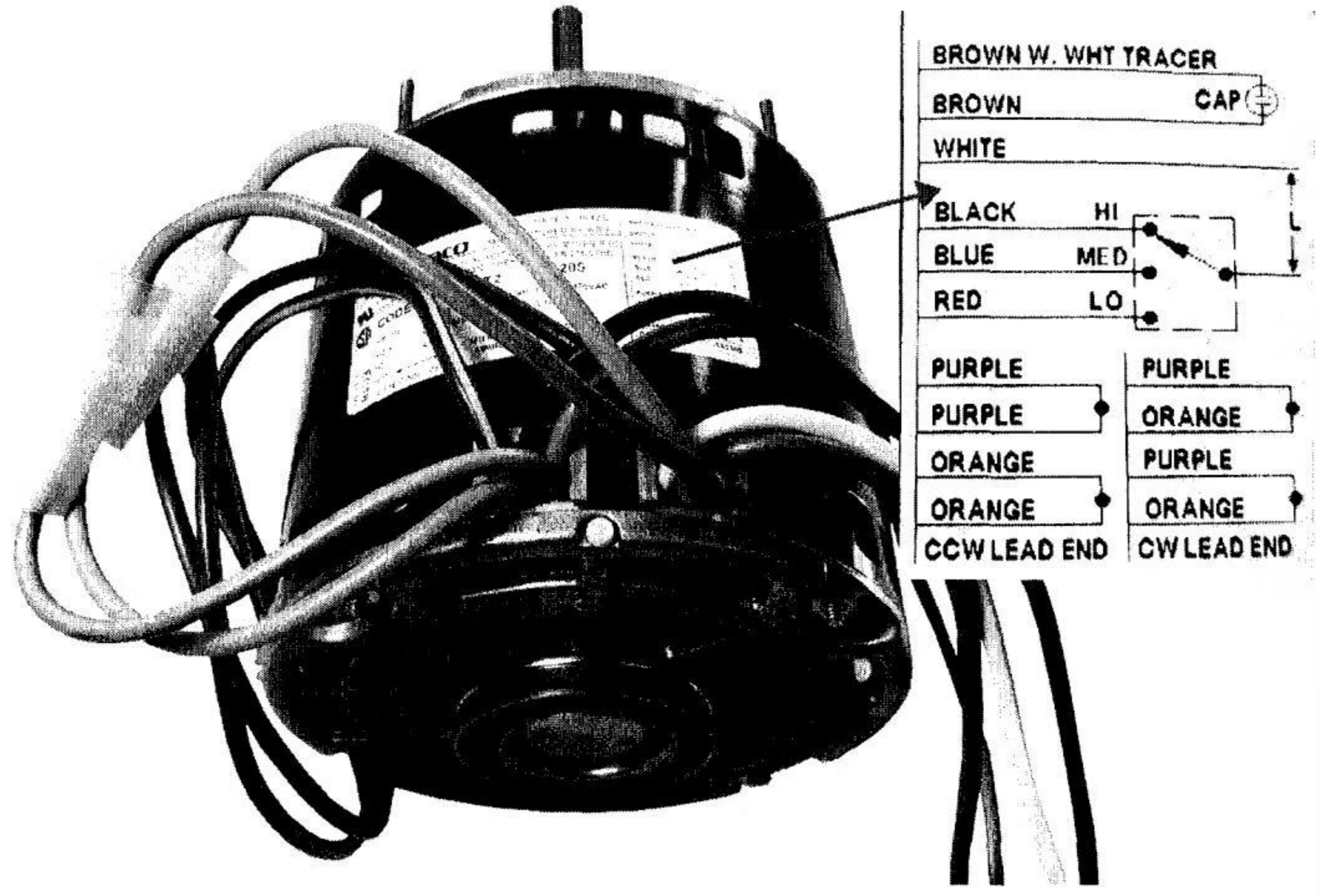
Speed Selection

For single speed operations, only one of the speed taps is wired to the hot leg of the power supply. The other unused hot wire leads are capped and taped separately.

Multi-Speed Motor Wiring

Multispeed fan motor

Courtesy of Camosun College, Rodney Lidstone, licenced under CC BY



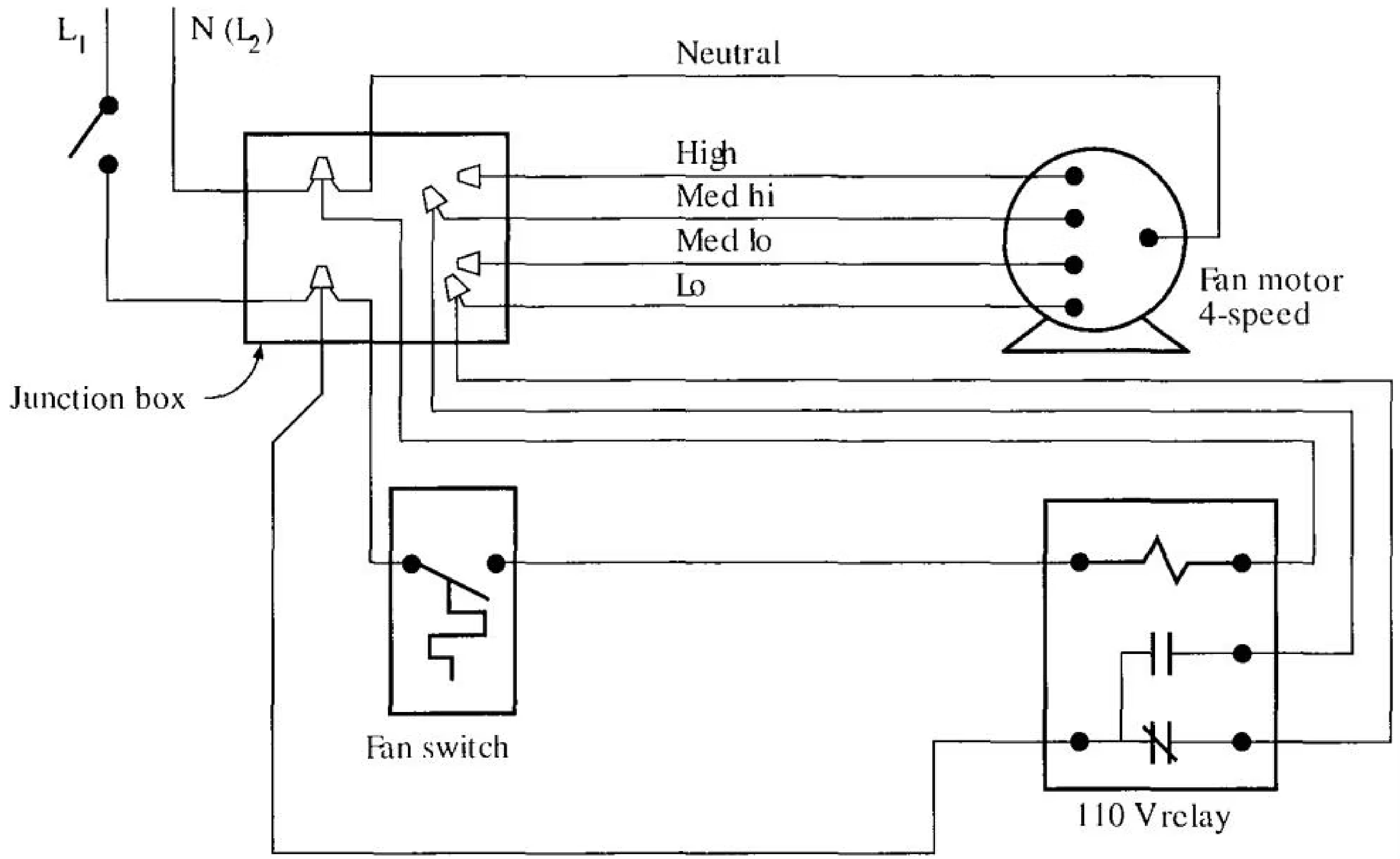
Wiring Configuration

The wiring schematic on the fan indicates the speed color codes. Note the brown wires for the external run capacitor and the orange and purple wires that can be switched to change the fan direction of rotation (CCW or

Operation

The motor remains in the off position until there is a call to circulate the heated air throughout the heating system. The fan motor then circulates the heated air at the determined speed (high, medium, low).

Two-Speed Fan Operation



Older Furnace Systems

For older furnaces, when more than one speed was required, a multiple speed motor needed to be connected to a relay so that two speed taps could be used.

Some systems were designed so that the fan motor operated at a low speed on the off cycle to provide building air circulation. It then operated at high speed when the fan switch closed to provide heated air circulation.

Relay Operation

A single-pole, double-throw relay can open one circuit and close another circuit at the same time.

A relay connected to the Lo speed tap and to the Med-hi on a four-speed motor will operate at low speed until the fan switch energizes the relay. Once energized, the relay switch powers the medium-high circuit, and the fan speed increases.

Modern Furnace Control Boards

Modern furnaces use an electronic circuit board with multiple fan speed terminals to switch fan speeds. The circuit board energizes the appropriate terminal to match the operating parameters of the furnace such as low heat, high heat, or cooling.

Speed Wire Connection

The appropriate motor speed wire is connected to the appropriate terminal, and any speed wires not required are connected to the terminals marked "unused" or "parked" wire.

Speed Configuration

The manufacturer gives recommended blower speed for the various stages, but this always needs to be field verified for each particular installation.

Performance Specifications

The manufacturer also specifies the temperature rise and the maximum external static pressure for the furnace.

Figure 6-24
Multispeed fan connection points on circuit board
Courtesy of White-Rodgers, part of Emerson Climate Technologies

Variable Speed DC Motors

Where a load is driven by a motor and its speed needs to be varied, a DC motor may be used. A DC motor includes two main circuits:

Field Circuit

The stationary component that creates the magnetic field.

Armature Circuit

Rotates with the drive shaft and interacts with the field circuit.

In general, DC motors have the characteristic of delivering a momentary high torque under load conditions at speeds above zero to full speed. This characteristic is ideal for acceleration and deceleration applications. These motors are also more energy efficient than AC motors.

Series Motor

High starting torque but poor speed regulation.

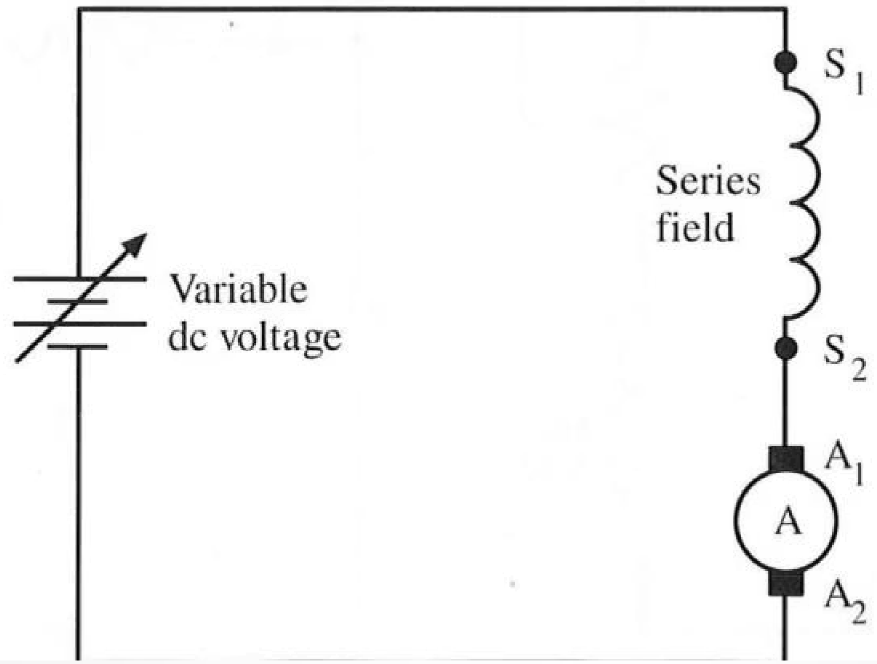
Shunt Motor

Fairly high torque and constant speed regulation under any load.

Compound Motor

Combines features of both series and shunt motors for high torque and good speed control.

Figure 6-25
Variable speed dc series motor



DC Series Motor

Speed Control

The speed of a DC series motor is controlled by varying the source voltage that is applied in series with the field and armature circuits.

Characteristics

Although its starting torque is high, its speed regulation is poor.

The speed varies significantly with changes in load - as load decreases, speed increases dramatically.

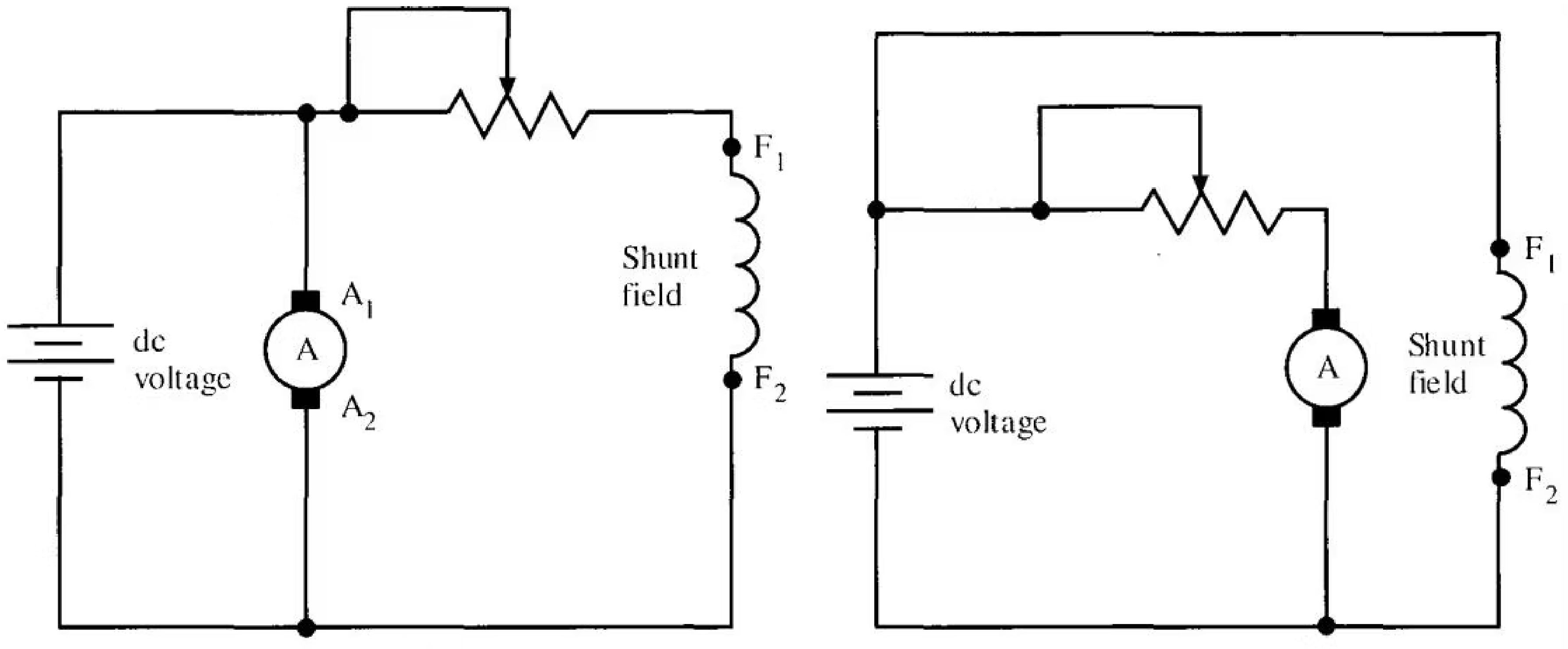
Applications

Used in applications requiring high starting torque and where variable speed is acceptable or desirable.

Common in traction applications like electric vehicles, cranes, and hoists.

DC Shunt Motor

Figure 6-26
Variable speed dc shunt motor



(a) Field voltage varied
(b) Armature voltage varied

Applications

Where a fairly high torque is required and constant speed regulation under any load is desired, a DC shunt motor is used.

These motors maintain relatively constant speed regardless of load changes, making them ideal for applications requiring precise speed control.

Speed Control Methods

To control the speed of this kind of motor, either:

- The voltage to the field circuit is varied (field control)
- The voltage to the armature is varied (armature control)

Each method provides different speed control characteristics and is selected based on the specific application requirements.

DC Compound Motor

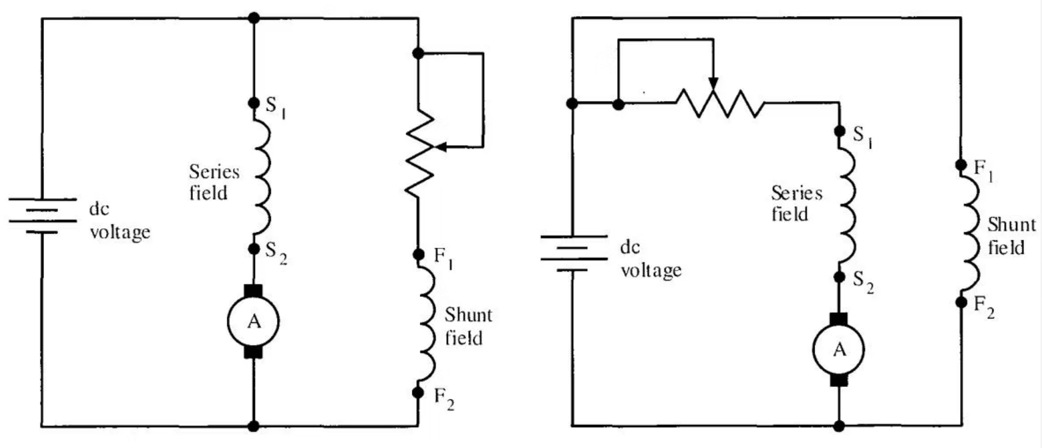
Design

In applications where it is desirable to have both a high torque and good speed control characteristics, a DC compound motor is used.

Operation

Combines the characteristics of both series and shunt motors by having both series and shunt field windings.

The series field provides high starting torque while the shunt field provides good speed regulation.



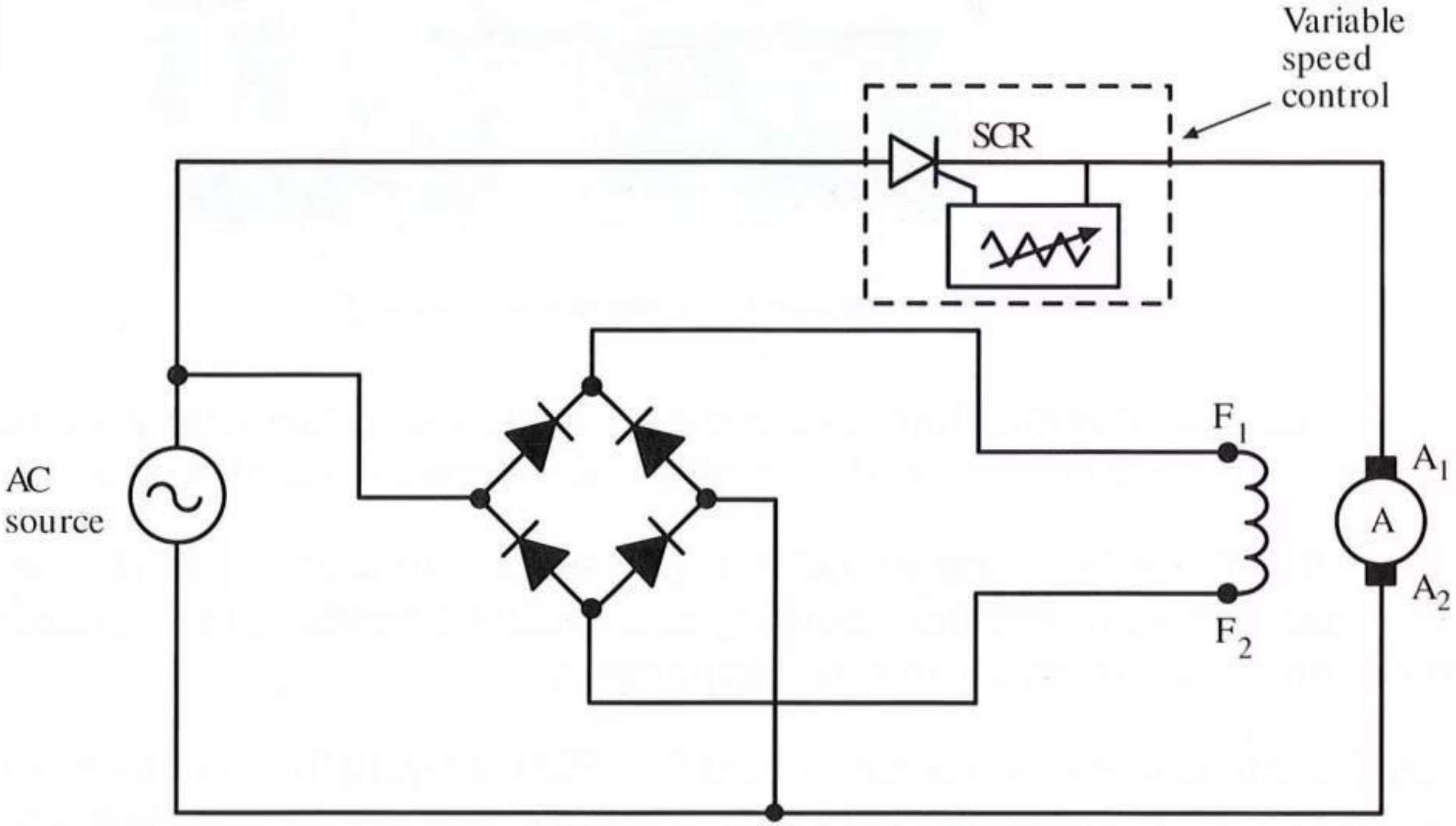
(a) Current varied in shunt field (b) Voltage varied across armature circuit

Speed Control

Two methods of variable speed control are available, similar to those used in shunt motors.

The compound configuration allows for more flexible control options to match specific application requirements.

Solid-State Devices in Speed Control



Historical Development

Prior to the discovery of solid-state devices, it was common to control the speed of DC motors by using rheostats to adjust the DC voltage source.

Since solid-state devices are much smaller in size and are more energy-efficient - they do not dissipate heat like rheostats - these devices are now used as speed control devices.

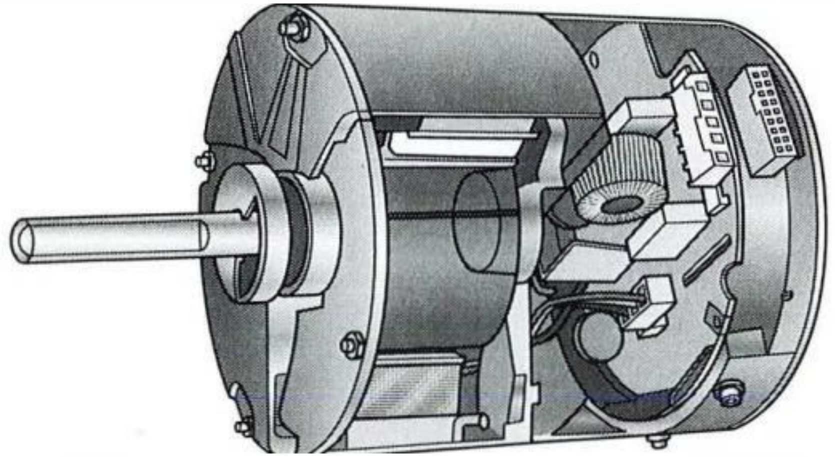
Modern Control Systems

A typical variable speed control uses silicon-controlled rectifiers (SCRs) and other solid-state components.

With solid-state devices, there is no longer a need for a DC source because these devices also convert AC to DC. The net result is that a DC motor can be energized from an AC source.

This provides more efficient, precise, and reliable speed control than older mechanical methods.

Electronically Commutated Motor (ECM)



The ECM is a brushless DC, three-phase motor with a permanent magnet rotor. Motor phases are sequentially energized by the electronic control, powered from a single-phase supply.

Construction

The GE ECM variable speed motor is built as two separate components: the motor, which does not have any windings in it, and the controls section.

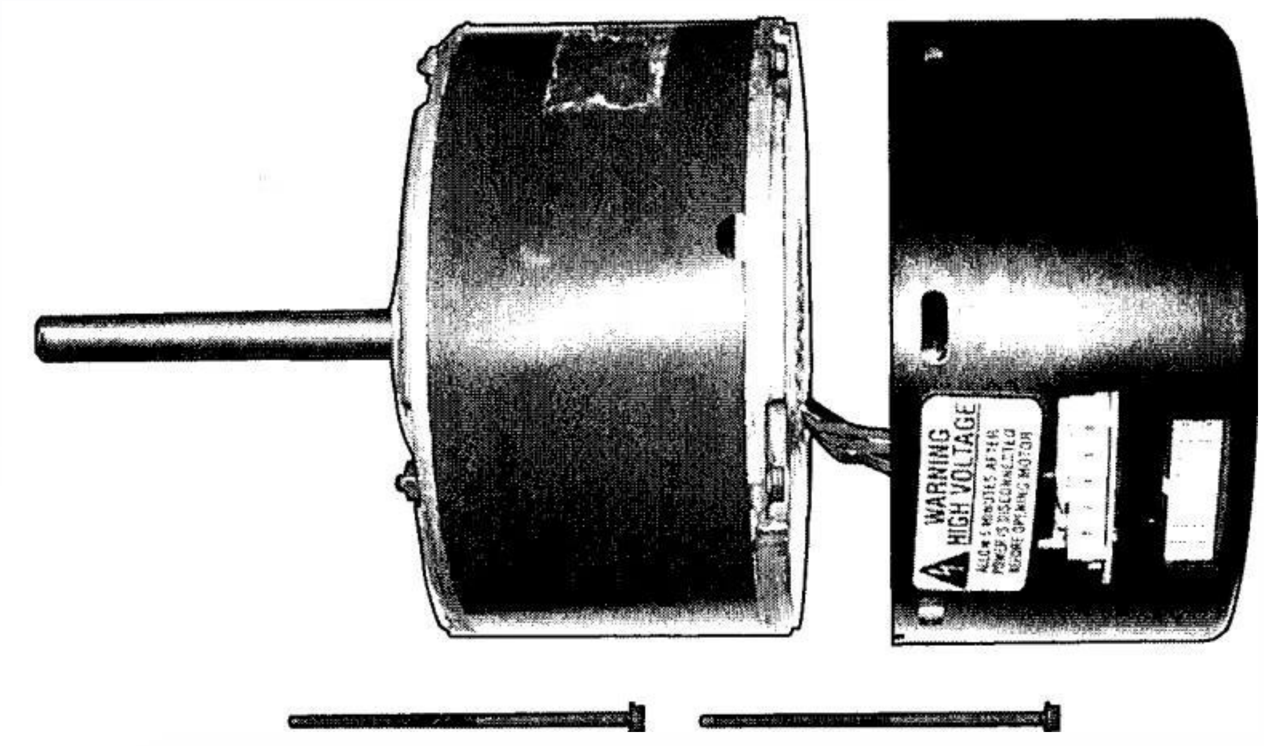
Control System

The controls section includes a microprocessor calibrated at the factory to suit the piece of equipment and enable the motor to adapt its speed to match the system conditions.

Applications

The ECM is widely used in most new furnaces and air handlers as it can supply the correct programmed air flow (CFM) by monitoring the relationship between speed, torque, and airflow.

ECM Motor Components



Motor Module

The motor component contains the permanent magnet rotor and stator assembly.

Unlike traditional motors, it doesn't have conventional windings but relies on the control module to energize the appropriate phases.

The design eliminates brushes, making it more reliable and efficient than traditional DC motors.

Control Module

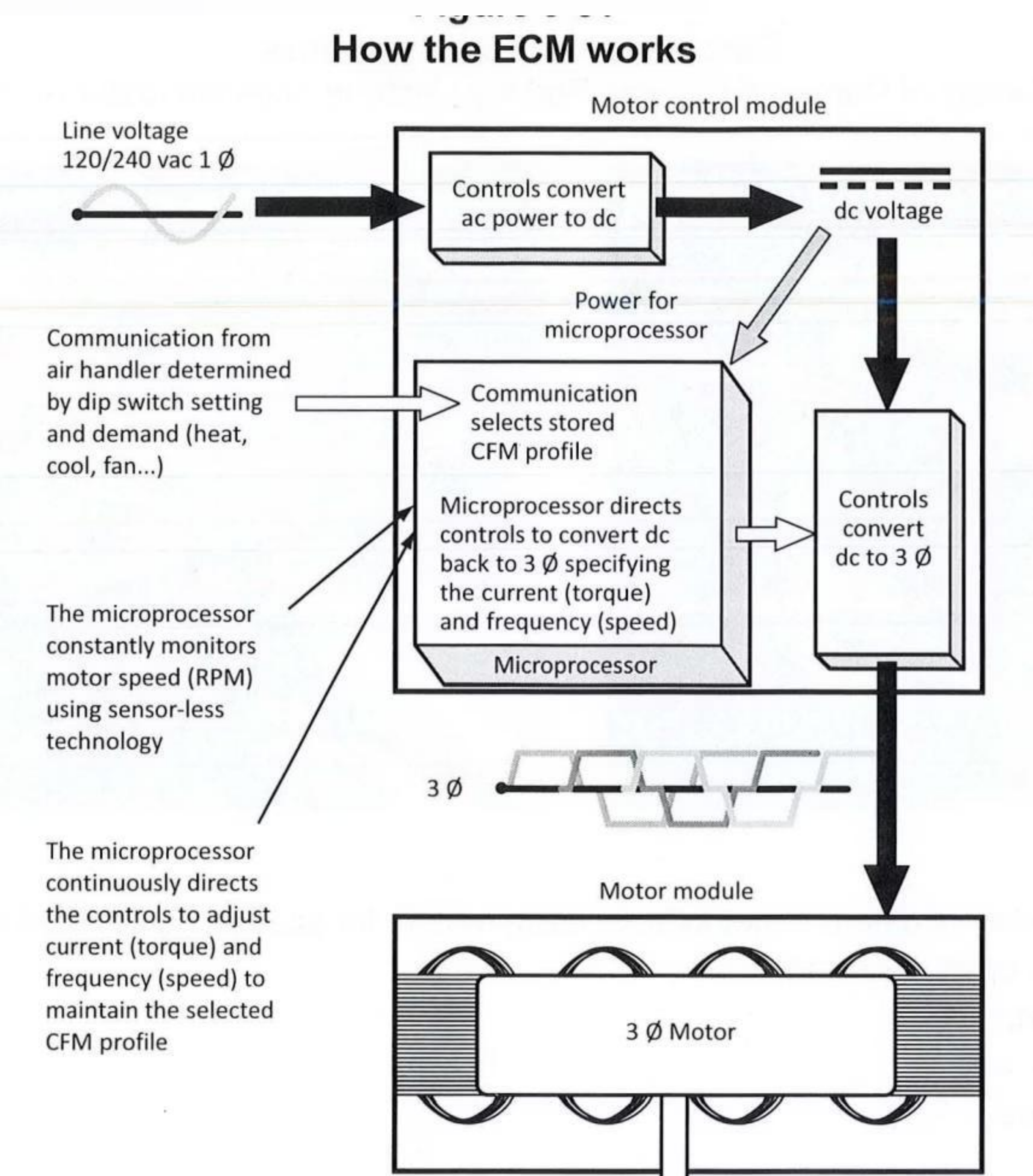
Houses the microprocessor and power electronics that control the motor operation.

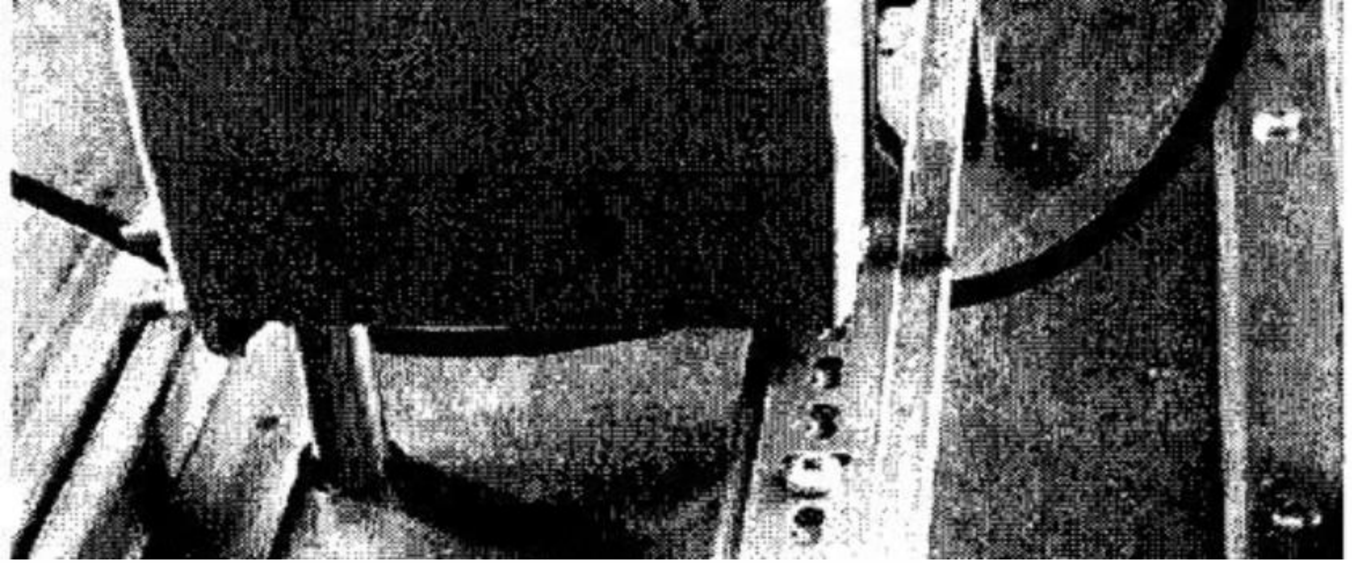
Programmed at the factory to match the specific equipment requirements.

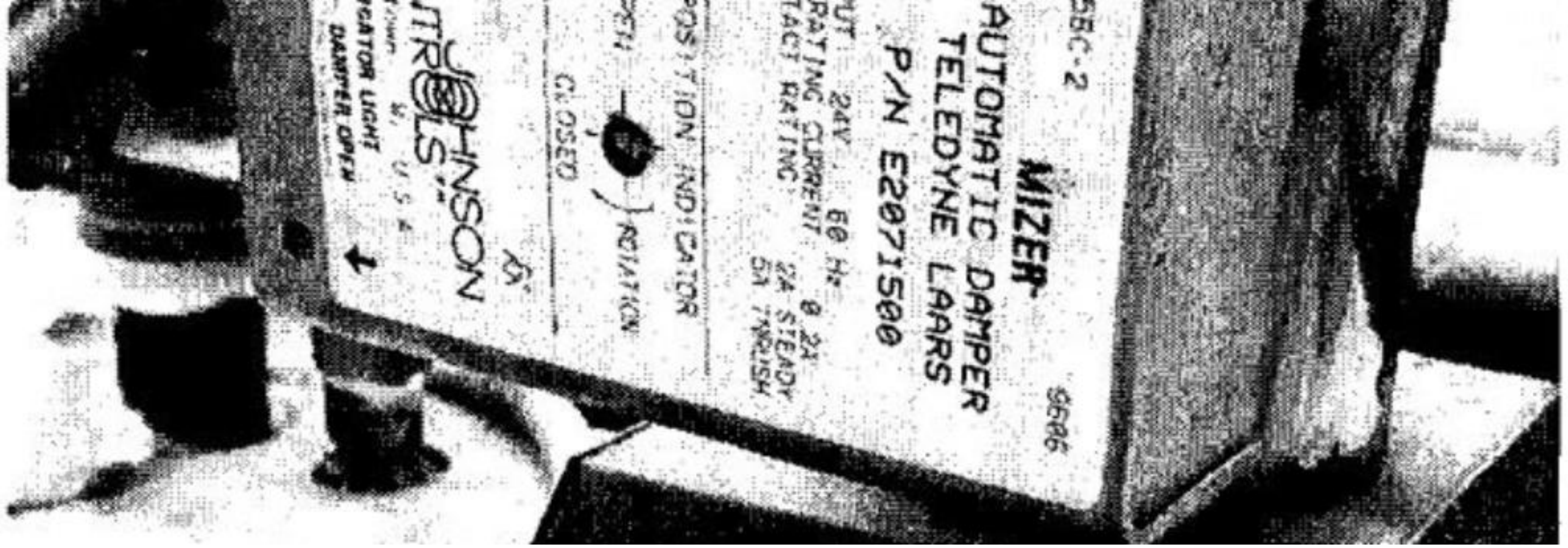
Provides precise control of speed, torque, and airflow based on system demands.

Connects to the main control board via a multi-pin harness to receive operating commands.

ECM Operation Principles







Motion Control Positioning Motors

There are many examples of valves and dampers that are automatically operated by motors. Some applications may only require a fully open or closed position, whereas others require a full range of positions (modulation).

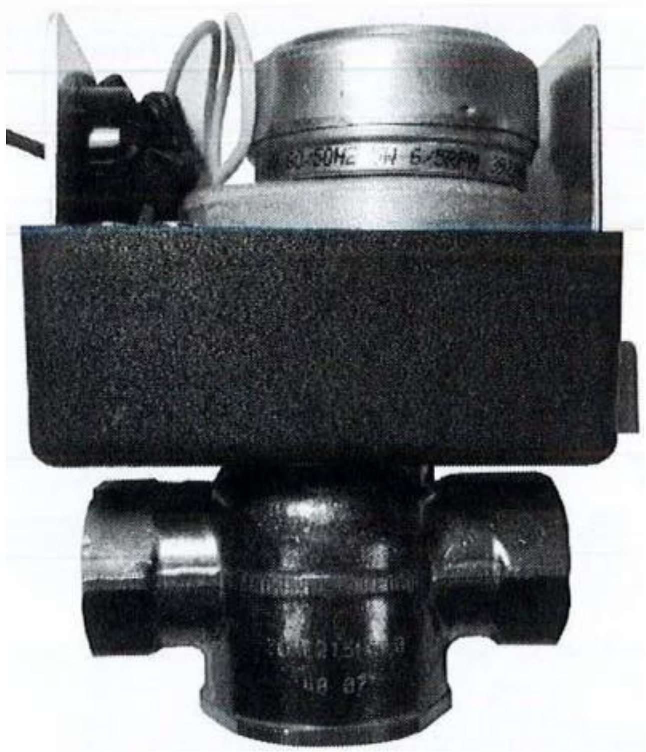
Common Names

- Actuating motors
- Motor operators
- Modulating motors
- Electronic actuators

Positioning Methods

- Powered fully open or closed
- Floating action
- Servo motors
- Stepper motors

Fully Open or Fully Closed Motor Operators



Basic Operation

A basic open or closed motorized system is often used on dampers and hydronic control valves.

They receive a 24V AC or 110V AC signal, which energizes the synchronous motor opening or closing the valve.

Mechanism

When power is applied, the motor and gears act against the force of a spring to operate the valve.

When power is removed, the spring returns the valve to its resting position.

These types of valve consume power whenever they are active and, typically, when the system controls are calling for heat.

The motor runs until the valve is fully open or closed and then stalls as the actuator mechanism cannot move any further - valve position feedback may be used with some controllers.

Modulating Motor Actuators

You can use a modulating actuator to position the control valve in response to the system requirements.

Floating Action

Floating action valve motor actuators receive a powered voltage control signal (24V AC, 110V AC, or 230V AC) in order to move a valve.

The floating action controller either provides power to drive the motor further open or closed.

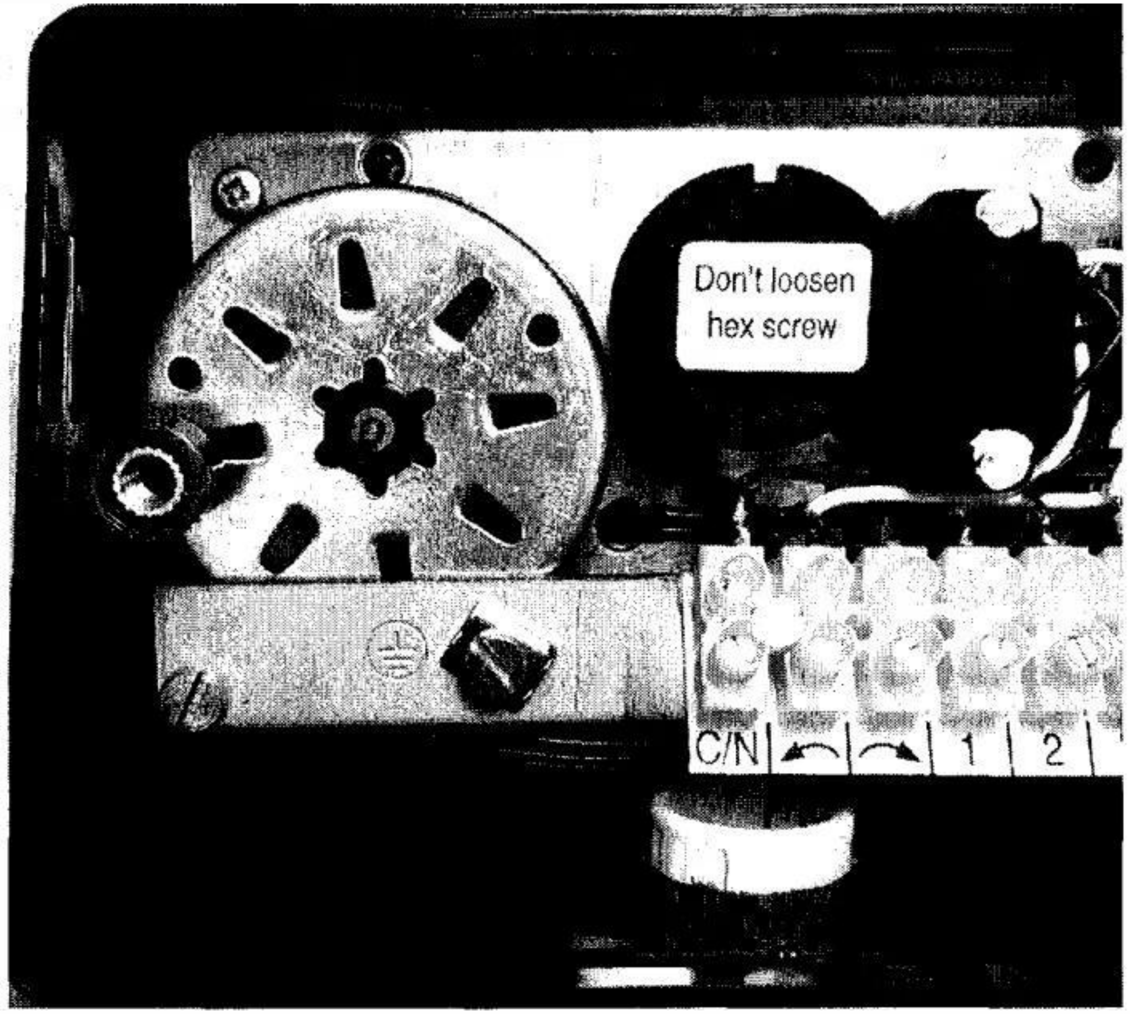
If no power is supplied, the actuating motor remains at its present position.

Positioning Method

This is a simple and cost-effective method for controlling the position of a mixing valve.

It uses the timing of the actuator to position the valve. For example, if it needs to be at 20% open and the actuator is a 90 second model, from full closed, it will send an open command for 18 seconds.

Floating Action Positioning Motor



Control Signals

Floating action motors typically operate on 24V AC control signals.

The controller sends signals to either open or close the valve/damper incrementally.

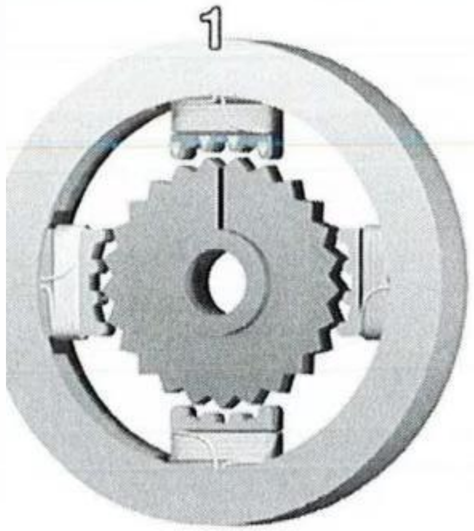
When no signal is present, the actuator holds its position.

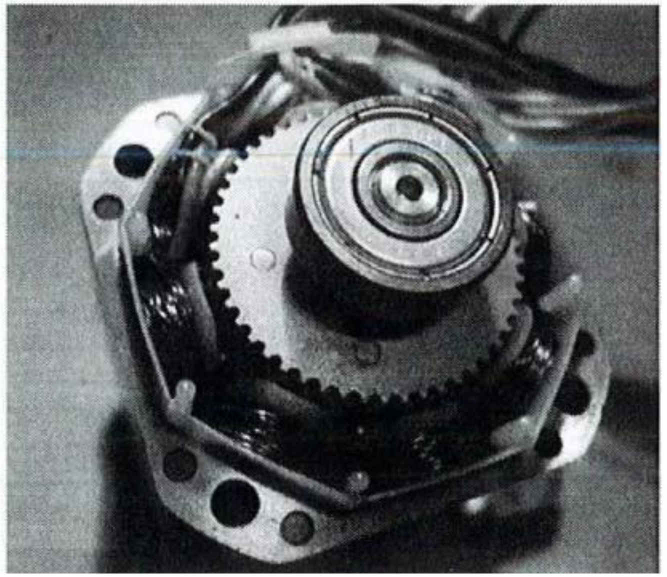
Applications

Commonly used in HVAC systems for:

- Zone control dampers
- Mixing valves for hydronic systems
- Variable air volume (VAV) box dampers
- Other applications requiring proportional control

Stepper Motors





A stepper motor operator is an open loop positioning system that converts digital pulses into mechanical shaft rotation. It is a brushless DC electric motor that moves in increments or steps, rather than turning smoothly as a conventional motor does.

Construction

In a stepper motor, there is an internal rotor made of a magnetic wheel with a large number of projected (salient) poles and controlled by a set of external magnets switched electronically.

The number of poles and magnets determines the size of the incremental rotation in degrees and can vary depending on the application; it can be from 90° to 0.75°, corresponding to 4 to 500 steps per revolution.

Operation

Inside the device, sets of coils produce magnetic fields that interact with the fields of permanent magnets.

The coils are switched on and off in a specific sequence (steps) by a microcontroller to cause the motor shaft to turn one step or pole at a time.

By sending out a control number of steps, the motor can be turned to the desired angle.

The motor can also operate in either direction (clockwise or counter-clockwise) and hold at a certain position until different coils are energized.

Stepper Motor Applications

Gas Valve Control

The image shows a gas valve that utilizes a stepper motor to modulate the servo regulator on the valve.

This enables it to fully modulate the manifold pressure and therefore the firing rate of the appliance.

Precision Control

Stepper motors provide precise positioning capability, allowing for exact control of gas flow.

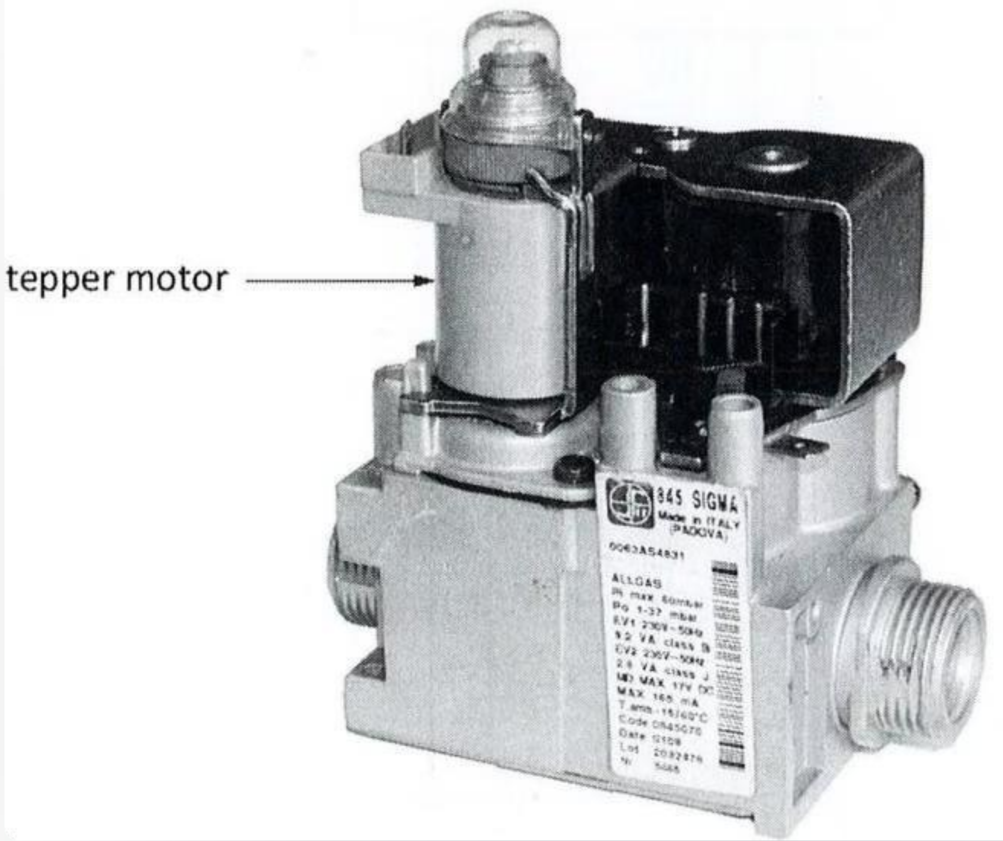
The digital control signals can position the valve at any point in its range with high repeatability.

Other HVAC Applications

Beyond gas valves, stepper motors are used in various HVAC applications requiring precise positioning:

- Electronic expansion valves in refrigeration systems
- Precision damper controls
- Zone control systems

Figure 6-36
Modulating combination gas valve
Courtesy of SIT S.p.A



Servo Motors

Figure 6-37
Servo motor actuator

A servo motor operator is a part of a closed loop system. Along with the motor, a positioning circuit is included in the modulating actuator, which accepts an analogue control signal (typically 0-10V or 4-20mA).

Control Signal Input

The actuator interprets the control signal as the valve position between the limit switches.

Position Feedback

The actuator has a position sensor (usually a potentiometer), which feeds the actual valve position back to the positioning circuit.

Signal Comparison

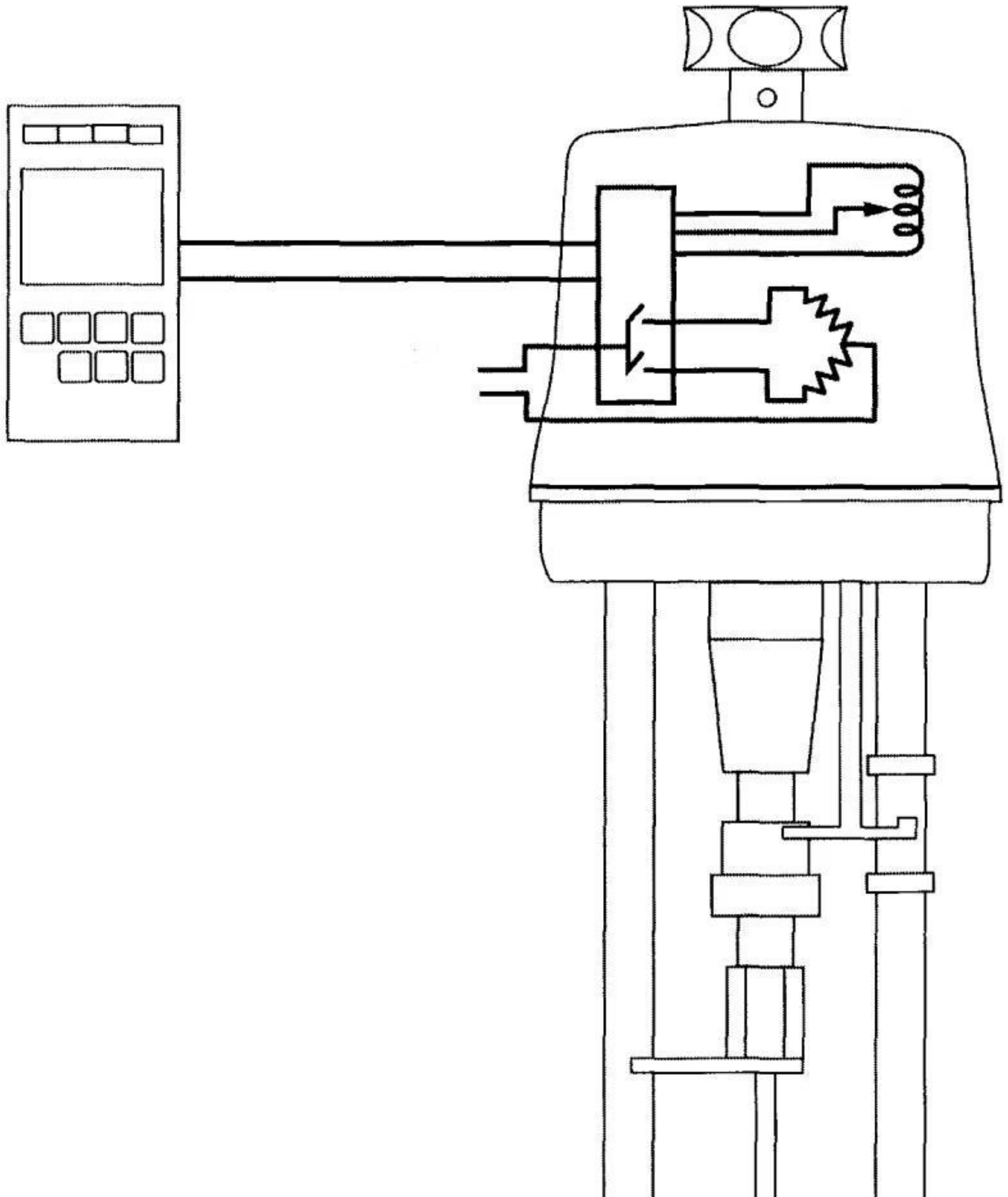
The controller compares the desired position (input signal) with the actual position (feedback signal).

Position Adjustment

The actuator can be positioned along its stroke in proportion to the control signal, with continuous adjustment to maintain the exact position.

The servo motor systems are used where a high degree of accuracy and acceleration are required.

Servo Motor Applications



Motor Selection Considerations

Application Requirements

Different motors are needed for different tasks because motors have different starting and running characteristics.

Torque Needs

Compressors require a motor with a high starting torque and good running efficiency. Small propeller fans use motors with a low starting torque and average running efficiency.

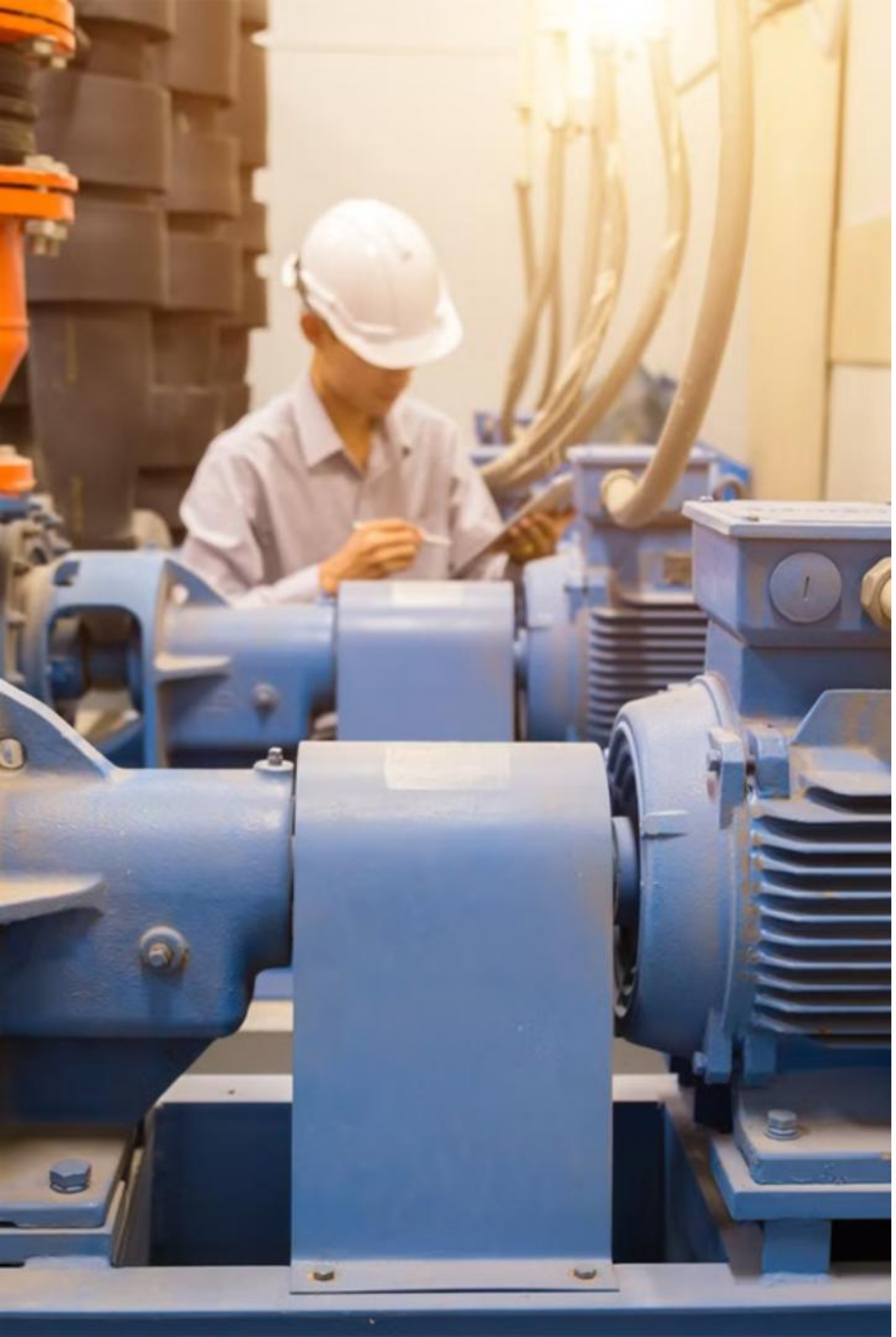
Power Supply

Motors are classified according to the type of AC power (three-phase or single-phase) and the motor's principle of operation.

Environmental Factors

Consider ambient temperature, humidity, and exposure to contaminants when selecting a motor.

Always consult the manufacturer's manuals and instructions before choosing or installing a motor to ensure proper selection for the specific application.



Motor Maintenance Best Practices

Regular Inspection

Periodically check motors for unusual noise, vibration, or heat which can indicate developing problems.

Inspect mounting bolts and connections to ensure they remain tight.

Bearing Maintenance

Follow manufacturer's recommendations for lubrication intervals and procedures.

For motors with grease fittings, avoid over-greasing which can damage seals and cause overheating.

Electrical Checks

Periodically measure current draw to ensure it remains within nameplate specifications.

Check insulation resistance to detect deterioration before failure occurs.

Cleanliness

Keep motors clean and free from dust, dirt, and oil which can impede cooling and cause insulation breakdown.

Ensure ventilation openings remain unobstructed for proper cooling.

Reversible by transposing armature leads.

FIELD—Reversible by connecting either field lead to line.

CONTROLLED SERIES-WOUND—Non-reversible.

Troubleshooting Motor Issues

Problem	Possible Causes	Solutions
Motor fails to start	No power, faulty capacitor, open circuit, mechanical binding	Check power supply, test/replace capacitor, check wiring, check for mechanical obstructions
Motor overheats	Overload, poor ventilation, incorrect voltage, bearing failure	Verify load is within rating, ensure proper airflow, check voltage, inspect/replace bearings
Excessive noise	Worn bearings, misalignment, loose parts, electrical problems	Replace bearings, realign motor, tighten components, check electrical connections
Motor runs but load doesn't move	Broken coupling, sheared key, belt issues	Inspect and replace coupling, check key and keyway, adjust/replace belts

Energy Efficiency Considerations

Future Trends in Motor Technology

IoT Integration

Motors with built-in sensors and connectivity for remote monitoring and predictive maintenance.

Higher Efficiency Standards

Continued development of more efficient motor designs to meet stricter energy regulations.

Advanced Materials

New magnetic materials and insulation systems allowing for smaller, more powerful motors.

Integrated Controls

More sophisticated onboard electronics with adaptive algorithms for optimal performance.

The future of electric motors in HVAC applications is moving toward smarter, more connected devices that can communicate with building management systems and adapt to changing conditions automatically. These advancements will continue to improve efficiency, reliability, and ease of maintenance while reducing energy consumption and environmental impact.