

CHAPTER 14: Electricity for Gas Technicians

Learning Objectives

Upon completion of this chapter, you will be able to:

1. **Understand** fundamental electrical theory including voltage, current, resistance, and power calculations
2. **Apply** Ohm's Law to solve electrical circuit problems
3. **Demonstrate** safe electrical work practices and lockout/tagout procedures
4. **Use** electrical measurement tools including multimeters and clamp meters
5. **Identify** electrical components commonly found in gas heating systems
6. **Analyze** control circuits and wiring diagrams
7. **Install and troubleshoot** thermostats and control devices
8. **Diagnose** motor problems and understand motor control systems
9. **Follow** Canadian Electrical Code requirements relevant to gas installations
10. **Interpret** ladder diagrams and schematic symbols

Introduction

Electrical systems are integral to modern gas heating equipment. From simple thermostats to complex electronic control boards, gas technicians must understand electrical fundamentals to properly install, maintain, and troubleshoot heating systems. This chapter provides comprehensive coverage of electrical theory and practical applications specific to gas technician work.

While gas technicians are not electricians, understanding electricity is essential for:

- Troubleshooting control circuits
- Installing thermostats and controls
- Diagnosing motor failures
- Ensuring safe operation of gas equipment
- Coordinating with electricians when necessary

This chapter emphasizes practical applications while maintaining respect for electrical safety and Canadian Electrical Code requirements.

14.1 Basic Electrical Theory

Understanding Electricity

Electricity is the flow of electrons through a conductor. To understand electrical systems in gas equipment, we need to grasp four fundamental concepts:

Voltage (E or V)

- The electrical pressure or potential difference
- Measured in volts (V)
- Similar to water pressure in a pipe
- Common voltages in HVAC:
 - 24VAC (control circuits)
 - 115/120VAC (standard equipment)
 - 208/230VAC (larger equipment)
 - 460VAC (commercial/industrial)

Current (I)

- The flow of electrons
- Measured in amperes (amps or A)
- Similar to water flow rate
- Types of current:
 - Direct Current (DC): flows in one direction
 - Alternating Current (AC): reverses direction periodically

Resistance (R)

- Opposition to current flow
- Measured in ohms (Ω)
- Similar to pipe restrictions in water systems
- Factors affecting resistance:
 - Material type (copper vs. steel)
 - Wire length (longer = more resistance)
 - Wire diameter (smaller = more resistance)
 - Temperature (higher = more resistance in most conductors)

Power (P)

- The rate of doing work
- Measured in watts (W)
- Calculated as: $P = V \times I$
- Common power ratings:
 - Blower motors: 1/4 to 1 HP (186-746W)
 - Inducer motors: 50-150W
 - Transformers: 20-75VA

Ohm's Law

Ohm's Law describes the relationship between voltage, current, and resistance:

$$E = I \times R$$

Where:

- E = Voltage (volts)
- I = Current (amps)
- R = Resistance (ohms)

Variations of Ohm's Law:

- $I = E/R$ (finding current)
- $R = E/I$ (finding resistance)

Practical Applications:

Example 1: Finding Current A 24V transformer supplies power to a gas valve with 12Ω resistance.

- $I = E/R = 24V \div 12\Omega = 2A$

Example 2: Finding Resistance A blower motor draws 5A at 115V.

- $R = E/I = 115V \div 5A = 23\Omega$

Example 3: Voltage Drop A long thermostat wire has 2Ω resistance carrying 0.5A.

- $E = I \times R = 0.5A \times 2\Omega = 1V$ drop

Power Calculations

Basic Power Formula: $P = E \times I$

Combined with Ohm's Law:

- $P = I^2 \times R$
- $P = E^2/R$

Three-Phase Power: $P = \sqrt{3} \times E \times I \times PF$

Where PF = Power Factor (typically 0.8-0.95 for motors)

Practical Examples:

Single-Phase Motor:

- Voltage: 115V
- Current: 4.5A
- Power: $P = 115V \times 4.5A = 517.5W$

Heating Element:

- Voltage: 230V
- Resistance: 25Ω
- Power: $P = E^2/R = 230^2 \div 25 = 2,116W$

AC vs. DC Power

Direct Current (DC)

- Constant voltage polarity
- Used in:
 - Electronic control boards (rectified)
 - Flame sensors (microamps DC)
 - Some smart thermostats
 - Battery backup systems

Alternating Current (AC)

- Voltage alternates polarity
- Standard frequency: 60 Hz in North America
- Used in:
 - Most HVAC equipment
 - Control transformers
 - Motors and compressors
 - Standard electrical supply

Key AC Concepts:

- **Peak Voltage:** Maximum instantaneous value
- **RMS Voltage:** Root Mean Square (effective value)
 - 120VAC RMS = 170V peak
- **Frequency:** 60 cycles per second (60 Hz)
- **Phase:** Single-phase or three-phase power

Series and Parallel Circuits

Series Circuits Characteristics:

- Single path for current flow
- Current same throughout circuit
- Voltage divides across loads

- Total resistance: $R_T = R_1 + R_2 + R_3...$

Applications in HVAC:

- Safety control circuits
- Limit switches in series
- Thermostat circuits

Parallel Circuits Characteristics:

- Multiple paths for current
- Voltage same across all branches
- Current divides between branches
- Total resistance: $1/R_T = 1/R_1 + 1/R_2 + 1/R_3...$

Applications in HVAC:

- Operating circuits
- Multiple motors or loads
- Control relay contacts

Series-Parallel Combinations Most HVAC circuits combine both:

- Safety controls in series
- Operating loads in parallel
- Control and power circuits separate

14.2 Electrical Safety

Electrical Hazards in Gas Work

Gas technicians face unique electrical hazards:

Shock Hazards

- Working in confined spaces
- Wet or damp conditions
- Metallic ductwork and piping
- Mixed voltages (24V to 600V)

Arc Flash Risks

- Opening electrical panels
- Testing live circuits

- Motor disconnects
- Control panel work

Secondary Hazards

- Falls from ladders due to shock
- Fires from electrical faults
- Explosion risks in gas environments
- Burns from heated components

Safe Working Practices

Pre-Work Safety

1. **Hazard Assessment**
 - Identify all electrical sources
 - Check for water or moisture
 - Assess workspace conditions
 - Review equipment specifications
2. **Planning**
 - Determine required PPE
 - Gather proper tools
 - Plan lockout procedures
 - Coordinate with other trades

During Work

1. **Voltage Verification**
 - Test meter on known source
 - Check circuit with meter
 - Test meter again
 - Treat all circuits as live until proven otherwise
2. **Safe Positioning**
 - Stand on dry, insulated surface
 - Keep one hand free when possible
 - Position body to side of panels
 - Maintain clear escape route
3. **Tool Usage**
 - Use insulated tools
 - Inspect tools before use
 - Use proper meter settings
 - Never bypass safety devices

Lockout/Tagout Procedures

Standard LOTO Process:

1. **Preparation**
 - Identify all energy sources
 - Notify affected personnel
 - Gather locks and tags
2. **Shutdown**
 - Follow normal shutdown procedure
 - Turn off disconnect switches
 - Close manual gas valves
3. **Isolation**
 - Open electrical disconnects
 - Close and lock gas valves
 - Disconnect control power
4. **Lockout/Tagout**
 - Apply personal lock
 - Attach warning tag
 - Each worker applies own lock
 - Keep key in personal possession
5. **Stored Energy Release**
 - Discharge capacitors
 - Bleed gas lines
 - Allow motors to stop
 - Release spring tension
6. **Verification**
 - Attempt normal startup
 - Test with meter
 - Verify zero energy state
7. **Work Performance**
 - Complete required work
 - Maintain locks throughout
8. **Restoration**
 - Remove tools and materials
 - Reinstall guards
 - Verify safe conditions
 - Remove locks in reverse order
 - Test operation

Canadian Electrical Code Basics

Relevant CEC Sections for Gas Technicians:

Section 2 - General Rules

- Electrical room access
- Working clearances
- Disconnect requirements

Section 4 - Conductors

- Wire sizing for motors
- Temperature ratings
- Voltage drop limits

Section 10 - Grounding and Bonding

- Equipment grounding
- Bonding gas piping
- CSST bonding requirements

Section 14 - Protection and Control

- Overcurrent protection
- Motor protection
- Control circuit protection

Section 26 - Installation of Electrical Equipment

- Furnace connections
- Appliance requirements
- Disconnect switches

Section 28 - Motors and Generators

- Motor installations
- Overload protection
- Motor controllers

Key Requirements:

- Disconnect within sight and 3m of furnace
- Proper wire sizing for load
- Overcurrent protection sizing
- Grounding of all equipment
- Proper junction box usage
- Maintaining manufacturer clearances

Personal Protective Equipment

Minimum PPE for Electrical Work:

1. **Safety Glasses**
 - Side shields required
 - Arc-rated for panel work

2. Insulated Gloves

- Class 0 minimum (1000V)
- Inspected before each use
- Leather protectors worn over

3. Arc-Rated Clothing

- Minimum 8 cal/cm²
- No synthetic materials
- Long sleeves required

4. Safety Footwear

- CSA approved
- Electrical hazard rated
- Non-conductive soles

Additional PPE When Required:

- Face shield for arc flash risk
- Insulating mats
- Hot stick for remote operation
- Voltage-rated tools

Arc Flash Awareness

Arc Flash Basics:

- Temperature can exceed 19,000°C
- Pressure wave can exceed 2,000 lbs/sq.ft
- Sound can exceed 140 dB
- Duration typically 1-5 cycles

Protection Measures:

1. Maintain Safe Distance

- Work de-energized when possible
- Use remote racking
- Install barriers

2. PPE Selection

- Based on incident energy
- Follow arc flash labels
- Higher PPE for higher risk

3. Work Practices

- Minimize exposed live parts
 - Use insulated tools
 - Position body safely
 - Have escape route planned
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14.3 Electrical Measurement

Using Multimeters

Digital Multimeter Components:

- Display (LCD/LED)
- Function selector
- Input jacks
- Test leads
- Range selector (auto/manual)

Basic Functions:

- Voltage (AC/DC)
- Current (limited)
- Resistance
- Continuity
- Capacitance (some models)
- Temperature (some models)

Safety Ratings:

- CAT I: Electronic circuits
- CAT II: Household receptacles
- CAT III: Distribution panels
- CAT IV: Utility connections

HVAC work typically requires CAT III 600V minimum

Voltage Testing

AC Voltage Measurement:

1. **Preparation**
 - Select VAC function
 - Insert leads (black to COM, red to V)
 - Select appropriate range (if manual)
2. **Testing Procedure**
 - Test meter on known source
 - Place leads on test points
 - Read display
 - Document reading
3. **Common Measurements**
 - Line voltage: 115V, 208V, 230V, 460V
 - Control voltage: 24VAC

- Voltage drop across components

DC Voltage Measurement:

- Select VDC function
- Observe polarity
- Common in:
 - Flame sensors (microvolts)
 - Electronic boards (5V, 12V, 24V)
 - Battery systems

Safety Practices:

- Never exceed meter ratings
- Start with highest range
- Keep fingers behind guards
- One hand operation when possible

Continuity Testing

Purpose:

- Check for complete circuit path
- Verify switch operation
- Find broken wires
- Test fuses

Procedure:

1. **Ensure Power is OFF**
2. Isolate component if possible
3. Select continuity (Ω or \bullet))
4. Zero meter if required
5. Test across component
6. Listen for beep or check reading

Interpreting Results:

- Continuity: $< 1\Omega$ (beep sounds)
- No continuity: OL or infinite
- High resistance: numerical value

Common Applications:

- Limit switch testing
- Thermostat contacts

- Fuse testing
- Wire tracing
- Motor winding checks

Resistance Measurement

Applications in HVAC:

- Motor windings
- Heating elements
- Thermistors
- Solenoid coils
- Sensor resistance

Measurement Procedure:

1. Power OFF and verified
2. Disconnect component
3. Select ohms (Ω)
4. Choose appropriate range
5. Zero meter if needed
6. Measure resistance
7. Compare to specifications

Typical Resistance Values:

Component	Typical Resistance
Gas valve solenoid	10-50 Ω
Blower motor winding	2-20 Ω
Inducer motor	10-50 Ω
Transformer primary	1-5 Ω
Transformer secondary	0.1-1 Ω
Limit switch (closed)	< 1 Ω
Flame sensor	Infinite (clean)

Current Measurement

In-Line Current (Multimeter):

- Limited to 10A typically
- Requires breaking circuit
- Used for small loads only

Clamp Meter Measurement:

Advantages:

- No circuit interruption
- Safer operation
- Higher current ranges
- Quick measurements

Procedure:

1. Select AC amps
2. Zero meter if needed
3. Open clamp jaws
4. Clamp around single conductor
5. Read display
6. Compare to nameplate

Important Notes:

- Clamp single conductor only
- Not around entire cable
- Can multiply turns for low current
- Some measure DC current

Typical Current Draws:

Component	Typical Current
1/3 HP blower	3.5-4.5A
1/2 HP blower	4.5-6A
Inducer motor	0.5-1.5A
Gas valve	0.2-0.5A
Hot surface igniter	3-5A
Control transformer	0.3-0.7A

Safety Precautions**Before Testing:**

- Inspect meter and leads
- Check meter battery
- Verify meter ratings
- Select correct function
- Wear appropriate PPE

During Testing:

- Keep leads separated
- Don't exceed ratings
- Be aware of surroundings
- Maintain stable position
- Watch for unexpected readings

After Testing:

- Remove leads from circuit first
- Then remove from meter
- Store properly
- Document readings

Common Mistakes to Avoid:

1. Wrong function selected
 2. Measuring resistance on live circuit
 3. Exceeding meter ratings
 4. Using damaged leads
 5. Improper range selection
 6. Not zeroing meter
 7. Testing without PPE
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14.4 Electrical Components in Gas Systems

Transformers

Purpose: Convert line voltage (115V/230V) to control voltage (24V)

Types:

1. **Control Transformers**
 - 40VA most common
 - 20VA to 75VA range
 - Class 2 (current limited)
2. **Multi-Tap Transformers**
 - Multiple primary voltages
 - 115/208/230V common
 - Allows field voltage selection

Specifications:

- **VA Rating:** Volt-Ampere capacity
- **Primary Voltage:** Input voltage

- **Secondary Voltage:** Output voltage (typically 24VAC)
- **Frequency:** 60 Hz standard
- **Temperature Rise:** 55°C typical

Testing Transformers:

1. **Primary Voltage Check**
 - Measure across primary terminals
 - Should match nameplate
2. **Secondary Voltage Check**
 - Measure across secondary
 - Should be 24-28VAC (no load)
3. **VA Load Test**
 - Measure secondary current
 - Calculate: $VA = 24V \times \text{Current}$
 - Should not exceed rating

Common Problems:

- Open primary winding
- Shorted windings
- Overloaded (overheating)
- Incorrect wiring
- Wrong voltage tap

Relays and Contactors

Relays Electromagnetic switches for control circuits

Components:

- Coil (24V typical)
- Contacts (NO, NC, or both)
- Armature
- Spring return

Types:

1. **General Purpose**
 - SPDT, DPDT configurations
 - 24V coil typical
 - Contacts rated 10-30A
2. **Fan Relays**
 - Controls blower motor
 - 24V coil
 - Heavy-duty contacts

3. Sequencing Relays

- Time delay built-in
- Stages heating elements
- Prevents power surge

Testing Relays:

1. Coil resistance: 10-50 Ω typical
2. Coil voltage: 24VAC applied
3. Contact operation: continuity check
4. Contact resistance: < 1 Ω closed

Contactors Heavy-duty relays for large loads

Specifications:

- Higher current ratings (20-100A+)
- 24V or line voltage coils
- Multiple pole configurations
- Designed for frequent cycling

Applications:

- Electric heating elements
- Large blower motors
- Compressors
- Commercial equipment

Switches

Limit Switches Safety devices that open on high temperature

Types:

1. **Primary Limit**
 - Manual reset
 - 200°F typical
 - Prevents overheating
2. **Fan Limit**
 - Auto reset
 - Controls blower operation
 - 90°F ON, 120°F OFF typical
3. **Rollout Switch**
 - Detects flame rollout
 - Manual or auto reset
 - Multiple locations

Testing:

- Continuity when cold
- Opens at rated temperature
- Check for proper location
- Verify secure mounting

Pressure Switches**Types:**

1. **Furnace Pressure Switch**
 - Proves inducer operation
 - Differential type
 - 0.2" to 1.5" W.C. typical
2. **Gas Pressure Switch**
 - High/low gas pressure
 - Safety shutdown
 - Manual reset often

Testing:

- Continuity at rest (NO or NC)
- Operation at rated pressure
- Tubing connections
- Diaphragm integrity

Flow Switches

- Prove air or water flow
- Paddle or differential type
- Used in commercial systems

Manual Switches

- Disconnect switches
- Service switches
- Door interlock switches

Thermostats (Basic Overview)

Detailed coverage in Section 14.7

Functions:

- Temperature sensing

- Switching control circuits
- System mode selection
- Fan control

Types:

- Mechanical (bimetal)
- Electronic
- Programmable
- Smart/WiFi

Solenoids

Gas Valve Solenoids

Operation:

- Electromagnetic coil
- Opens valve when energized
- Spring return when de-energized
- 24VAC typical

Types:

1. **Single Stage**
 - One solenoid
 - Full capacity only
2. **Two Stage**
 - Two solenoids
 - Low and high fire
3. **Modulating**
 - Variable position
 - Precise control

Testing:

- Coil resistance: 10-50Ω
- Current draw: 0.2-0.5A
- Mechanical operation
- No leakage when closed

Other Solenoids:

- Pilot valves
- Zone valves
- Oil valves

- Refrigerant valves

Motors

Blower Motors

PSC (Permanent Split Capacitor)

- Single-phase
- Capacitor run
- Multiple speeds (taps)
- 1/4 to 1 HP typical

ECM (Electronically Commutated Motor)

- Variable speed
- High efficiency
- Built-in controls
- Constant airflow

Inducer Motors

- Shaded pole or PSC
- 3000-3450 RPM
- 0.5-2.0 amps typical
- Sealed bearings

Testing Motors:

1. Winding resistance
2. Current draw
3. Capacitor check
4. Bearing condition
5. Rotation direction

Detailed motor coverage in Section 14.8

Capacitors

Types:

Run Capacitors

- Continuous duty
- Oil-filled
- Metal case

- 370V or 440V rating
- 5-80 μ F typical

Start Capacitors

- Intermittent duty
- Electrolytic
- Plastic case
- 125V or 250V rating
- 50-500 μ F typical

Testing Capacitors:

1. **Visual Inspection**
 - Bulging case
 - Oil leakage
 - Burn marks
2. **Capacitance Test**
 - Discharge first
 - Use capacitor tester
 - Within $\pm 10\%$ of rating
3. **Resistance Test**
 - Should charge then decay
 - Infinite resistance final

Safety:

- Always discharge before handling
- Use insulated screwdriver
- Short terminals together
- Wait 60 seconds

14.5 Control Circuits

24V Control Systems

Advantages of 24V Controls:

- Safer to work with
- Lower current requirements
- Smaller wire sizes
- Less expensive components
- Code compliance easier

Basic 24V Circuit:

```
Transformer Secondary (24VAC)
|
R (24V Hot)
|
Thermostat
|
W (Heat Call)
|
Gas Valve
|
C (Common)
|
Transformer Secondary Return
```

Control Circuit Components:

1. **Power Source**
 - Control transformer
 - 24VAC output
 - 40VA typical
2. **Controls**
 - Thermostat
 - Limit switches
 - Pressure switches
 - Safety controls
3. **Loads**
 - Gas valves
 - Relay coils
 - Damper motors
 - Electronic boards

Wire Color Standards:

- R: 24V power (red)
- C: Common (blue)
- W: Heat (white)
- Y: Cooling (yellow)
- G: Fan (green)

115V Circuits

Line Voltage Components:

- Blower motors
- Inducer motors
- Ignition systems
- Pumps

- Transformer primary

Circuit Protection:

- Circuit breaker or fuse
- Sized per CEC
- 125% of motor FLA
- Time-delay type for motors

Wiring Requirements:

- 14 AWG minimum for 15A
- 12 AWG for 20A circuits
- Proper junction boxes
- Strain reliefs required

Line Voltage vs. Low Voltage

Line Voltage (115/230V)

- Powers major components
- Requires licensed electrician for new installation
- Higher safety risks
- Larger wire sizes

Low Voltage (24V)

- Control circuits
- Class 2 wiring
- Gas technician installable
- Smaller wire (18-20 AWG)

Separation Requirements:

- Cannot share same raceway
- Maintain physical separation
- Use barriers in control panels
- Separate junction boxes

Safety Circuits

Series Wiring Configuration All safety controls wired in series

Purpose:

- Any open switch stops operation

- Fail-safe design
- Multiple protection points

Common Safety Controls in Series:

1. High limit switch
2. Rollout switches
3. Pressure switches
4. Blocked vent switch
5. Condensate overflow switch

Circuit Example:

```

24V Hot (R)
|
High Limit (NC)
|
Rollout Switch 1 (NC)
|
Rollout Switch 2 (NC)
|
Pressure Switch (NO when proven)
|
Thermostat (W)
|
Gas Valve
|
Common (C)

```

Testing Safety Circuits:

- Check each switch individually
- Verify proper operation
- Test under operating conditions
- Document all readings

Operating Circuits

Parallel Wiring Configuration Loads connected in parallel

Purpose:

- Independent operation
- Full voltage to each load
- Individual control possible

Common Parallel Loads:

- Gas valve stages

- Multiple relays
- Zone valves
- Humidifier
- Electronic air cleaner

Circuit Example:

```

24V Hot (through safeties)
  |
+---> Gas Valve Stage 1
  |
+---> Gas Valve Stage 2
  |
+---> Blower Relay Coil
  |
All return to Common (C)

```

Common vs. Hot Wiring

Common Side Switching:

- Rarely used
- Safety concerns
- Not recommended
- Difficult troubleshooting

Hot Side Switching:

- Standard practice
- Safer operation
- Easier troubleshooting
- Controls interrupt power

Best Practices:

1. Always switch hot side
2. Common remains continuous
3. Use single point ground
4. Maintain proper polarity

Troubleshooting Tips:

- Measure from hot to common
 - Check voltage at each point
 - Verify common connections
 - Look for voltage drops
-

14.6 Reading Wiring Diagrams

Ladder Diagrams

Characteristics:

- Vertical power rails
- Horizontal rungs (circuits)
- Left rail: Hot
- Right rail: Common/Neutral
- Easy to follow current path

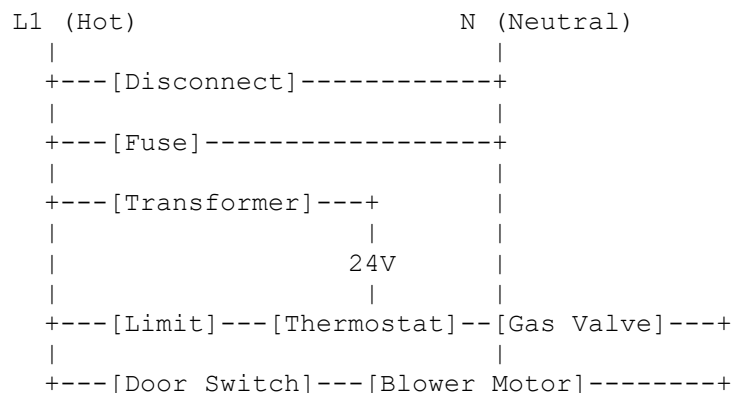
Reading Ladder Diagrams:

1. **Start at Top**
 - Power source location
 - Main disconnect
2. **Follow Each Rung**
 - Left to right
 - Through all components
 - To common side
3. **Identify Circuits**
 - Safety circuits
 - Control circuits
 - Operating circuits

Advantages:

- Clear circuit paths
- Easy troubleshooting
- Shows electrical operation
- Standard format

Example Ladder Diagram:



Pictorial Diagrams

Characteristics:

- Shows physical layout
- Component locations
- Wire routing
- Actual appearance

Uses:

- Installation reference
- Component identification
- Wire tracing
- Visual learning

Limitations:

- Harder to trace circuits
- Can be cluttered
- Not ideal for troubleshooting

Reading Pictorial Diagrams:

1. Identify major components
2. Follow wire colors
3. Check connection points
4. Verify terminal markings

Schematic Symbols

Common Electrical Symbols:

Symbol	Component
--------	-----------

- -	Capacitor
-/-	Switch (open)
-•-	Switch (closed)
-[R]-	Resistor
-[M]-	Motor
-(L)-	Coil/Solenoid
->←-	Contacts (NO)
-><-	Contacts (NC)

Symbol Component

-[F]-	Fuse
\perp	Ground
\sim	AC Source
\equiv	DC Source

Switch Symbols:

- SPST: Single Pole Single Throw
- SPDT: Single Pole Double Throw
- DPST: Double Pole Single Throw
- DPDT: Double Pole Double Throw
- NO: Normally Open
- NC: Normally Closed

Relay Representation:

- Coil shown separately
- Contacts shown in circuits
- Dashed line links them
- Number/letter designation

Following Circuit Paths

Systematic Approach:

1. **Identify Power Source**
 - Line voltage
 - Control voltage
 - DC power supplies
2. **Trace Hot Side**
 - Through all controls
 - To load device
 - Note all switches
3. **Trace Common Side**
 - From load
 - Back to source
 - Check for interruptions
4. **Check Parallel Paths**
 - Alternative routes
 - Multiple loads
 - Bypass circuits

Troubleshooting Method:

1. Start at inoperative component
2. Work backward to power source
3. Test voltage at each point
4. Find where voltage stops
5. Component before stop is problem

Identifying Components

Component Identification Methods:

Reference Designators:

- M1, M2: Motors
- K1, K2: Relays/Contactors
- T1: Transformer
- C1, C2: Capacitors
- S1, S2: Switches
- V1: Valves
- F1, F2: Fuses
- L1, L2: Limits

Wire Labels:

- Numbers: 1, 2, 3
- Letters: R, W, G, Y, C
- Combinations: W1, W2

Terminal Markings:

- Input/Output
- Line/Load
- COM, NO, NC
- L1, L2, T1, T2

Color Coding:

- Black: Line voltage hot
- White: Neutral
- Green: Ground
- Red: Switched hot
- Blue: Common (24V)

Troubleshooting with Diagrams

Step-by-Step Process:

1. **Obtain Correct Diagram**
 - Model specific
 - Current revision
 - Match equipment
2. **Understand Normal Operation**
 - Sequence of operation
 - Expected voltages
 - Normal component states
3. **Identify Problem Circuit**
 - What's not working?
 - Related components
 - Common circuit?
4. **Plan Testing Sequence**
 - Start points
 - Test locations
 - Expected readings
5. **Perform Tests**
 - Follow diagram
 - Record readings
 - Compare to expected
6. **Locate Fault**
 - Open circuit
 - Short circuit
 - Failed component
 - Loose connection

Common Diagram Issues:

- Revisions not matching
- Field modifications
- Worn/faded diagrams
- Missing information

Tips for Success:

1. Keep diagrams clean and dry
2. Laminate frequently used ones
3. Mark test points
4. Note field changes
5. Use highlighting for circuits

14.7 Thermostats and Control Devices

Mechanical Thermostats

Bimetal Operation:

- Two different metals bonded
- Different expansion rates
- Bends with temperature change
- Makes/breaks contacts

Mercury Bulb Type:

- Glass bulb with mercury
- Tilts with bimetal movement
- Mercury connects contacts
- Being phased out (environmental)

Snap-Action Type:

- Mechanical contacts
- Spring-loaded action
- Positive on/off
- Magnetic assist possible

Components:

1. **Sensing Element**
 - Bimetal coil/strip
 - Exposed to room air
2. **Switching Mechanism**
 - Mercury or mechanical
 - Makes/breaks circuit
3. **Anticipator**
 - Small resistor
 - Prevents overshoot
 - Adjustable (0.1-1.2A)

Adjustments:

- Temperature calibration
- Anticipator setting
- Leveling (critical)
- Cycle rate

Electronic Thermostats

Components:

1. **Temperature Sensor**

- Thermistor
- RTD
- Solid-state sensor
- 2. **Electronic Circuit**
 - Comparator
 - Switching circuit
 - Power supply
- 3. **Output**
 - Relay
 - Triac
 - Solid-state switch

Advantages:

- More accurate ($\pm 0.5^{\circ}\text{F}$)
- No leveling required
- Digital display
- No anticipator needed
- Longer life

Features:

- LED/LCD display
- Push-button control
- Battery backup
- Self-diagnostics

Programmable Thermostats

Programming Features:

- 5+2 day (weekday/weekend)
- 7 day (individual)
- 5-1-1 (weekday/Sat/Sun)

Typical Schedules:

- Wake
- Leave
- Return
- Sleep

Energy Saving Features:

- Setback temperatures
- Vacation mode

- Adaptive recovery
- Optimal start

Installation Considerations:

- C-wire requirement
- Battery backup
- Compatibility check
- System configuration

Smart Thermostats

Features:

- WiFi connectivity
- Smartphone control
- Learning capability
- Occupancy sensing
- Weather adaptation
- Energy reports

Common Brands:

- Nest
- Ecobee
- Honeywell Home
- Emerson Sensi

Installation Requirements:

- C-wire (or adapter)
- WiFi network
- Smartphone app
- Account setup
- System compatibility

Advanced Features:

- Geofencing
- Voice control
- Integration with smart home
- Maintenance reminders
- Filter monitoring
- Equipment runtime tracking

Heat-Only vs. Heat-Cool

Heat-Only Wiring:

- R: 24V power
- W: Heat call
- G: Fan (optional)
- C: Common (if needed)

Heat-Cool Wiring:

- R: 24V power
- W: Heat call
- Y: Cool call
- G: Fan
- C: Common
- O/B: Reversing valve (heat pump)

System Switch:

- Heat
- Cool
- Auto (changeover)
- Emergency Heat (heat pump)
- Off

Fan Switch:

- Auto (with heat/cool)
- On (continuous)

Multi-Stage Controls**Two-Stage Heating:**

- W1: First stage (low fire)
- W2: Second stage (high fire)
- Timer or temp differential
- Improved comfort
- Better efficiency

Staging Logic:

1. Small temperature drop: W1 only
2. Larger drop: W1, then W2
3. Quick recovery: Both stages

Two-Stage Cooling:

- Y1: First stage
- Y2: Second stage
- Similar logic to heating

Heat Pump Systems:

- Multiple stages possible
- Auxiliary heat stages
- Emergency heat
- Defrost control

Proper Installation and Wiring

Location Requirements:

- 5 feet above floor
- Interior wall preferred
- Away from drafts
- Away from heat sources
- Not behind doors
- Good air circulation

Wiring Installation:

1. **Power Off**
 - Turn off furnace power
 - Verify with meter
2. **Remove Old Thermostat**
 - Label wires first
 - Take photo for reference
 - Don't let wires fall in wall
3. **Mount Baseplate**
 - Level is critical
 - Use anchors if needed
 - Route wires through center
4. **Connect Wires**
 - Match letters
 - Secure connections
 - No bare wire showing
 - Bundle excess
5. **Configure Settings**
 - System type
 - Stages
 - Fan control
 - Temperature differential
6. **Test Operation**

- All modes
- Stage operation
- Fan control
- Temperature accuracy

Common Wiring Problems:

- Crossed wires
- Loose connections
- Missing C-wire
- Wrong configuration
- Incompatible system

Troubleshooting:

1. No power: Check transformer and fuse
2. No heat: Test W terminal voltage
3. Short cycling: Check anticipator/settings
4. Won't maintain temp: Check location
5. Erratic operation: Check connections

14.8 Motors and Motor Controls

Blower Motors

PSC Motors (Permanent Split Capacitor)

Construction:

- Single-phase motor
- Run capacitor required
- Multiple speed taps
- Centrifugal switch not needed

Specifications:

- Horsepower: 1/8 to 1 HP
- Voltage: 115V or 230V
- Speed: 1075 RPM typical
- Current: 2-8 amps

Speed Taps:

- Black: High

- Blue: Medium-High
- Yellow: Medium-Low
- Red: Low
- White: Common

Testing PSC Motors:

1. **Winding Resistance**
 - Power off
 - Disconnect capacitor
 - Measure between taps
 - Common to each speed: 2-20 Ω
2. **Capacitor Test**
 - Discharge first
 - Test capacitance
 - Within $\pm 10\%$ of rating
3. **Current Draw**
 - Each speed
 - Compare to nameplate
 - High current = problem

ECM Motors (Electronically Commutated Motor)

Advantages:

- Variable speed capability
- 30-50% more efficient
- Constant CFM
- Quieter operation
- Soft start/stop

Components:

- Permanent magnet rotor
- Electronic control module
- No capacitor needed
- Integrated controls

Programming:

- DIP switches
- Programming pins
- Digital interface
- Manufacturer specific

Testing ECM Motors:

1. **Power Supply**
 - 115V or 230V to module
 - 24V control signals
2. **Control Signals**
 - Check for heat call (W)
 - Check for cool call (Y)
 - Check for fan call (G)
3. **Module Diagnostics**
 - LED indicators
 - Error codes
 - Refer to manual

Common ECM Problems:

- Module failure
- Power surge damage
- Moisture damage
- Programming errors
- Communication issues

Inducer Motors

Purpose:

- Pre-purge combustion chamber
- Create draft for venting
- Prove venting before ignition

Types:

1. **Shaded Pole**
 - Simple construction
 - Lower efficiency
 - No capacitor
2. **PSC Type**
 - Higher efficiency
 - Capacitor required
 - More torque

Specifications:

- Speed: 3000-3450 RPM
- Current: 0.5-1.5A
- Voltage: 115V typical

Testing Inducer Motors:

1. **Visual Inspection**
 - Wheel condition
 - Bearing play
 - Housing cracks
2. **Electrical Tests**
 - Winding resistance: 10-50Ω
 - Current draw: per nameplate
 - Capacitor (if present)
3. **Operational Test**
 - Proper rotation
 - No unusual noise
 - Adequate pressure

Common Problems:

- Seized bearings
- Cracked wheel
- Water damage
- Capacitor failure
- Winding failure

Circulator Pumps

Types:

1. **Wet Rotor**
 - Water lubricated
 - Quiet operation
 - No coupling
2. **Dry Rotor**
 - Oil lubricated
 - Separate motor
 - Coupling required

Specifications:

- Single-phase typical
- 1/12 to 1/6 HP
- 115V operation
- Multiple speeds possible

Testing:

1. Current draw
2. Bearing condition
3. Impeller freedom

4. Seal integrity

Common Issues:

- Air locked
- Seized bearings
- Failed capacitor
- Damaged impeller

Motor Protection Devices

Internal Protection:

1. **Thermal Overload**
 - Embedded in windings
 - Auto-reset type
 - Opens on overtemperature
2. **Current Overload**
 - Senses current
 - Built into motor
 - Auto or manual reset

External Protection:

1. **Circuit Breaker**
 - Sized at 125% FLA
 - Time-delay type
 - Manual reset
2. **Fuses**
 - Dual-element type
 - Time-delay
 - 125% FLA sizing
3. **Overload Relays**
 - Adjustable
 - Manual reset
 - Class 10 or 20

Protection Coordination:

- Breaker > Overload > Motor rating
- Time-current curves
- Selective coordination

Troubleshooting Motor Problems

Systematic Approach:

1. Visual Inspection

- Physical damage
- Burnt smell
- Oil leaks
- Loose connections

2. Mechanical Checks

- Free rotation
- Bearing condition
- Coupling alignment
- Load condition

3. Electrical Testing

- Voltage at motor
- Current draw
- Winding resistance
- Ground fault test
- Capacitor test

Common Motor Problems:

Won't Start:

- No power
- Open winding
- Seized bearings
- Failed capacitor
- Open thermal overload
- Incorrect wiring

Runs But Trips:

- Overloaded
- Low voltage
- High ambient temperature
- Restricted airflow
- Worn bearings
- Winding deterioration

Noisy Operation:

- Worn bearings
- Misalignment
- Loose mounting
- Unbalanced rotor
- Debris in housing

Overheating:

- Overloaded
- Poor ventilation
- High ambient
- Voltage imbalance
- Frequent starting

Testing Procedures:

Insulation Resistance Test:

1. Disconnect motor
2. Megohmmeter at 500V
3. Test to ground
4. Minimum 1 MΩ

Winding Resistance Test:

1. Power off
2. Disconnect leads
3. Measure each winding
4. Compare phases
5. Should be balanced

Current Imbalance Test:

1. Measure each phase
2. Calculate average
3. Maximum deviation 10%

Power Factor Test:

- Indicates motor efficiency
- Low PF = problems
- Use power analyzer

Repair vs. Replace Decision:

- Motor age
- Repair cost vs. new
- Efficiency improvements
- Availability
- Downtime considerations

Chapter Review

Key Concepts Summary

1. Electrical Fundamentals

- Ohm's Law: $E = I \times R$
- Power: $P = E \times I$
- Series vs. parallel circuits
- AC vs. DC current

2. Safety Priorities

- Lockout/tagout procedures
- Arc flash protection
- Proper PPE usage
- Canadian Electrical Code compliance

3. Measurement Skills

- Multimeter operation
- Safe testing practices
- Interpreting readings
- Troubleshooting methods

4. Component Knowledge

- Transformer operation
- Relay and contactor function
- Motor types and testing
- Control circuit design

5. Practical Applications

- Reading wiring diagrams
- Thermostat installation
- Motor troubleshooting
- Control circuit analysis

Ohm's Law Calculations

Practice Problems:

1. A gas valve draws 0.3A at 24V. Calculate resistance.
 - $R = E/I = 24V \div 0.3A = 80\Omega$
2. A blower motor has 15Ω resistance at 115V. Find current.
 - $I = E/R = 115V \div 15\Omega = 7.67A$
3. Calculate power for motor in problem 2.
 - $P = E \times I = 115V \times 7.67A = 882W$
4. A transformer supplies 40VA at 24V. Maximum current?
 - $I = VA/V = 40VA \div 24V = 1.67A$
5. An element has 30Ω resistance at 230V. Find power.
 - $P = E^2/R = 230^2 \div 30 = 1,763W$

Circuit Analysis Exercises

Series Circuit: Three limit switches ($R=0.5\Omega$ each) in series.

- Total resistance: $0.5 + 0.5 + 0.5 = 1.5\Omega$
- Current same throughout
- Voltage divides equally

Parallel Circuit: Two gas valves ($R=40\Omega$ each) in parallel.

- Total resistance: $1/R_T = 1/40 + 1/40 = 20\Omega$
- Voltage same across both
- Current divides equally

Series-Parallel: Safety switches in series, loads in parallel

- Analyze series portions first
- Then parallel branches
- Combine for total

Wiring Diagram Interpretation

Exercise 1: Trace Circuit Path Given a ladder diagram:

1. Start at L1 (hot)
2. Through disconnect
3. Through limit switch
4. Through thermostat
5. To gas valve
6. Return to neutral

Exercise 2: Identify Problem Blower won't run:

1. Check door switch
2. Test fan relay
3. Verify control voltage
4. Test motor windings
5. Check capacitor

Exercise 3: Multi-Stage System Two-stage furnace operation:

1. W1 energizes stage 1
2. W2 energizes stage 2
3. Both can run together
4. Safety controls affect both

Component Testing Procedures

Transformer Testing:

1. Primary voltage: $115V \pm 10\%$
2. Secondary voltage: 24-28V no load
3. Secondary current: $< \text{rated VA}/24$
4. Temperature: $< 140^{\circ}\text{F}$

Relay Testing:

1. Coil resistance: $10\text{-}50\Omega$
2. Coil energized: 24VAC
3. Contacts closed: $< 1\Omega$
4. Contacts open: Infinite

Motor Testing:

1. Winding resistance: Balanced
2. Current draw: $< \text{nameplate}$
3. Insulation resistance: $> 1M\Omega$
4. Capacitor: $\pm 10\%$ of rating

Capacitor Testing:

1. Discharge safely
2. Visual inspection
3. Capacitance measurement
4. Resistance test

Troubleshooting Scenarios

Scenario 1: No Heat Call Symptoms: Thermostat calling, no operation

Diagnosis Steps:

1. Check 24V at thermostat R
2. Check voltage at W when calling
3. Test limit switches
4. Check pressure switch
5. Test gas valve

Solution: Open limit switch found

Scenario 2: Blower Won't Stop Symptoms: Continuous blower operation

Diagnosis Steps:

1. Check thermostat G terminal
2. Test fan relay contacts

3. Check for stuck relay
4. Verify control board

Solution: Welded relay contacts

Scenario 3: Intermittent Operation Symptoms: Random shutdowns

Diagnosis Steps:

1. Monitor when failure occurs
2. Check all connections
3. Test components hot
4. Look for loose wires
5. Check for overheating

Solution: Loose wire connection

Scenario 4: Short Cycling Symptoms: Rapid on/off cycling

Diagnosis Steps:

1. Check thermostat location
2. Test anticipator setting
3. Verify limit operation
4. Check for restrictions
5. Test gas pressure

Solution: Dirty filter causing high limit

Scenario 5: Tripping Breaker Symptoms: Breaker trips on startup

Diagnosis Steps:

1. Check current draw
2. Test motor windings
3. Check for shorts
4. Test capacitor
5. Verify wire sizing

Solution: Failed run capacitor

Safety Reminders

1. **Always verify power is off**
2. **Use proper PPE**
3. **Test meters before use**

4. **Follow lockout/tagout**
5. **Never bypass safety controls**
6. **Respect electrical hazards**
7. **Know your limitations**
8. **Call electrician when required**

Professional Practices

1. **Documentation**
 - Record all readings
 - Note wire locations
 - Document changes
 - Keep service records
2. **Customer Communication**
 - Explain electrical safety
 - Describe work performed
 - Review maintenance needs
 - Provide cost estimates
3. **Code Compliance**
 - Follow CEC requirements
 - Maintain clearances
 - Use approved materials
 - Obtain permits when required
4. **Continuous Learning**
 - Study new technologies
 - Attend training sessions
 - Read technical bulletins
 - Practice troubleshooting

Conclusion

Electrical knowledge is essential for modern gas technicians. From basic circuit theory to complex control systems, understanding electricity enables proper installation, maintenance, and troubleshooting of gas equipment. Safety must always be the primary concern when working with electrical systems.

Key takeaways:

- Master Ohm's Law and basic calculations
- Always follow safety procedures
- Develop systematic troubleshooting skills
- Understand control circuit operation
- Know when to call qualified electricians
- Continue learning as technology advances

Remember: Electricity demands respect. A thorough understanding of electrical principles, combined with safe work practices, ensures professional success and personal safety in the gas technician trade.