CSA Unit 5 : Basic Electricity

Chapter 1
Electrical Safety for Gas Technicians

Gas technicians and fitters often work with electrical equipment that can pose serious safety risks. This presentation covers essential knowledge about electrical hazards, applicable codes, and safety procedures that every gas technician should know to protect themselves and others.

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Created
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Purpose and Objectives

Purpose

Gas technicians/fitters often work in a variety of situations with electrical equipment that can cause injury to themselves and others. Students must be thoroughly familiar with electrical hazards, applicable electrical codes, and safety procedures that relate to their work as gas technicians/fitters.

Learning Objectives

Identify electrical safety hazards

Recognize potential dangers when working with electrical equipment

Describe electrical code safety requirements

Understand the regulations that govern electrical work

Describe lock-out and tagging procedures

Learn proper protocols for securing electrical equipment

Describe requirements of applicable electrical safety codes

Apply relevant standards to your work as a gas technician

Key Terminology

Arcing

Lightning-like discharge of electricity across an insulating medium or air space

Electric shock

Physiological reaction or injury that results from electric current passing through the (human) body

Equipotential

Having the same potential

Static charge

Accumulated electric charge that is present on an object

Static electricity

Energy in the form of a stationary electric charge such as that stored in thunderclouds or produced by friction

Zero mechanical state

State when you make all energy sources, including electrical, pneumatic, hydraulic, or gravitational, inoperative

Milliampere (mA)

Unit of electric current equal to one thousandth of an ampere

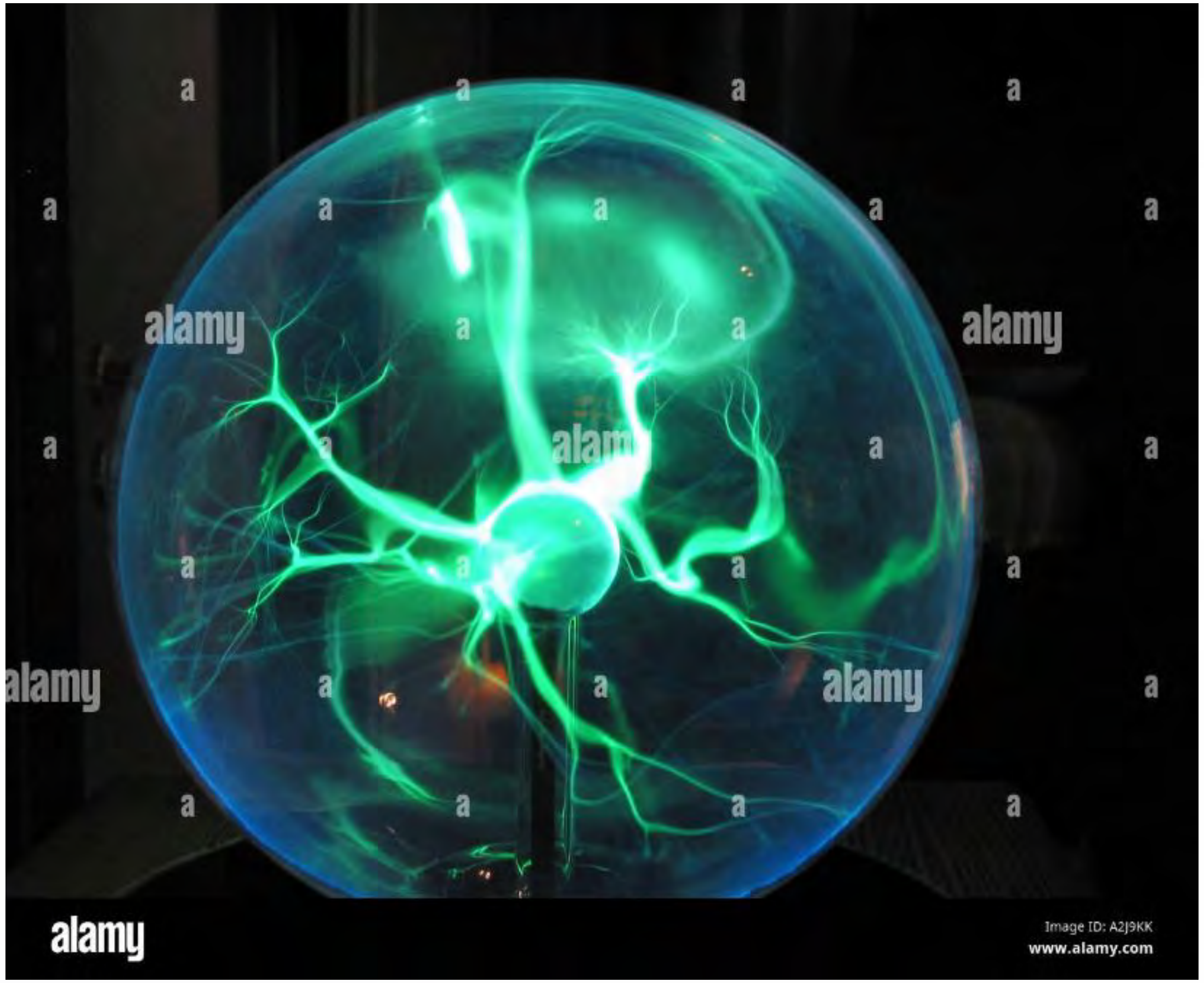
Electrical Safety Hazards

Two common electrical hazards are static electricity and electric shock.

Static Electricity

Static electricity is energy in the form of a stationary electric charge such as that stored in thunderclouds or produced by friction. A static charge is the accumulated electric charge that is present on an object.

The main danger from static electricity is arcing. Arcing is a lightning-like discharge of electricity across an insulating medium or air space. The arc can ignite flammable gases or materials that it comes in contact with. A good example of this phenomenon is the ignition of the fuel mixture by a spark plug in an automobile engine.



Electric Shock

When working with electrical equipment, you must be constantly aware of the hazard of electric shock. You must know what factors increase the danger of shock, how to avoid shock, and what to do when dealing with a shock victim.

Factors affecting electric shock:

- Amount and path of current
- Type of voltage (AC or DC)
- Value of voltage
- Length of time the body is energized
- Condition of the skin
- Area of contact

Current Effects on Human Body

Range (mA)	Effect
1 or less	No sensation
1-8	Shock is felt but not painful. Victim can let go. Muscular control is kept.
8-15	Shock is painful. Victim can let go. Muscular control is kept.
15-20	Shock is painful. Victim cannot let go. Muscular control is lost. Breathing is difficult.
20-50	Shock is very painful. Victim cannot let go. There are severe muscular contractions.
50-200	Severe muscular contractions and nerve damage. Possible ventricular fibrillation of the heart, causing death.
Over 200	Severe burns and muscular contractions. Victim cannot breathe during shock.

Note: Currents in the lethal range do not always cause death if the victim is given immediate medical attention.

Voltage and Current Dangers

Voltage Risks

In practice, operating a flashlight is usually perfectly safe. This is because the flashlight cell has a very low voltage that cannot overcome the resistance of human skin and current flow is limited.

The danger of shock increases as voltage increases, but low voltages are not necessarily safe. Contact with 120 volts AC, the common household voltage, has led to more deaths than with any other voltage. Note that AC voltages above 750 volts are high voltage.

DC Voltage Dangers

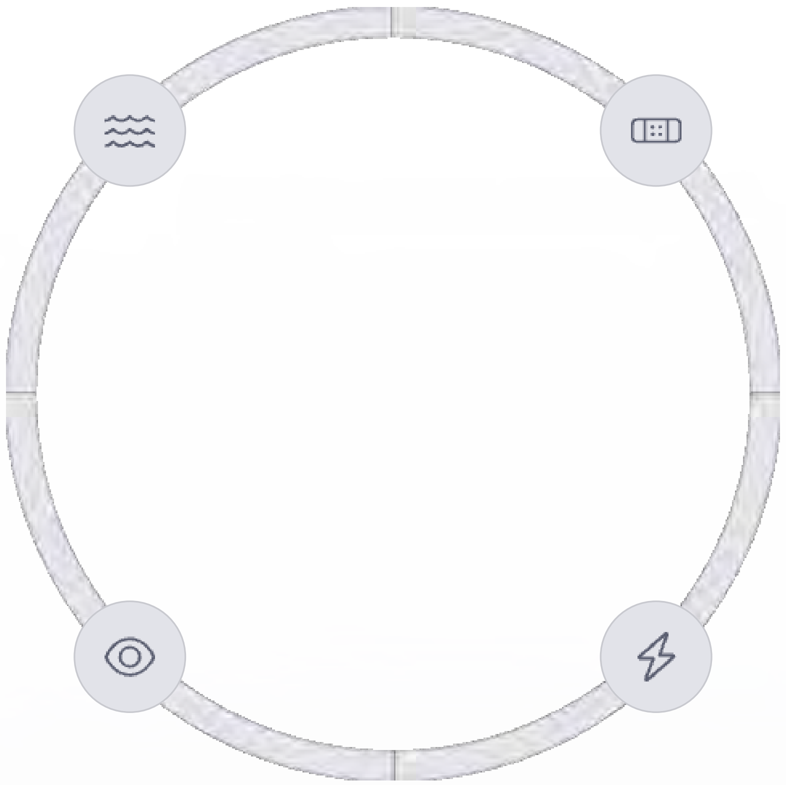
DC voltages can be very dangerous. Industrial voltages as small as 42 volts DC can be lethal.

Although 75 volts can be just as lethal as 1000 volts, victims of high-voltage shock usually respond better to resuscitation. Provided that they receive the artificial respiration immediately, their chance of survival is good. On the other hand, victims of low-voltage shock do not respond well to artificial respiration, because the low-voltage shock causes uncoordinated twitching of the walls of the heart, which interferes with sudden restoration of normal pulses.

Human Body Resistance Factors

Moisture and Salt

When skin is wet or salty, its resistance drops to several hundred from several thousand ohms. Therefore, weather can affect the hazard of shock. Wet, humid, or hot weather causes perspiration, thus reducing resistance. On the other hand, cold, dry weather may increase skin resistance. Vigorous exercise can also increase perspiration and reduce resistance.



Abrasions

Because the insulating layers of skin are absent, abrasions reduce body resistance to well below 100 ohms.

Contact Points

The body has different resistance at different contact points. Between the ears, body resistance is only 100 ohms. Measured from hand to foot, resistance is nearly 500 ohms.

Applied Voltage and Duration

Skin resistance changes according to the applied voltage. Resistance is lower at high voltages. The longer the application of the voltage to the skin, the lower the resistance.

Rescuing Shock Victims

Act Fast

The most important thing is to ACT FAST. The resistance of the victim decreases with time, and the victim can die in just a few seconds.

Protect Yourself

Never touch a victim who is still connected to the electric power. If you do, you will also experience shock.

Disconnect Power

First, try to disconnect the electricity. If you cannot quickly find the switch or plug, try to pull the victim and live conductor(s) apart. Use a dry wooden pole or some other dry insulating material (such as wood, glass, paper, cloth, etc.). Do not use your hands or a conducting material.

Begin Resuscitation

If the victim is unconscious and has stopped breathing, start artificial respiration at once. DO NOT STOP until a medical authority advises you to stop.

Five Steps to Rescue a Shock Victim

Protect yourself

Do not touch the energized victim

Free the victim

Disconnect from electrical contact

Apply CPR

Use artificial respiration as necessary

Call for help

Contact doctor, nurse, fire department, rescue unit, or police unit

Continue resuscitation

Until a medical authority advises you to stop

Grounding

Proper grounding of tools, equipment, and sources of static discharge is essential for reducing the risk of electrical hazards.

You shall effectively ground portable tools and equipment that require grounding and are not permanently connected to the wiring system through the use of approved three-wire cords and three-prong polarized plugs inserted in grounded polarized receptacles.

You must install ground straps where necessary to prevent static discharge.

Double-Insulated Tools

Many modern portable tools may not have a three-pronged plug but instead are double-insulated and have a two-pronged plug. A tool that is double-insulated provides equivalent shock hazard protection as a tool with a three-pronged grounded plug.

If you use a power tool with a two-pronged plug, ensure that the tool is double-insulated. To determine if the tool is double-insulated, the tool should have certification (e.g., by CSA) and marking with either the words "DOUBLE INSULATED" or the following symbol:

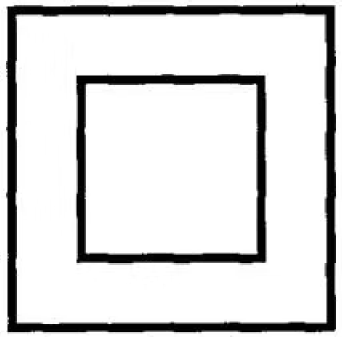


Figure 1-1 Double insulated symbol

Electrical Code Safety Requirements

Code References

Electrical safety codes contain sections and specific rules that deal with the installation and maintenance of electrical equipment as it relates to gas-fired equipment. Most provincial electrical codes are either based on or fully adopt the Canadian Electrical Code. However, some differences may exist, and you should always make reference the code accepted locally or provincially.

Canadian Electrical Code

The following provisions are part of the Canadian Electrical Code, Part I (C22.1-18).

Section 2 - General Rules

Rule 2-032 Damage and interference

1. No person shall damage any electrical installation or component thereof.
2. No person shall interfere with any electrical installation or component thereof except that when, in the course of alterations or repairs to non-electrical equipment or structures, it may be necessary to disconnect or move components of an electrical installation, it shall be the responsibility of the person carrying out the alterations or repairs to ensure that the electrical installation is restored to a safe operating condition as soon as the progress of the alterations or repairs will permit.

Rule 2-100 Marking of equipment

1. **Required Markings**

   Each piece of electrical equipment shall bear those of the following markings necessary to identify the equipment and ensure that it is suitable for the particular installation:

2. **Manufacturer Information**

   The maker's name, trademark, or other recognized symbol of identification

3. **Technical Specifications**

   Catalogue number or type, voltage, rated load amperes, watts, volt amperes, or horsepower

4. **Operational Details**

   Whether for AC, DC, or both; number of phases; frequency in hertz; rated load speed in revolutions per minute

5. **Safety Information**

   Designation of terminals; whether for continuous or intermittent duty; short-circuit current rating or withstand rating; evidence of approval

Service Box and Distribution Point Marking

Service Box Marking

At the time of installation, each service box shall be marked in a conspicuous, legible, and permanent manner, to indicate clearly the maximum rating of the overcurrent device that may be used for this installation.

Distribution Point Marking

At each distribution point, circuit breakers, fuses, and switches shall be marked, adjacent thereto, in a conspicuous and legible manner to indicate clearly:

- which installation or portion of installation they protect or control; and
- the maximum rating of overcurrent device that is permitted.

Additional Marking Requirements

Continuous Load Marking

Where the maximum continuous load allowed on a fused switch or circuit breaker as determined in accordance with Rule 8-104 5) and 6) is less than the continuous operating marking of the fused switch or circuit breaker, a permanent, legible caution marking shall be field applied adjacent to the fused switch or circuit breaker nameplate to indicate the maximum continuous loading permitted for connection to the fused switch or circuit breaker.

No Unauthorized Markings

The marking on electrical equipment shall not be added to, or changed, to indicate a use under this Code for which the equipment has not been approved.

Rule 2-110 Circuit voltage to-ground - Dwelling Units

Branch circuits in dwelling Units shall not have a voltage exceeding 150 volts to ground except that, where the calculated load on the service conductors of an apartment or similar building exceeds 250 kVA and where qualified electrical maintenance personnel are available, higher voltages not exceeding the voltage to ground of a nominal system voltage of 600Y/347V shall be permitted to be used in the dwelling Unit to supply the following fixed (not portable) equipment:

- space heating, provided that wall-mounted thermostats operate at a voltage not exceeding 300 volts-to-ground;
- water heating; and
- air conditioning.

Additional General Rules

Rule 2-122 Installation of electrical equipment

Electrical equipment shall be installed so as to ensure that after installation there is ready access to nameplates and access to parts requiring maintenance.

Rule 2-124 Installation of other than electrical equipment

Equipment or material of other than an electrical nature shall not be installed or placed so close to electrical equipment as to create a condition that is dangerous.

Rule 2-136 Insulation Integrity

All wiring shall be so installed that, when completed, the system will be free from short circuits and from grounds except as permitted in Section 10.

Rule 2-306 Shock and arc flash protection

Electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centres that are installed in other than dwelling Units and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn persons of potential electric shock and arc flash hazards.

Rules for Flammable Materials and Gas Equipment

Rule 2-320 Flammable material near electrical equipment

Flammable material shall not be stored or placed in dangerous proximity to electrical equipment.

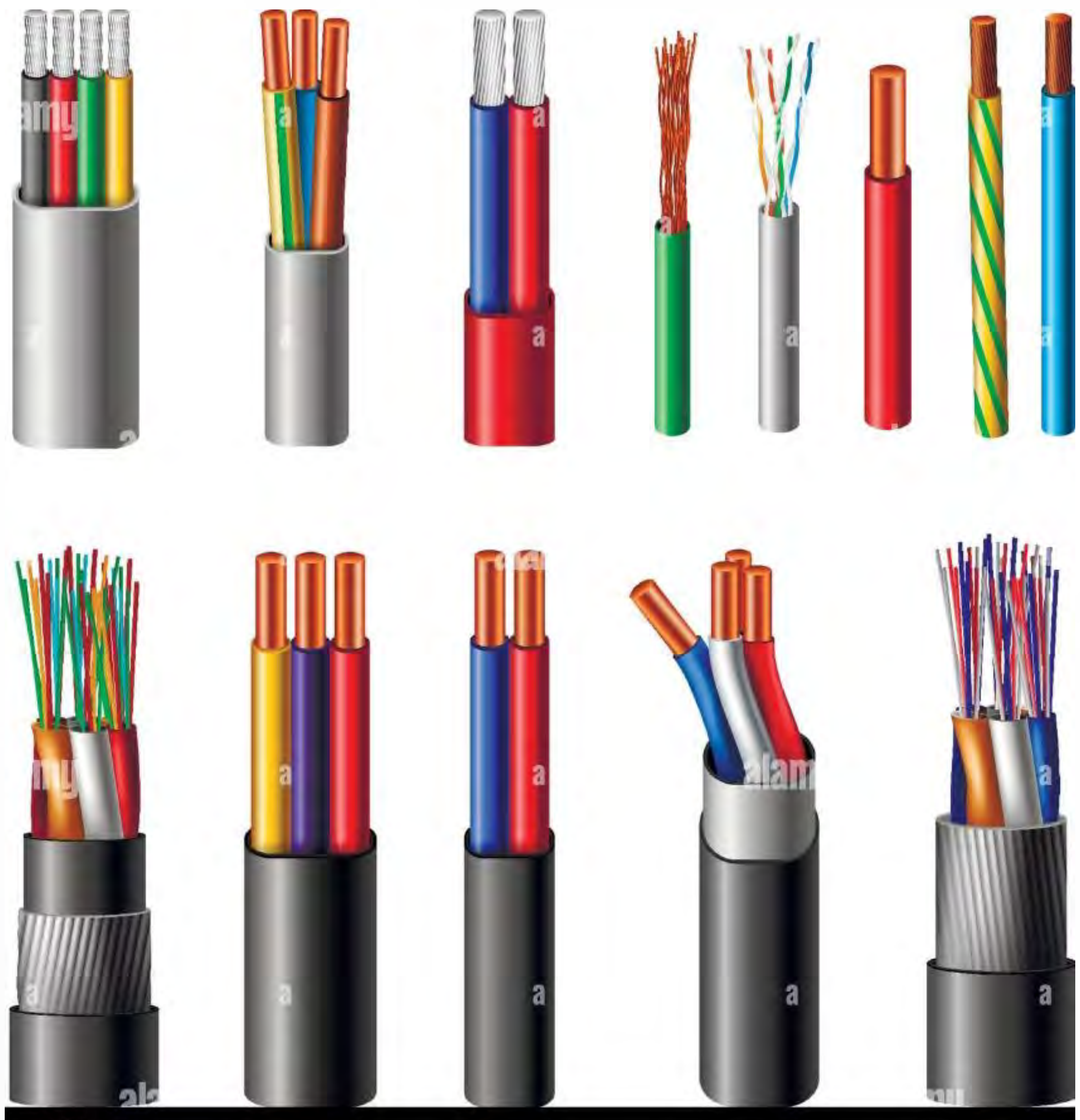
Rule 2-326 Electrical equipment near combustible gas equipment

The clearance distance between arc-producing electrical equipment and a combustible gas relief device or vent shall be in accordance with the requirements of CSA B149.1.

Section 4 - Conductors

Section 4 applies to conductors for lighting, appliance, and power supply circuits. It contains rules regarding the following:

- size of conductors;
- current ratings;
- insulation requirements; and
- permitted uses.



Section 10 - Grounding and Bonding

Rule 10-002 Object

The overall objective for grounding and bonding is to minimize the likelihood and severity of electric shock by establishing equipotentiality between exposed non-current-carrying conductive surfaces and nearby surfaces of the earth and to prevent damage to property during a fault, as follows:

Solidly Grounding

The objective of solidly grounding an electrical system and bonding its associated equipment is to establish a low impedance connection between the grounded conductor and the non-current-carrying conductive parts of the system to stabilize system voltage.

Impedance Grounding

The objective of grounding an electrical system through an impedance is to limit the magnitude of ground fault currents, minimize the damage to equipment resulting from a single ground fault, and stabilize system voltage.

Ungrounded System

The objective of an ungrounded system is to limit the magnitude of ground fault currents resulting from a single ground fault and minimize the damage to equipment on the occurrence of a single ground fault.

Bonding

The objective of bonding is to interconnect the non-current carrying conductive parts of electrical equipment and the system grounded point, where one exists, with sufficiently low impedance to facilitate the operation of protective devices and establish equipotentiality.

Equipotential Bonding of Non-Electrical Equipment

Rule 10-700

The following parts of non-electrical equipment shall be made equipotential with the non-current-carrying conductive parts of electrical equipment:

Water Systems

The continuous metal water piping system of a building supplied with electric power

Waste Systems

The continuous metal waste water piping system of a building supplied with electric power

Gas Systems

The continuous metal gas piping system of a building supplied with electric power

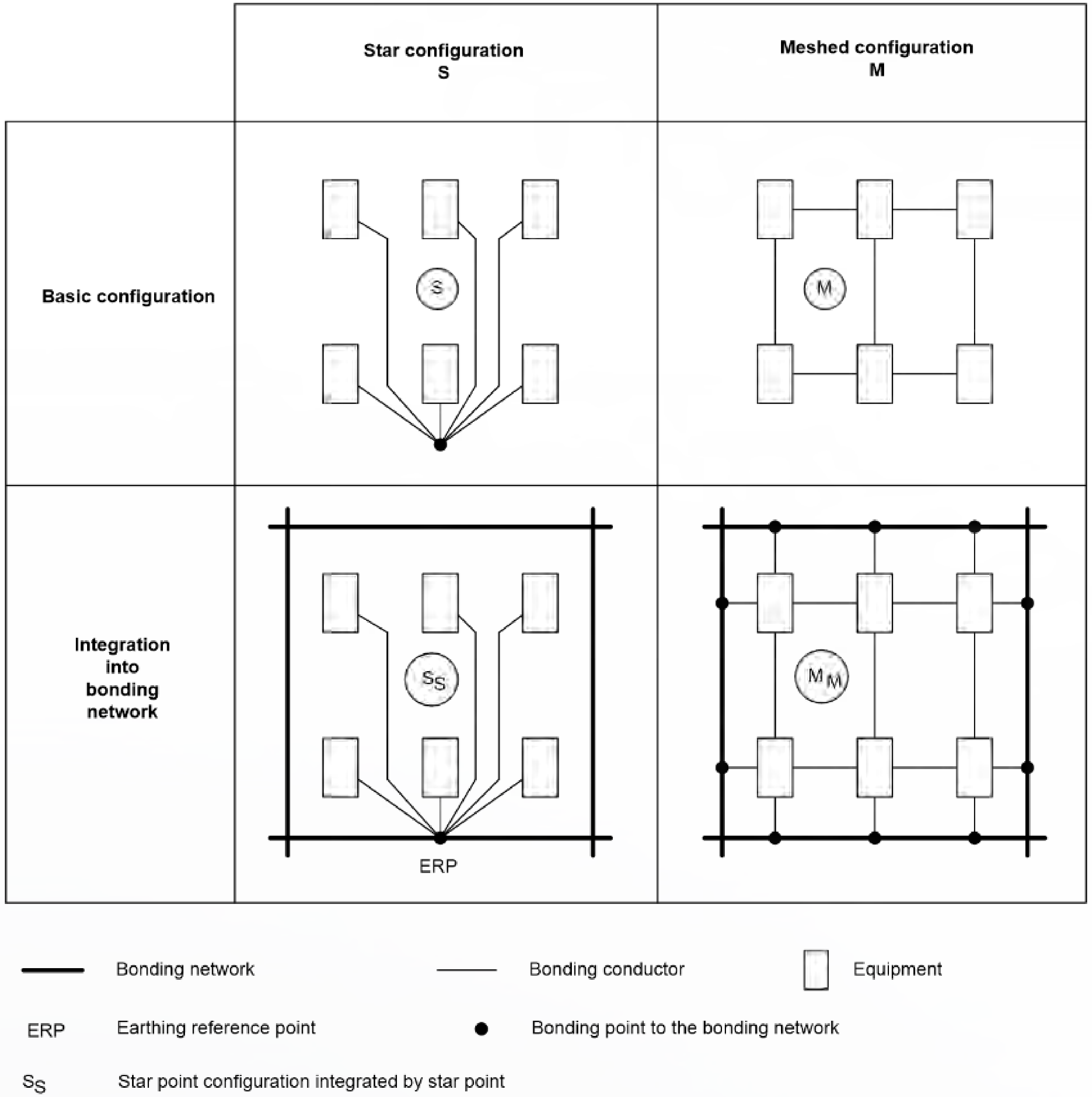
Other Systems

Raised floors of conductive material with electrical wiring under the raised floor; the conductive metal parts of structures that livestock access; and metal tower and station structures of passenger ropeways, passenger conveyors, or material ropeways

Equipotential Bonding Connections

Rule 10-706 Equipotential bonding connections to non-electrical equipment

Equipotential bonding connections to non-electrical materials shall be made mechanically secure and be suitable for the condition(s) to which they are subjected.



Lock-out and Tagging Procedures

General Procedures

As a gas technician/fitter, you may often be in an area where employees carry out maintenance procedures on powered machinery. During these times, detailed lock-out procedures are essential to prevent unexpected operation and energizing of the machinery you are working on.

Lock-out must involve more than merely disconnecting the power source. Electrically de-energized machinery that has its hydraulic systems still pressurized has already killed workers. Thus, you must assess the machine thoroughly, and make all energy sources, including electrical, pneumatic, hydraulic, or gravitational, inoperative. This is what you often call zero mechanical state.

Personal Lock-out Procedures

Use Personal Locks

As a technician/fitter, you should have your own lock and key (combination locks are not allowed), and use only these locks to lock out energy sources.

Inform Operators

Inform the machine operator of maintenance plans and tag the lock to identify the individual who has locked out the machinery.

Personal Responsibility

The only person permitted to remove the lock is the individual who placed the lock on the machinery.

Apply to All Equipment

Note that these procedures apply not only to stationary industrial equipment but also to mobile equipment, including passenger cars, truck equipment, and heavy construction equipment.

Canadian Electrical Code Lock-out Requirements

Rule 2-304 Disconnection

1. No repairs or alterations shall be carried out on any live equipment except where complete disconnection of the equipment is not practicable.
2. Three-way or four-way switches shall not be considered as disconnecting means.
3. Adequate precautions, such as locks on circuit breakers or switches, warning notices, sentries, or other equally effective means, shall be taken to prevent electrical equipment from being electrically charged when work is being done.

Lock-out Standards

Reference Standards

Reference CSA Z460 Control of hazardous energy-Lockout and other methods and CSA Z462 Workplace Electrical Safety.

Controlling hazardous energy associated with potentially harmful machines, equipment, or processes requires the safety team and individuals to follow strict guidelines. CSA Z460 and CSA Z462 are recognized Standards for the protection of personnel from injury from the inadvertent release of hazardous energy.

Hazardous Energy Release

Release of hazardous energy can include any motion, energization, start-up, or release of stored energy that, from the perspective of the person(s) at risk, is either unintended or deliberate. Lock-out is recognized as the primary method of hazardous energy control.

Workers must consult the employer's policies and procedures before conducting any work on equipment and systems with hazardous energy. Training and supervision are a requirement: always attain authorization from the employer or supervisor before attempting any work.

Worker Responsibilities for Lock-out

Personal Responsibility

Each worker who works on the machinery or equipment requiring lock-out procedures must be responsible for locking the control devices and removing his or her own locks on the completion of his or her work.

Verification

The person applying the first lock in a lock-out procedure must forthwith ensure that operation is not possible for the locked-out machinery or equipment.

Lock Removal

Only the person or persons who installed the locks can remove them, or in emergency, the senior shift supervisor on duty who must first make every effort to contact the individual who installed the lock and then ensure safe operation of the machinery or equipment.

Shift Changes

Workers coming on shift shall place their own locks on all control devices before the individuals going off shift remove their locks, or shift supervisors may lock out the control devices during shift changes to allow workers going off shift to remove their locks.

Key Box System

Qualified Workers

Two qualified workers, one of whom may be a supervisor, must be responsible for locking out the multiple control devices, each using a set of locks, keyed alike, but not keyed to the other set.

Documentation

The qualified workers must complete, sign, and post the checklist adjacent to the key box and place in the key box the keys for the locks or other positive sealing devices acceptable to the authority having jurisdiction.

Additional Workers

All other workers who must work on the machinery or equipment must also lock out the key box using personal locks before commencing maintenance or repair work.

Completion Process

On the completion of the work, all workers must remove their locks from the key box. The two qualified workers who locked out the equipment must then remove their locks from the key box and from the multiple lock-out points.

Written Procedure

A written key box lock-out procedure must remain posted at the key box location.

Central Control System Exception

Where a central control operator controls systems, the operator shall lock out the central control and record the portion locked out and the time. He or she shall re-energize the system on the instructions of the person who requested the de-energization, who has first determined that it is safe to do so.

Motor Disconnects

Where the intent of installing motor disconnect switches is for lock-out purposes, they must simultaneously disconnect both the motor and motor control circuits from their sources of supply. Such motor disconnect switches must be readily accessible, and where installed in elevated positions, access must be by means of a permanent ladder or by a stairway to a platform.

Working on De-energized Equipment

Worker in Charge

Before work commences on any part of an electrical power system that, for reasons of safety, must operate in a de-energized condition, the worker in charge shall ensure that de-energizing and grounding of the part of the system he/she is working on and lock-out of the controls are complete.

Assurance of De-energization

When the control devices are not under the direct control of the worker, he or she must receive assurance from the person in charge of the control devices that the work may safely proceed. The person giving the assurance must record such assurances.

Protection Against Re-energizing

Before commencing work on the de-energized part of the system, the worker in charge must ensure protection of all workers against re-energization.

Authority to Re-energize

Re-energization of the system must not take place except on the instructions of the worker who had requested the de-energizing or a supervisor who has first determined that it is safe to do so.

Electrical Inspections and Permits

Most jurisdictions require permits for all electrical work. The locally recognized electrical code, typically in Section 2.- General Rules cover the general rules governing the administration of electrical permits.

It is the responsibility of the electrical contractor or others responsible for carrying out the work to obtain a permit from the local electrical inspection department before commencing work with respect to installation, alteration, repair, or extension of any electrical equipment. A copy of the electrical permit must remain posted in a conspicuous place on the site of the work until completion of the electrical inspection.

Canadian Electrical Code Requirements

Code Reference

The Canadian Electrical Code contains sections and specific rules that deal with the installation and maintenance of electrical equipment as it relates to gas-fired equipment. The following criteria are part of the Canadian Electrical Code, Part I (CSA Standard C22.1-18), but it is important that you make reference to the Code approved in the jurisdiction of the work site.

Section 12 - Wiring Methods

Section 12 deals with wiring installation requirements.

Section 14 - Protection and Control

Section 14 covers the protection and control of electrical circuits and apparatus installed in accordance with Sections of the Code, including circuit breakers and fuses.

Section 26 - Installation of Electrical Equipment

Heating Equipment

Rule 26-800 Scope

Rules 26-802 to 26-808 apply to circuits supplying power for the operation and control of non-portable heating equipment that uses solid, liquid, or gaseous fuel.

Rule 26-802 Mechanical protection of cables

Cables for all branch circuit or tap conductors within 1.5 m from the floor shall be adequately protected from mechanical damage.

Safety Control Circuit Requirements

Voltage Limitation

4.8.5 The nominal supply voltage of a safety control circuit shall not exceed 120 V.

120V Branch Circuit

4.8.6 A safety control circuit intended to be supplied by a nominal 120 V branch circuit shall comply with the following:

- The circuit shall not be grounded within the equipment;
- The ungrounded conductor shall have an overcurrent protection device rated at not more than 125% of the current drawn by the circuit, except that this value may be increased because of inrush currents and ambient temperatures.

Alternative Supply

4.8.7 A safety control circuit supplied by other than as specified in Clause 4.8.6, such as one supplied by a battery or a transformer, shall comply with specific requirements for 2-wire circuits not exceeding 120V.

Circuit Interruption

4.8.8 A safety control shall interrupt the current in the ungrounded conductor of the circuit between the overcurrent protection and the load.

Rule 26-806 Heating Equipment Rated 117 kW and Less

Single Branch Circuit

Except as permitted by Subrule 3), all electric power for the heating Unit and associated equipment operating in connection with it shall be obtained from a single branch circuit that shall be used for no other purpose.

For the purpose of this Rule, circulating pumps and similar equipment need not be considered as associated equipment, provided that such equipment is not essential for the safe operation of the heating Unit.

Subrule 1) does not apply to a water heater using a gaseous fuel.

Tapping and Disconnecting

The branch circuit shall be permitted to be tapped as necessary to supply the various pieces of associated equipment, but there shall be no overcurrent protection supplied in the tap to any piece of associated equipment the operation of which is essential to the proper operation of the heating Unit, unless the control equipment is of such a nature that the heating Unit will be shut down if the associated equipment fails to function due to the operation of the overcurrent device.

Suitable disconnecting means shall be provided for the branch circuit.

Disconnecting Means for Heating Equipment

Circuit Breaker as Disconnect

The disconnecting means shall be permitted to be a branch circuit breaker at the distribution panelboard, provided that the panelboard is located between the furnace and the point of entry to the area where the furnace is located.

Separate Switch Requirements

Where a separate switch is required due to the unsuitable location of the branch circuit breaker, it shall:

- not be located on the furnace nor in a location that can be reached only by passing close to the furnace; and
- be marked to indicate the equipment it controls.

Rule 26-808 Heating Equipment Rated at More Than 117 kW

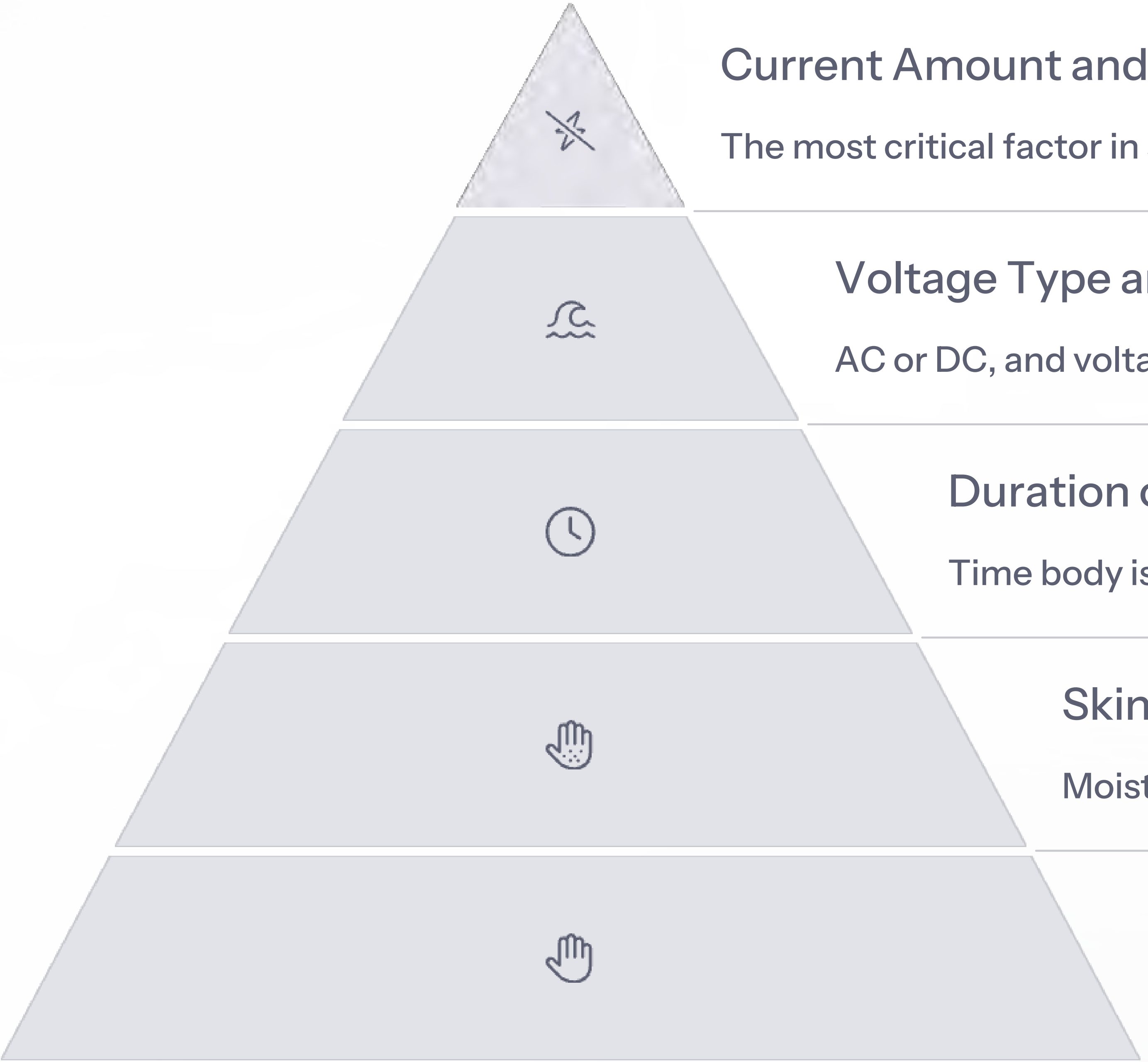
Power Supply

All electric power for the heating Unit and associated equipment operating in connection with it shall be obtained from a single feeder or branch circuit that shall not be used for other purposes.

Disconnecting Means

A suitable disconnecting means shall be provided for the feeder or branch circuit.

Factors Affecting Electric Shock



Current Amount and Path

The most critical factor in shock severity

Voltage Type and Value

AC or DC, and voltage level

Duration of Exposure

Time body is energized

Skin Condition

Moisture, salt, abrasions

Contact Area

Where current enters/exits body

Current Effects on the Human Body

1 mA

Threshold of Feeling

Current just perceptible

5 mA

Slight Shock

Painful but victim can let go

15 mA

Muscle Control Lost

Cannot let go, breathing difficult

50 mA

Lethal Threshold

Possible ventricular fibrillation

Electrical Safety Hazard Prevention

Identify Hazards

Recognize potential electrical dangers in the workplace

Implement Controls

Apply proper grounding, bonding, and insulation

Train Personnel

Ensure all workers understand electrical safety procedures

Regular Inspection

Maintain and test equipment and safety systems

Electrical Safety in Gas Equipment Installation

Know the codes

Understand electrical and gas code requirements

Use proper tools

Ensure tools are properly insulated and grounded

3

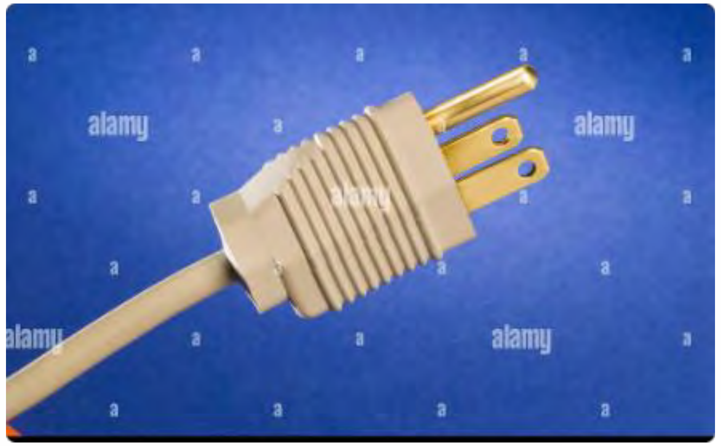
Verify power is off

Test circuits before beginning work

Lock-out/tag-out

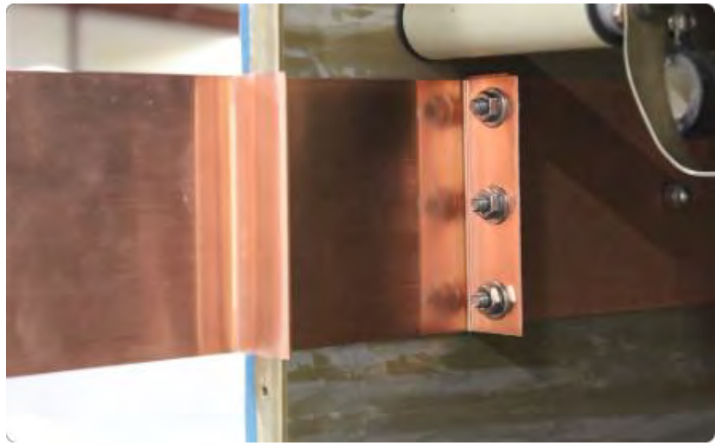
Secure all energy sources before servicing

Proper Grounding Techniques



Three-Prong Plugs

Ensure all three-wire cords and three-prong polarized plugs are inserted in grounded polarized receptacles for proper grounding of portable tools and equipment.



Ground Straps

Install ground straps where necessary to prevent static discharge, especially in areas where flammable gases may be present.

Double-Insulated Tools

Double-insulated tools provide equivalent shock hazard protection as grounded tools. Look for the double-insulated symbol or marking on the tool.

Personal Protective Equipment for Electrical Safety

Insulated Gloves

Rubber insulating gloves provide protection against electrical shock when working with or near energized equipment. Always inspect gloves for holes or damage before use.

Safety Footwear

Electrical hazard (EH) rated footwear provides secondary protection against incidental contact with electrical circuits of 600 volts or less under dry conditions.

Face and Eye Protection

Arc-rated face shields and safety glasses protect against arc flash and flying particles during electrical work.

Testing Equipment for Electrical Safety

Always use properly rated test equipment to verify that electrical circuits are de-energized before beginning work. Test equipment should be inspected before each use and calibrated regularly according to manufacturer specifications.

Lock-out/Tag-out Equipment


A comprehensive lock-out/tag-out program requires proper equipment to secure energy sources. Each worker should have their own personal locks and tags to ensure accountability and safety during maintenance procedures.

Static Electricity Control

Hazards of Static Electricity

Static electricity poses a significant risk in environments where flammable gases are present. The main danger is arcing, which can ignite flammable materials or gases.

A static charge can build up on objects through friction, particularly in dry environments or when materials are separated. This accumulated charge can discharge suddenly, creating a spark that may ignite flammable substances.

Control Measures

- Use proper grounding techniques for all equipment
- Install ground straps where necessary
- Use anti-static mats in work areas
- Maintain proper humidity levels when possible
- Wear anti-static footwear and clothing
- Use bonding wires to connect containers during liquid transfers

Electrical Safety Documentation

Permits

Obtain all required electrical permits before beginning work. Keep permits posted in a conspicuous location at the work site until inspection is complete.

Form

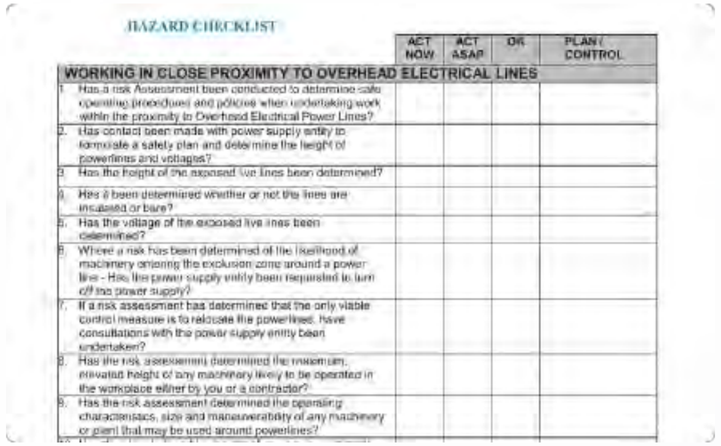
Date	[28/11/2050]
Time	[09:00 AM]
Equipment Name/ID	[Hydraulic Press HP-2001]
Department	[Production]
Performed By	[Your Name]
Supervisor	[Name]

Procedure Steps:

1. *Notification:* Notify all affected employees that a lockout/tagout procedure is going to be implemented and the reason for it.
2. *Identification:* Clearly identify the equipment or machinery to be locked out.

Lock-out Procedures

Document all lock-out procedures and maintain records of lock-out activities. Written procedures should be posted at key box locations.



HAZARD CHECKLIST

	ACT NOW	ACT ASAP	OK	PLAN / CONTROL
WORKING IN CLOSE PROXIMITY TO OVERHEAD ELECTRICAL LINES				
1. Has a risk Assessment been conducted to determine safe operating procedures and policies when undertaking work within the proximity to Overhead Electrical Power Lines?				
2. Has contact been made with power supply entity to formulate a safety plan and determine the height of powerlines and voltages?				
3. Has the height of the exposed live lines been determined?				
4. Has it been determined whether or not the lines are insulated or bare?				
5. Has the voltage of the exposed live lines been determined?				
6. Where a risk has been determined of the likelihood of machinery entering the exclusion zone around a power line - Has the power supply entity been requested to turn off the power supply?				
7. If a risk assessment has determined that the only viable control measure is to relocate the powerlines, have consultations with the power supply entity been undertaken?				
8. Has the risk assessment determined the maximum, elevated height of any machinery likely to be operated in the workplace either by you or a contractor?				
9. Has the risk assessment determined the operating characteristics, size and manoeuvrability of any machinery or plant that may be used around powerlines?				

Inspection Records

Maintain records of all electrical inspections, including notification to inspection authorities and results of inspections.

Electrical Safety Training Requirements

Code Knowledge

Understanding of applicable electrical codes

Hazard Recognition

Ability to identify electrical dangers

Safe Work Practices

Proper techniques and procedures

Emergency Response

First aid and rescue procedures

Electrical Safety Inspection Checklist

Cords and Plugs

Check for frayed cords, damaged insulation, and proper grounding pins

Receptacles

Ensure receptacles are properly grounded and not overloaded

Guards and Covers

Verify all electrical panels and junction boxes have proper covers

Moisture Protection

Check that electrical equipment is protected from water and moisture

Labeling

Confirm all electrical equipment is properly labeled and marked

6 Disconnecting Means

Verify accessible and functioning disconnects for all equipment

Electrical Safety for Specific Gas Equipment

Furnaces

Ensure proper grounding, dedicated circuit where required, and appropriate disconnecting means. Verify safety control circuits operate at no more than 120V.

Water Heaters

Check for proper electrical connections and grounding. Note that water heaters using gaseous fuel may not require a dedicated circuit.

Boilers

Verify appropriate disconnecting means and circuit protection. Ensure all safety controls interrupt the ungrounded conductor.

Gas Fireplaces

Check that electrical components are properly protected from heat and that wiring is rated for the temperature environment.

Emergency Response to Electrical Incidents

Assess the Situation

Quickly evaluate the scene for electrical hazards before approaching the victim. Look for downed power lines, energized equipment, or water near electrical sources.

Disconnect the Power

If possible, turn off the power at the circuit breaker, fuse box, or unplug the equipment. Never touch a person who is still in contact with an electrical source.

Call for Emergency Help

Contact emergency services immediately. Electrical injuries can cause internal damage that may not be immediately visible.

Provide First Aid

Once the victim is separated from the electrical source, check for breathing and pulse. Begin CPR if necessary and continue until emergency services arrive.

Document the Incident

Record all details of the incident, including the equipment involved, actions taken, and any witnesses present.

Review of Key Electrical Safety Concepts

Hazard Identification

Recognize static electricity and electric shock risks

Code Compliance

Follow all applicable electrical safety codes

Lock-out/Tag-out

Properly secure all energy sources before work

Proper Grounding

Ensure all equipment is correctly grounded

Personal Protection

Use appropriate PPE for electrical work

Emergency Response

Know how to safely respond to electrical incidents

CSA Unit 5

Chapter 2
Basic Electrical Theory and Concepts

Purpose and Objectives

Purpose

The gas technician/fitter requires a basic knowledge of electrical theory in order to understand the operation of electrical components and circuits.

Objectives

At the end of this Chapter, you will be able to:

- describe atoms, electrons, and electricity;
- describe electrostatic charges and fields; and
- describe the production and use of electricity.

Key Terminology

Atom

Smallest particle of matter that can take part in a chemical reaction

Conductor

Material through which electric current can pass

Electric current

Transfer of electrical energy from moving electrons

Electromagnetism

Phenomenon when any conductor of electric current acts like a magnet

Insulator

A substance or device that does not readily conduct electricity

Ion

An atom or molecule with a net electric charge due to the loss or gain of one or more electrons

Atoms and Molecules

Matter

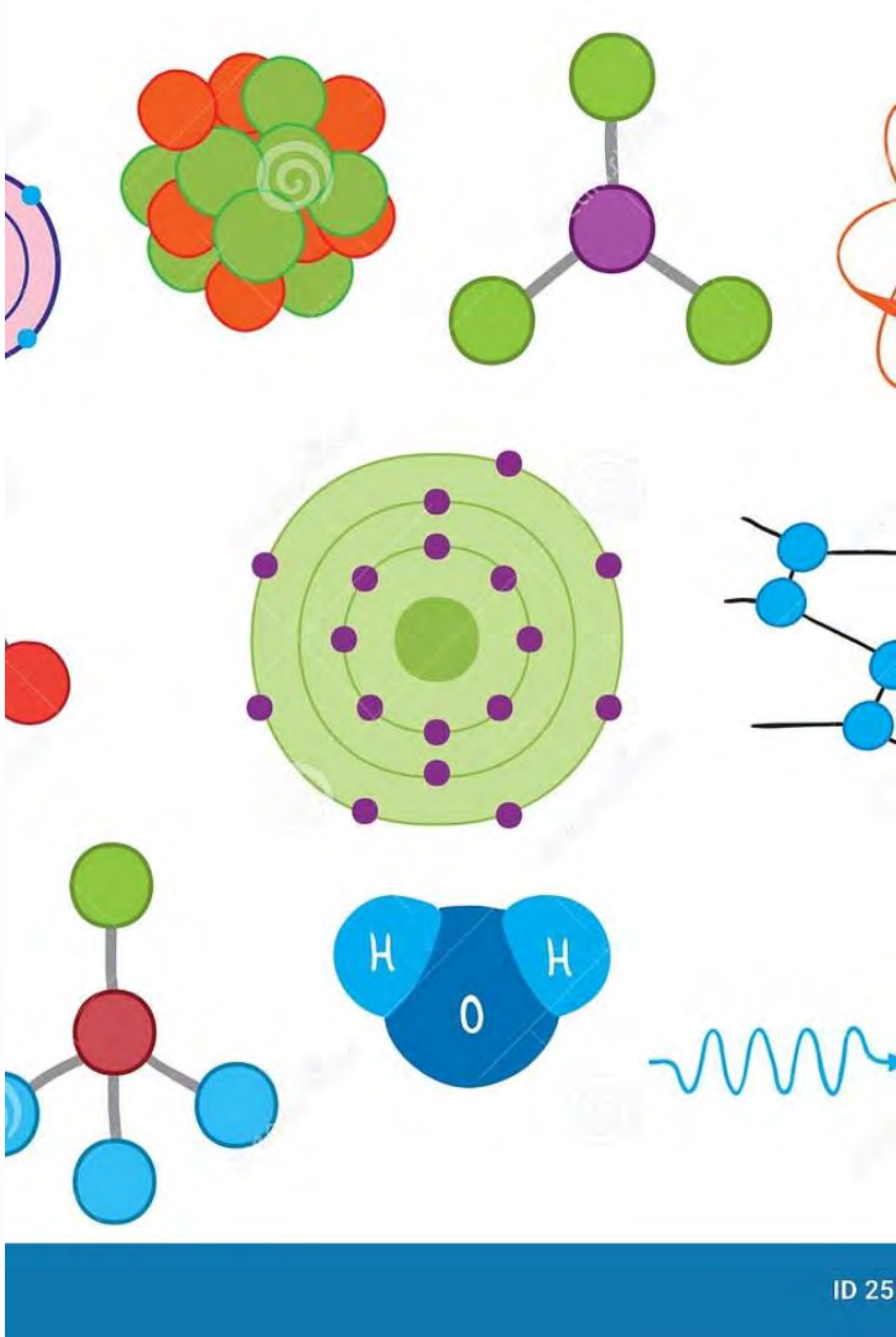
Everything that has mass or occupies space is what you call matter.

Atoms

The smallest particle of matter that can take part in a chemical reaction is an atom. Atoms are the submicroscopic building blocks of matter.

Molecules

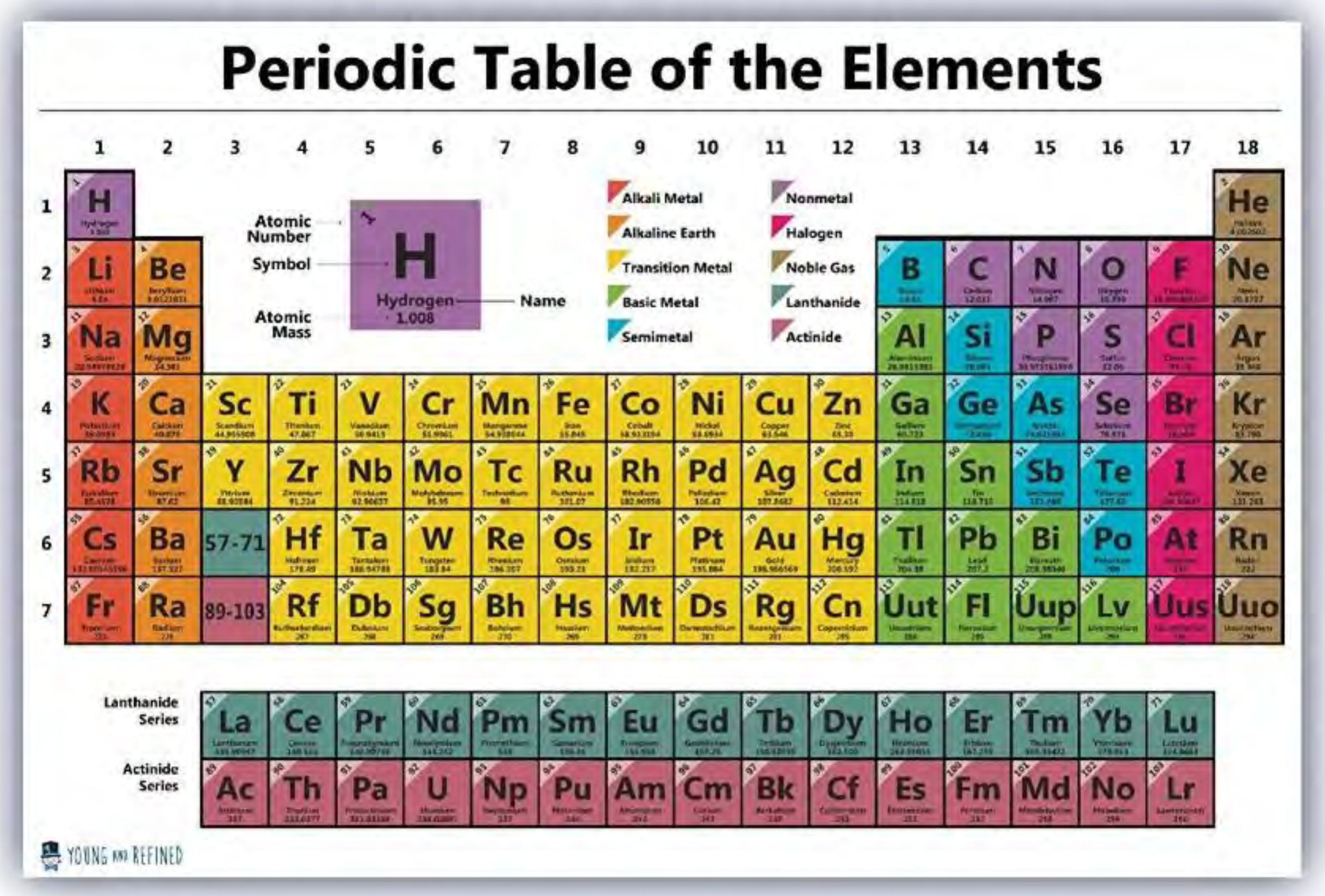
Atoms combine to form larger particles called molecules. Atoms and molecules are much too small to be seen or weighed directly.



Elements and Compounds

Elements

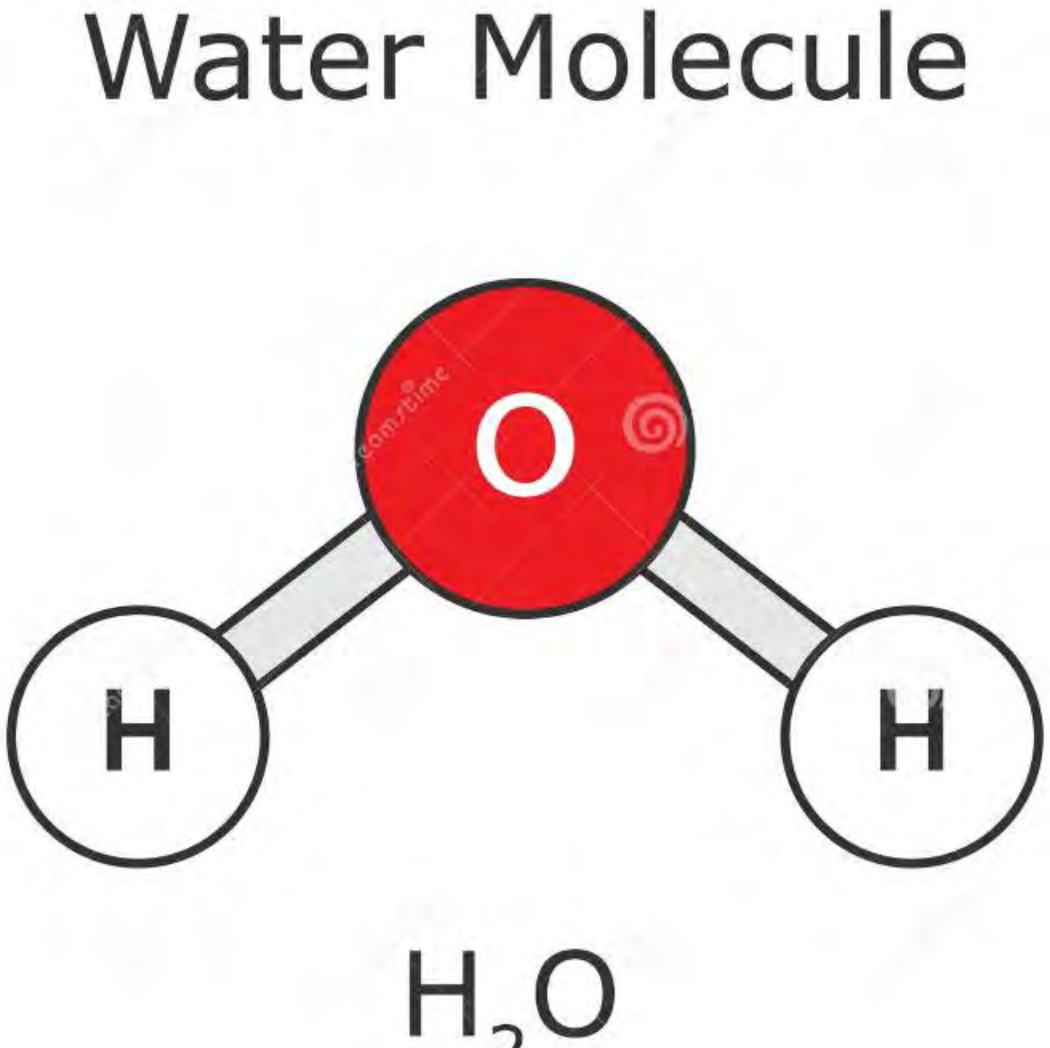
An element is a substance made up of only one kind of atom.



Compounds

A compound contains more than one type of atom, chemically combined.

Water is an example of a compound. Each water molecule is made up of one oxygen atom and two hydrogen atoms.



Atomic Structure

Nucleus

The centre of the atom is the nucleus (plural nuclei), which houses protons and neutrons.

Protons

Positively charged particles in the nucleus.

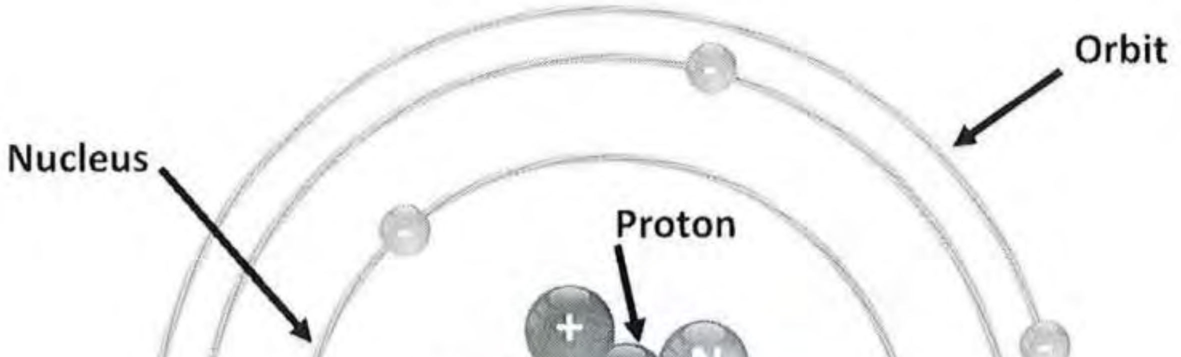
Neutrons

Neutral particles in the nucleus with about the same mass as protons.

Electrons

Negatively charged particles that revolve around the nucleus in orbits.

Figure 2-1
A carbon atom



Carbon Atom Structure

The diagram shows a carbon atom with 6 protons in its nucleus and 6 electrons revolving around it in orbits. The number of electrons, protons, and neutrons in the atoms of an element determines how that element behaves.

Atoms of different elements have different numbers of protons in their nuclei. This number is the atomic number that identifies that element. For example, the nucleus of a carbon atom always contains 6 protons, and you say that the atomic number of carbon is 6.

6

Carbon Atomic Number

Number of protons in a carbon atom

2

Helium Atomic Number

Number of protons in a helium atom

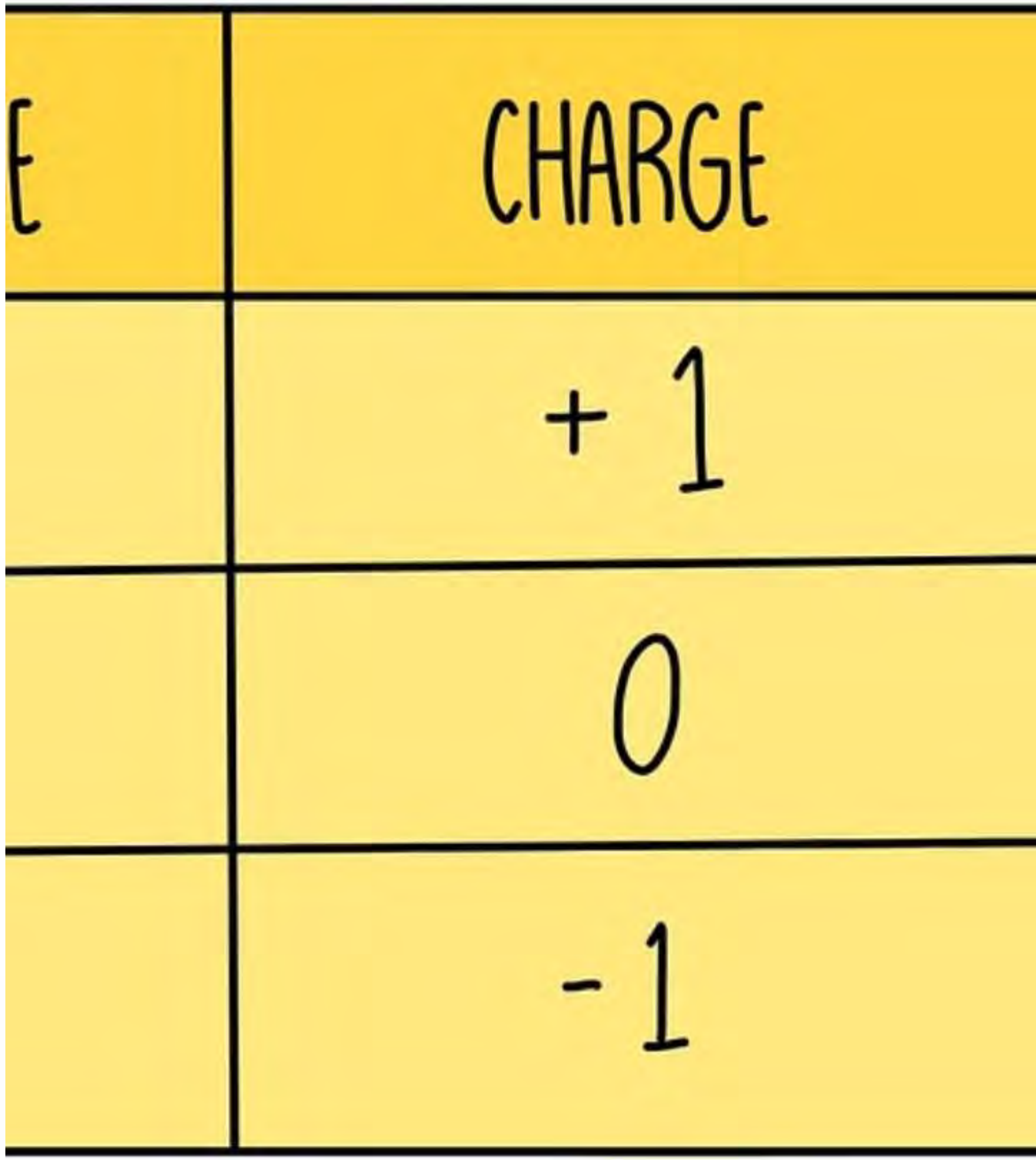
29

Copper Atomic Number

Number of protons in a copper atom

Subatomic Particles

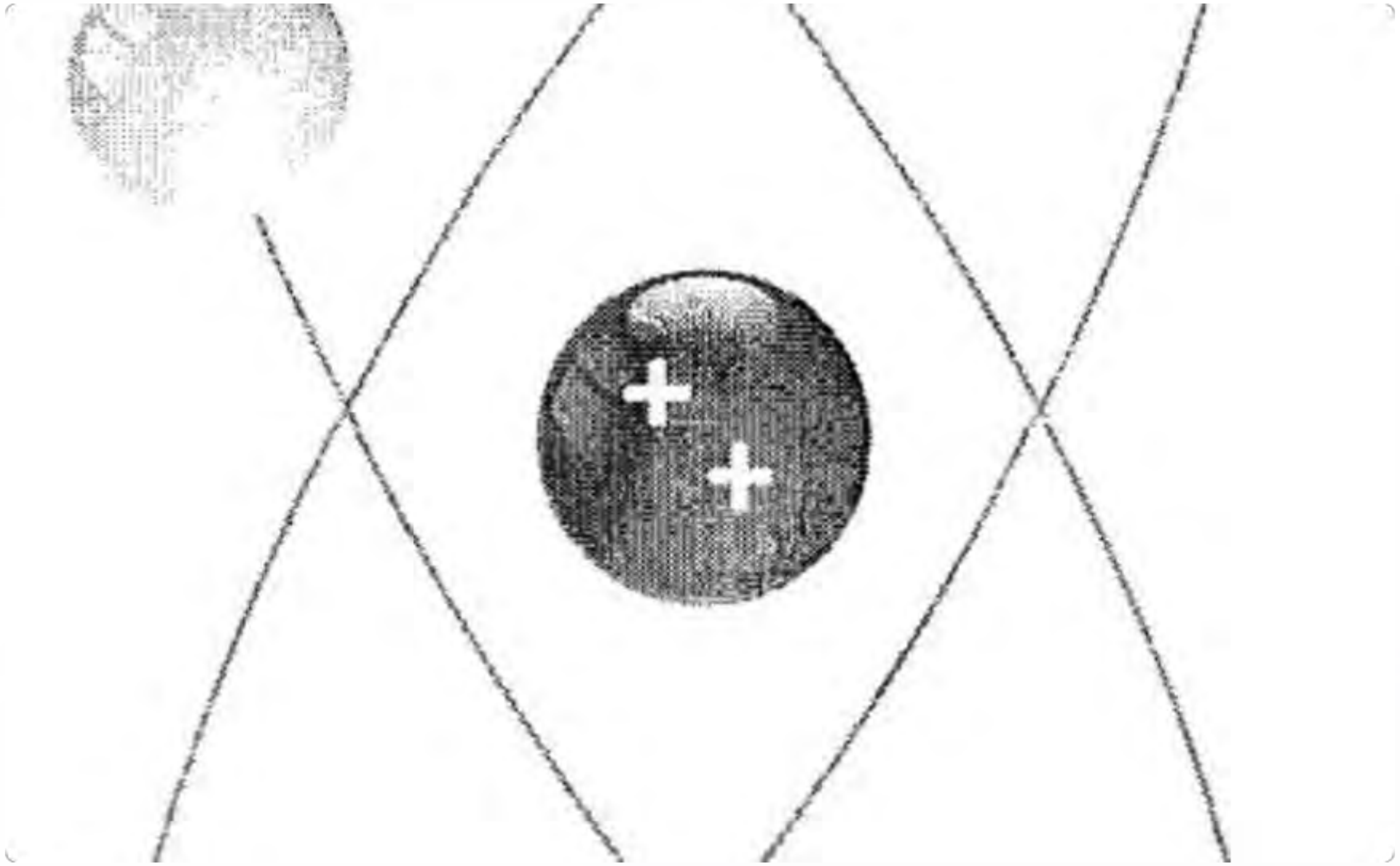
Particle	Charge	Location	Characteristics
Electron	Negative (-)	Orbits around nucleus	Easy to move, actively participates in transfer of electrical energy
Proton	Positive (+)	Nucleus	Influences flow of electrons, not directly active in electrical energy flow
Neutron	Neutral	Nucleus	Similar mass to proton



Electron and Proton Relationship

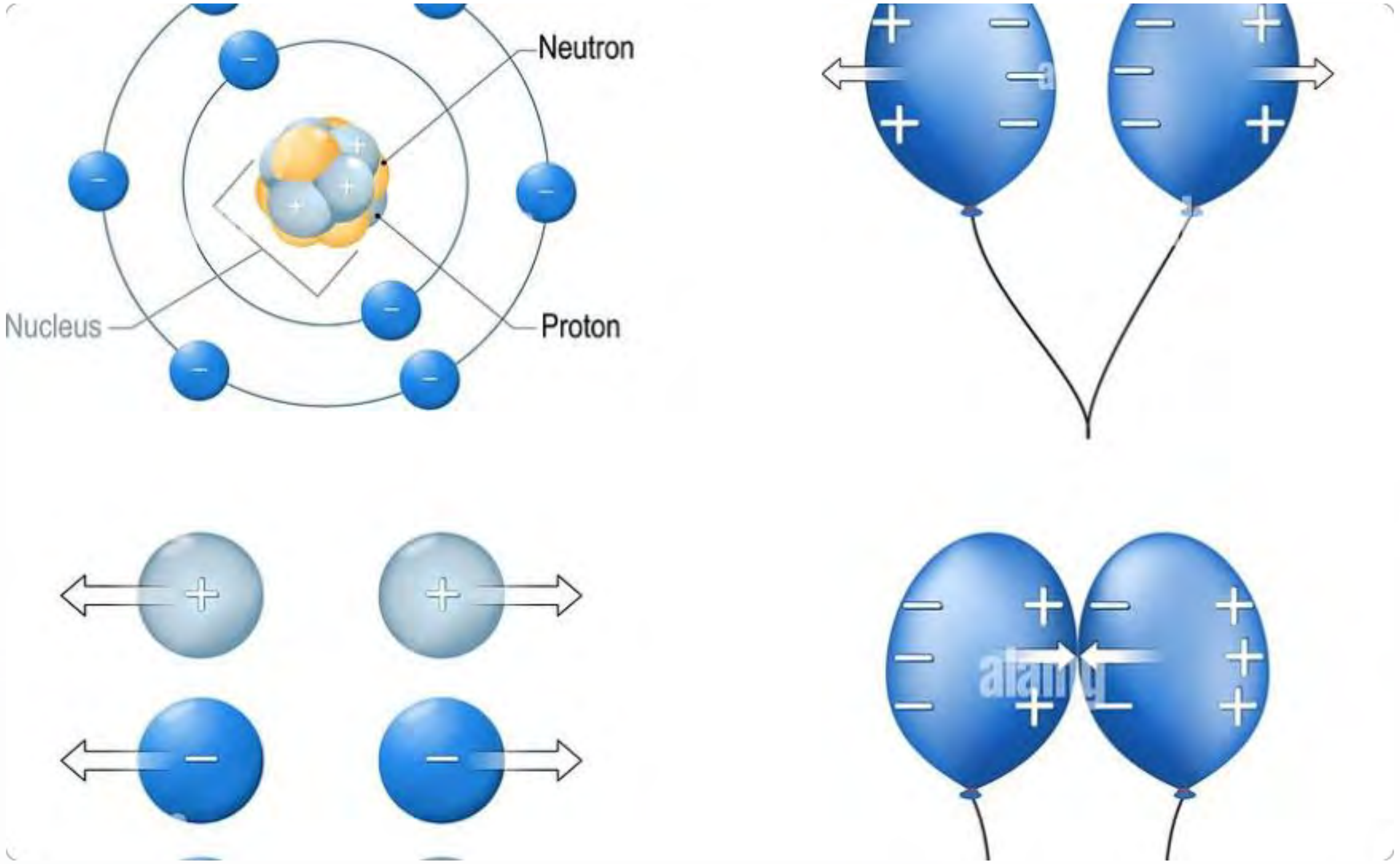
The electron carries the basic Unit of electrical charge. For historical reasons, an electron's charge is considered to be a negative(-) charge. Because it is free to move, an electron actively participates in the transfer of electrical energy.

The proton carries a positive(+) charge, opposite to that of an electron. It has the same size of charge as the electron's negative one. Protons are not directly active in the flow of electrical energy, but they do influence the flow of electrons.



Negative electrons revolve in orbits around the positively charged nucleus

The nucleus of an atom has an overall positive electrical charge due to the protons. The negatively charged electrons revolve around the positive nucleus.



Attraction Between Charges

The opposite charges of electrons and protons create an attraction that keeps electrons orbiting around the nucleus.

Atoms and Ions

Neutral Atom

Equal numbers of protons and electrons

Positive Ion

Atom loses one or more electrons

Negative Ion

Atom gains one or more electrons

Under normal circumstances, the atom has equal numbers of protons and electrons. These charges cancel each other out, and the atom as a whole is electrically neutral.

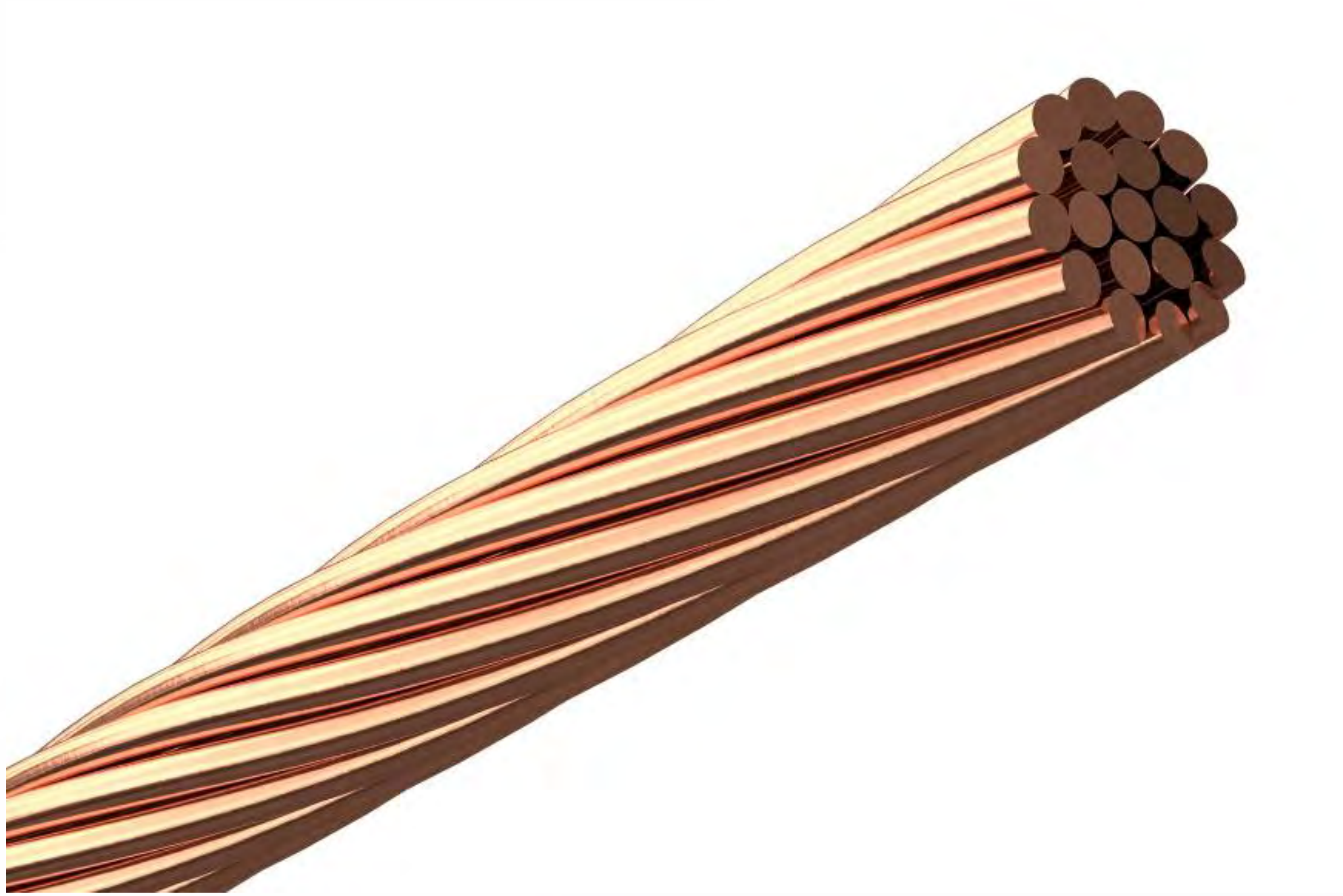
An atom can receive a negative charge through the addition of electrons. It can receive a positive charge through removal of electrons. When charging an atom occurs these ways, the atom becomes ionized and is now an ion. For example, a positive ion is an atom that has had one or more electrons removed.

Since protons are firmly bound into the nucleus, only electrons can take part in ionizing the atom.

Conductors and Insulators

Conductors

Some materials, including copper and aluminum, have electrons that are easy to free. They are said to have many free electrons and are conductors. Conductors allow easy transfer of electrical energy.



Insulators

Some other materials, such as glass and rubber, have electrons that are very difficult to free. They are said to have few free electrons and are insulators. Insulators block the transfer of electrical energy.

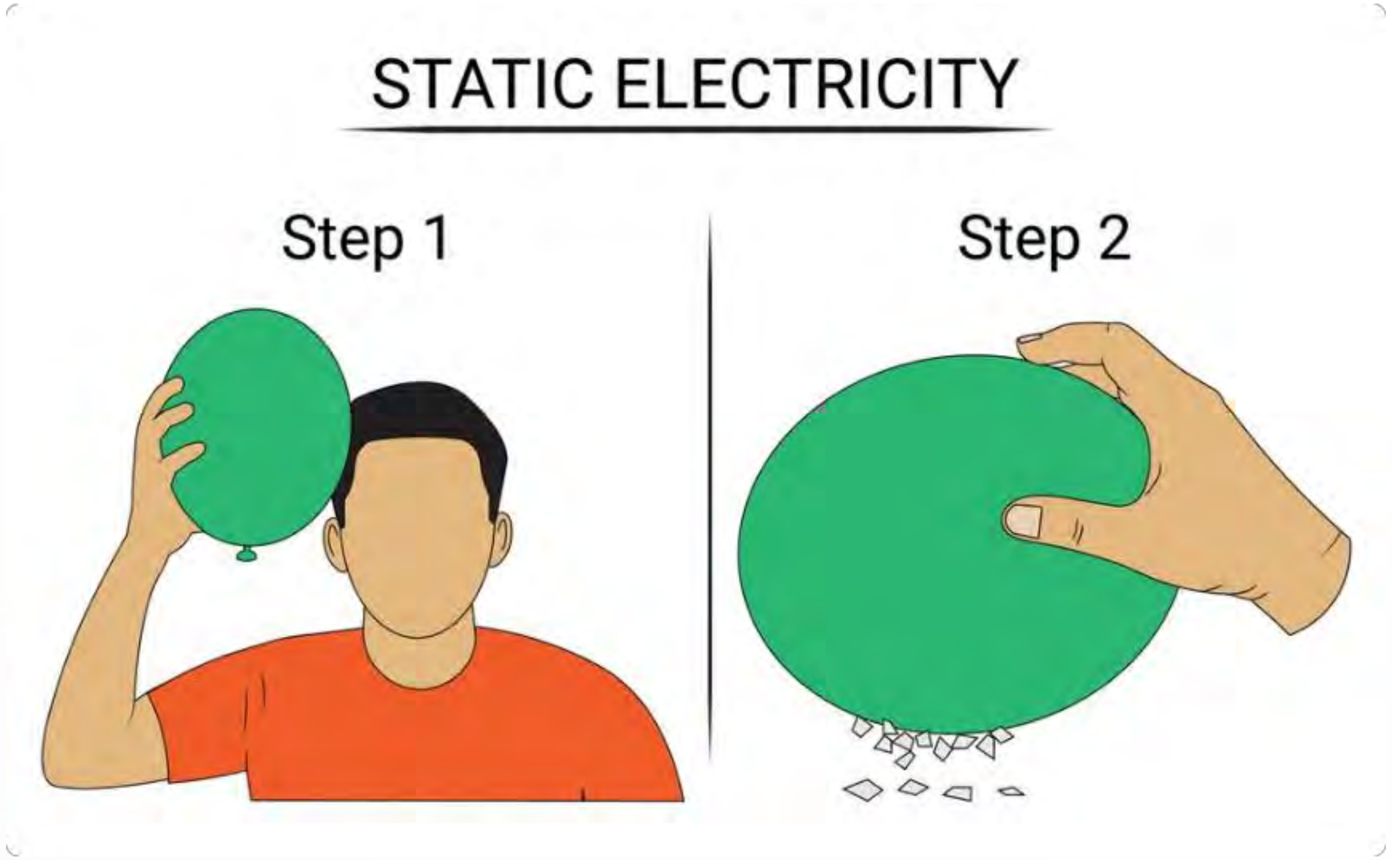
Electrostatic Charges and Fields

Electrostatic charges and fields are also known as static electricity. Static electricity is energy in the form of a stationary electric charge such as that stored in thunderclouds or produced by friction.

For example, when you rub together certain pairs of materials (such as fur and a rubber rod), an electrostatic charge is produced. The friction produces heat energy that releases electrons from the atoms on the surface of one of the materials.

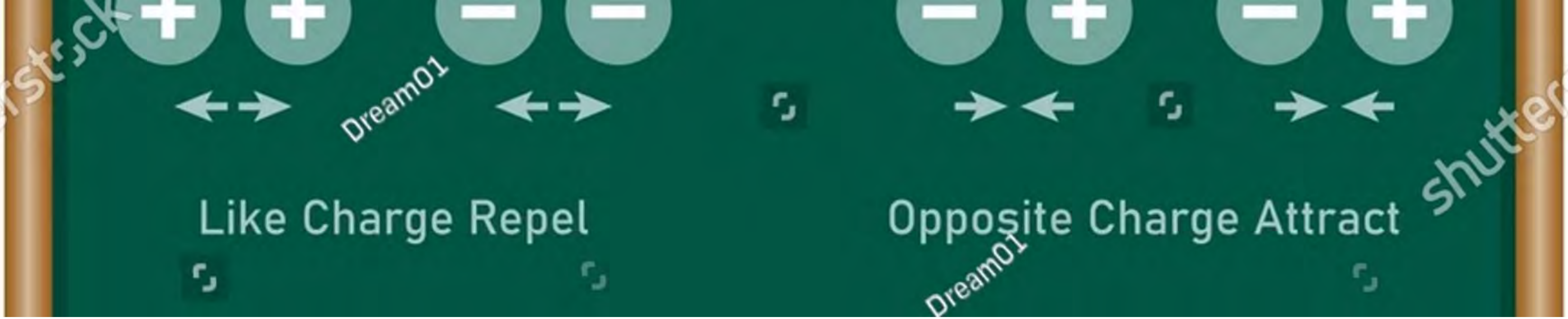
Static Electricity in Nature

Thunderclouds store static electricity that can be released as lightning.



Friction-Generated Static

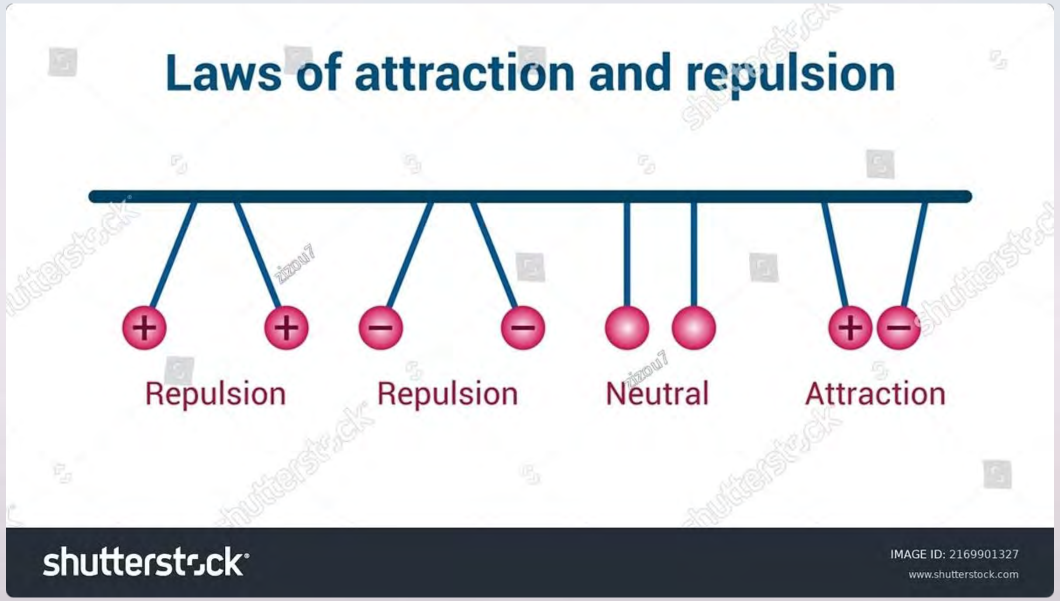
Rubbing materials together can generate static electricity through the transfer of electrons.



Electrical Charges

Electron/Proton Balance	Resulting Charge
Fewer electrons than protons	Has a positive charge
More electrons than protons	Has a negative charge
The same number of electrons and protons	Is neutral

An object may possess a positive electrical charge, a negative electrical charge, or it may be electrically neutral. The type of charge that an object has depends on the number of electrons and protons it has.



Law of Electrical Charges

The Fundamental Law

Like charges repel and unlike charges attract.

Negative and Negative

Negatively charged particles repel other negatively charged particles. They tend to move away from each other.

Positive and Positive

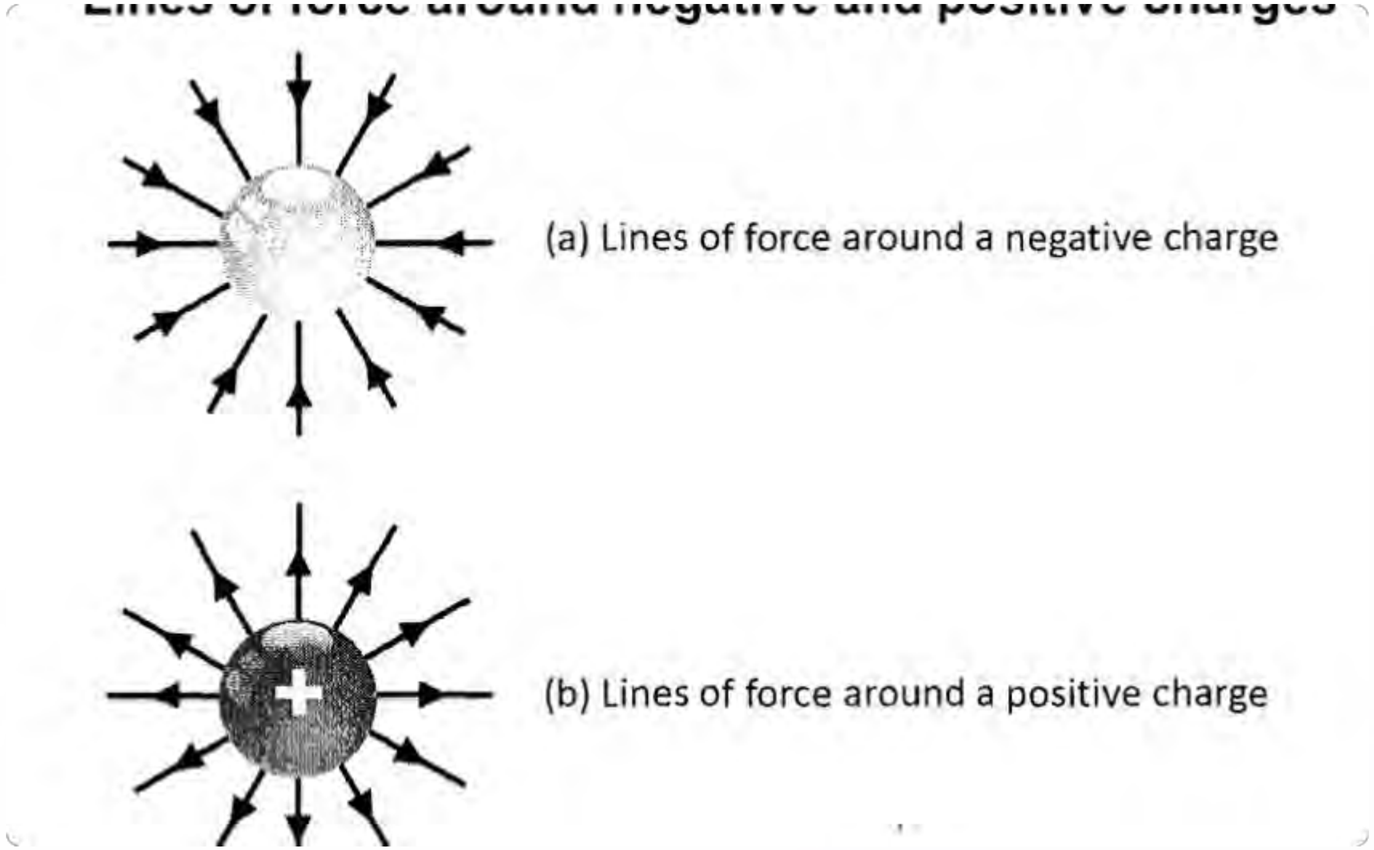
Positively charged particles repel each other. They tend to move away from each other.

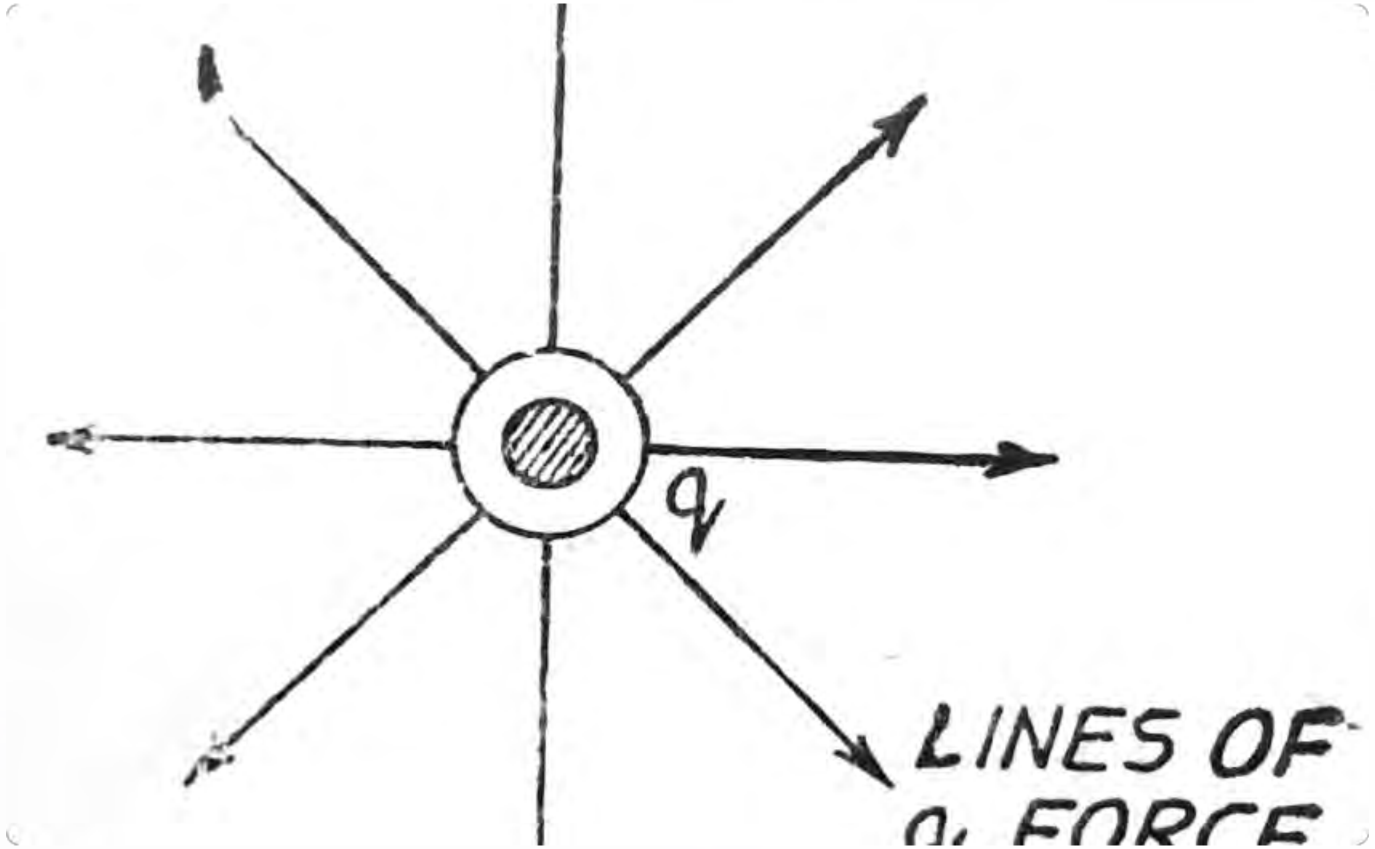
Positive and Negative

Negatively charged particles attract positively charged particles. They tend to move toward each other.

Electrostatic Forces and Fields

The electrical charges on protons and electrons are electrostatic charges. An electrostatic charge has an electrostatic field associated with it and, within this field, electrostatic forces occur. These forces are the forces of attraction and repulsion between charged particles.





Lines of Force Around a Negative Charge

Electrical diagrams show the lines of force around a negative charge as straight lines with arrows pointing toward the charge.

Lines of Force Around a Positive Charge

Diagrams show the lines of force around a positive charge as radiating outward from the charge.

Forces of Attraction and Repulsion

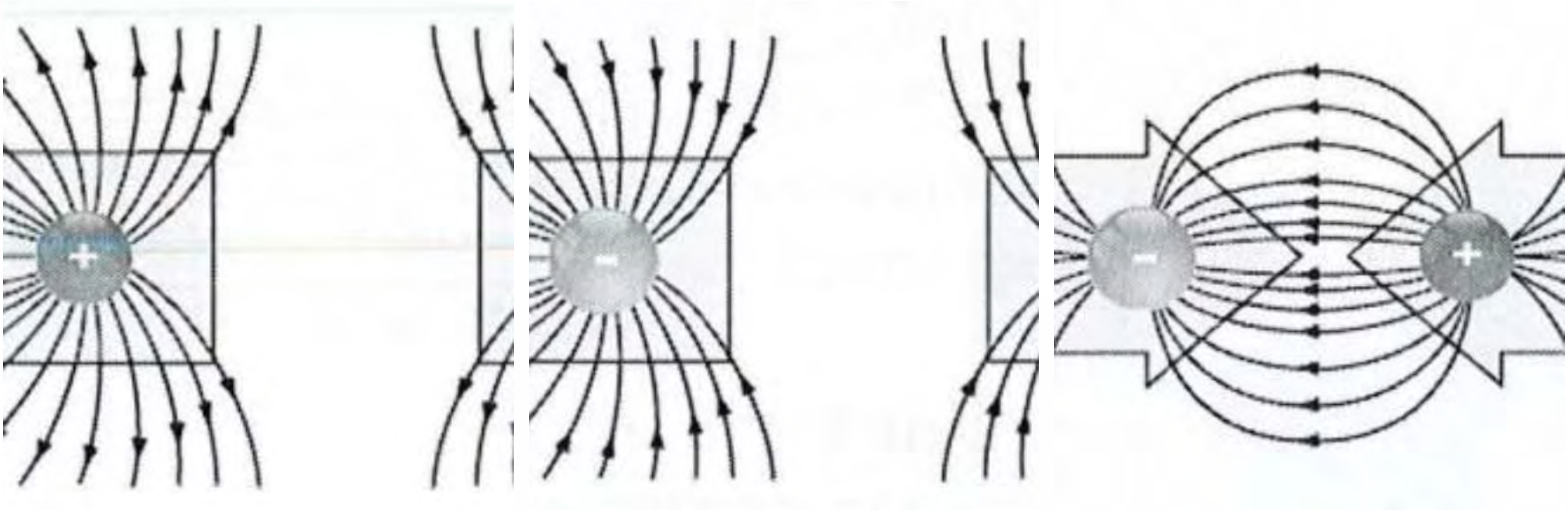


Figure 2-4 shows how the lines of force around positively and negatively charged objects cause forces of attraction and repulsion.

The strength of the forces of attraction and repulsion depends on:

- the amount of charge on each object; and
- the square of the distance between the objects.

The greater the electric charges on the objects, the greater the electrostatic force.

Production of Electricity

Heat - Thermoelectricity

The application of heat to two different metals joined together leads to the transfer of electrons across the junction.

Magnetism - Electromagnetism

When a conductor passes a magnetic field, the forces of the magnetic field act on the electrons in the conductor.

Chemicals - Electrochemistry

Chemical action results in the transfer of electrons from one electrode to another through an electrolyte.

Pressure - Piezoelectricity

Force from the application of pressure to certain crystal materials drives the free electrons out of orbit.

Light - Photoelectricity

When light strikes certain materials, the energy from the light causes the atoms to release electrons.

Thermoelectricity

Heat Application

Heat is applied to two different metals joined together

Electron Transfer

Electrons transfer across the junction

Charge Creation

One side becomes positive with respect to the other

Practical Application

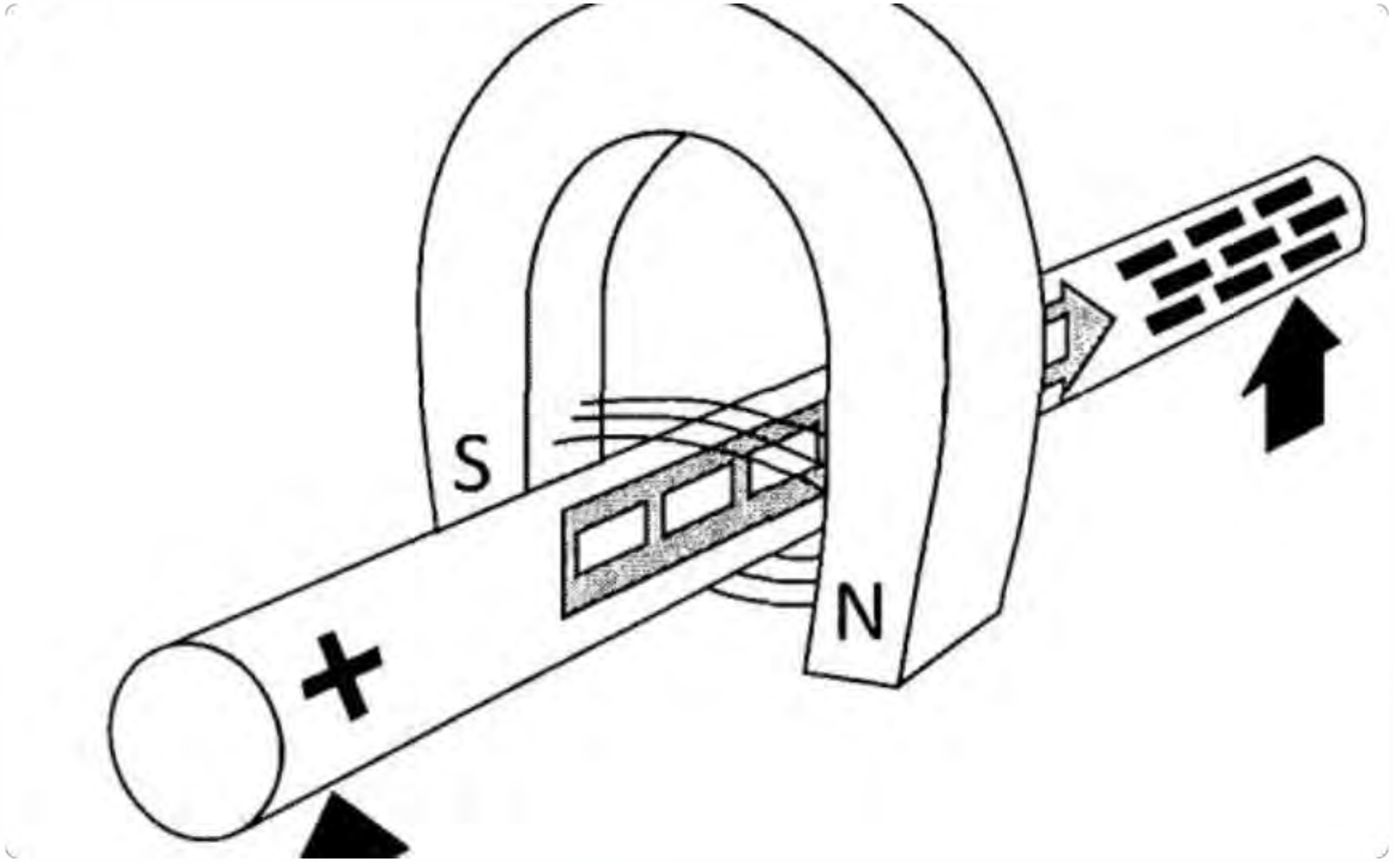
Thermocouples function as thermometers to detect and measure temperature

Thermocouples often function as thermometers to detect and measure temperature. The current that a thermocouple produces is enough to hold in a small electromagnet within a gas valve, indicating the presence or absence of a pilot flame.

Electromagnetism

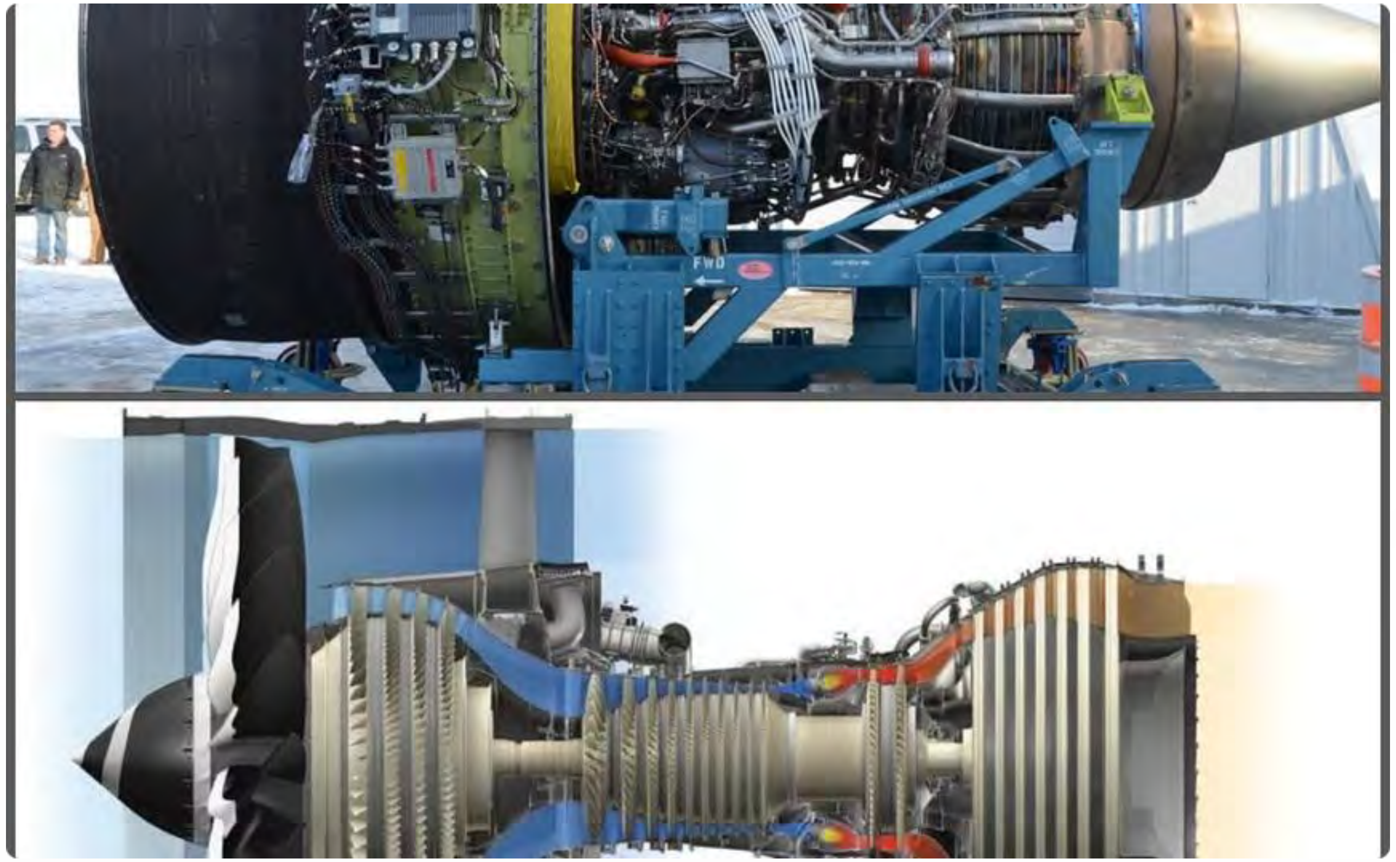
Magnetic force fields surround magnets, which have magnetic poles that attract or repel each other. When a conductor passes a magnetic field, the forces of the magnetic field act on the electrons in the conductor, causing them to move through the conductor.

The same thing happens if you hold steady the conductor in a moving magnetic field. An electric generator produces electricity by electromagnetism.



Conductor Passing Through Magnetic Field

When a conductor passes through a magnetic field, electrons in the conductor are forced to move, creating an electric current.



Electric Generator

Generators use the principle of electromagnetism to convert mechanical energy into electrical energy.

Electrochemistry - Batteries

A flashlight battery is a common example of the electrochemical production of electricity. A battery is a group of voltaic cells. A voltaic cell is a product of immersing two different metal electrodes in a chemical solution called electrolyte.

This creates a difference of potential between the two electrodes. Potential difference is the measure of the ability of a Unit of electrical charge to do a certain amount of work.

Chemical Reaction

Chemical action transfers electrons between electrodes

Charge Separation

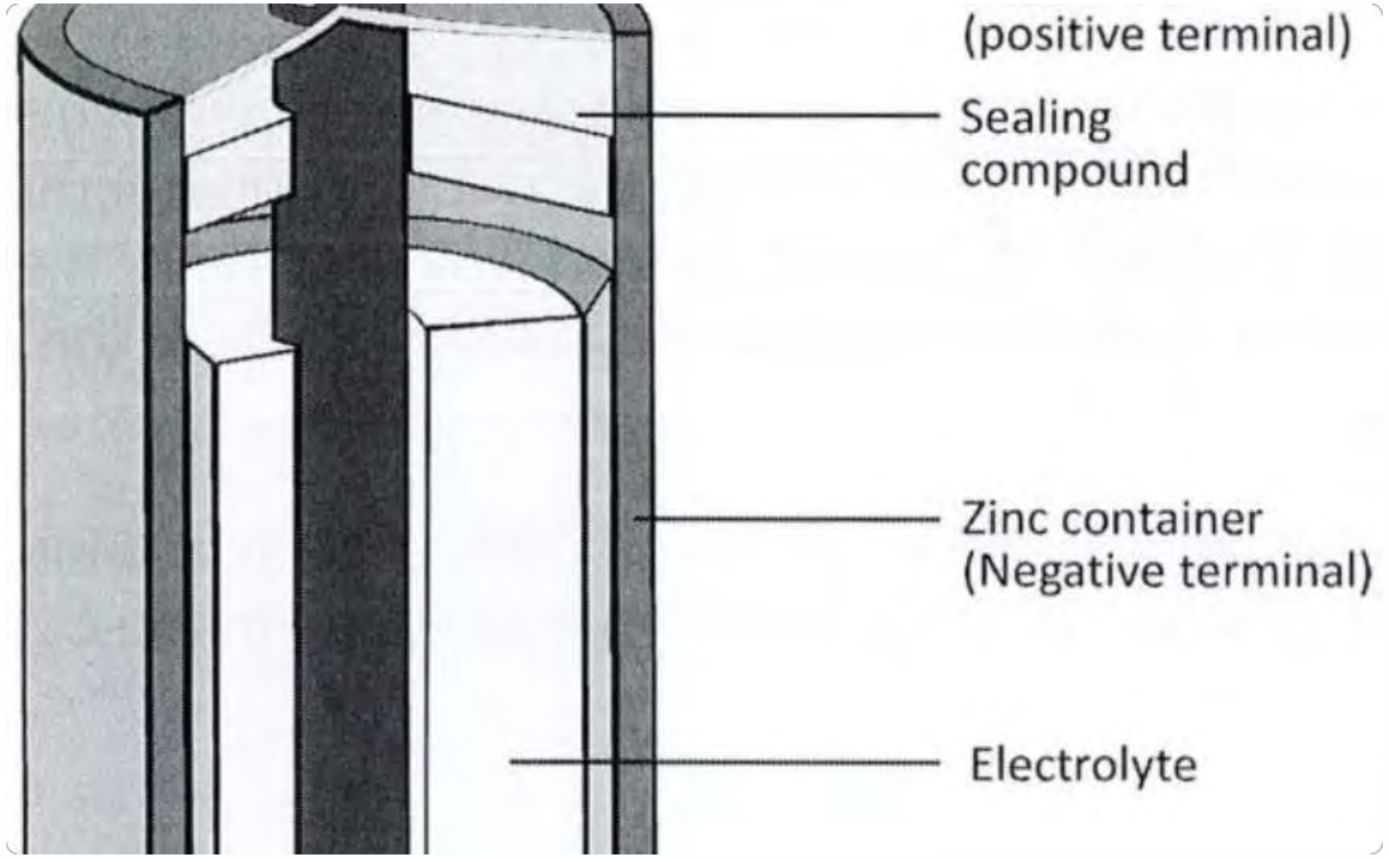
One electrode becomes positive, the other negative

Current Flow

Connecting a wire allows electric current to flow

Dry Cell Battery Structure

Flashlight batteries are dry cells. They have a liquid electrolyte, but it combines with other materials to form a paste. This allows the use of the cell in any position.



Typical Dry Cell Battery

The zinc battery container is the negative electrode, and a carbon rod in the centre of the cell is the positive electrode.

Internal Components

The space between the positive and negative electrodes contains a mixture of carbon, manganese dioxide, and electrolyte. The top of the cell has a seal to prevent evaporation, as the battery will not work when the electrolyte dries out.

Piezoelectricity

Pressure Application

Force is applied to crystal materials

Electron Movement

Free electrons are driven out of orbit

Charge Creation

Positive and negative charges build up on opposite sides

Force from the application of pressure to certain crystal materials drives the free electrons out of orbit. Positive and negative charges build up on opposite sides of the material. You use this principle in such things as spark igniters for gas barbecues.

Static vs. Dynamic Electricity

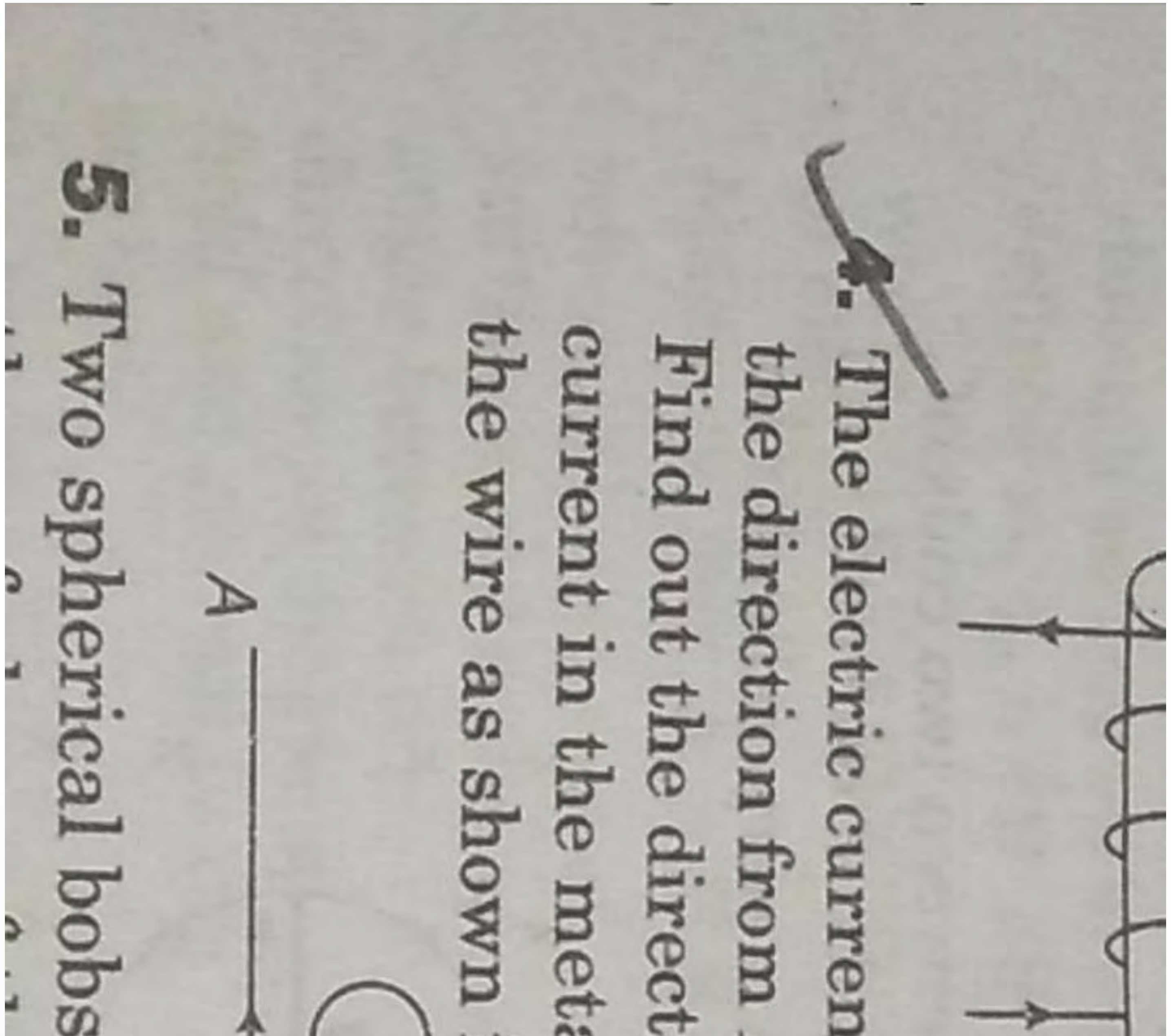
Static Electricity

In static electricity, electric charges are at rest. Static electricity normally does not perform useful work.

Dynamic Electricity (Electric Current)

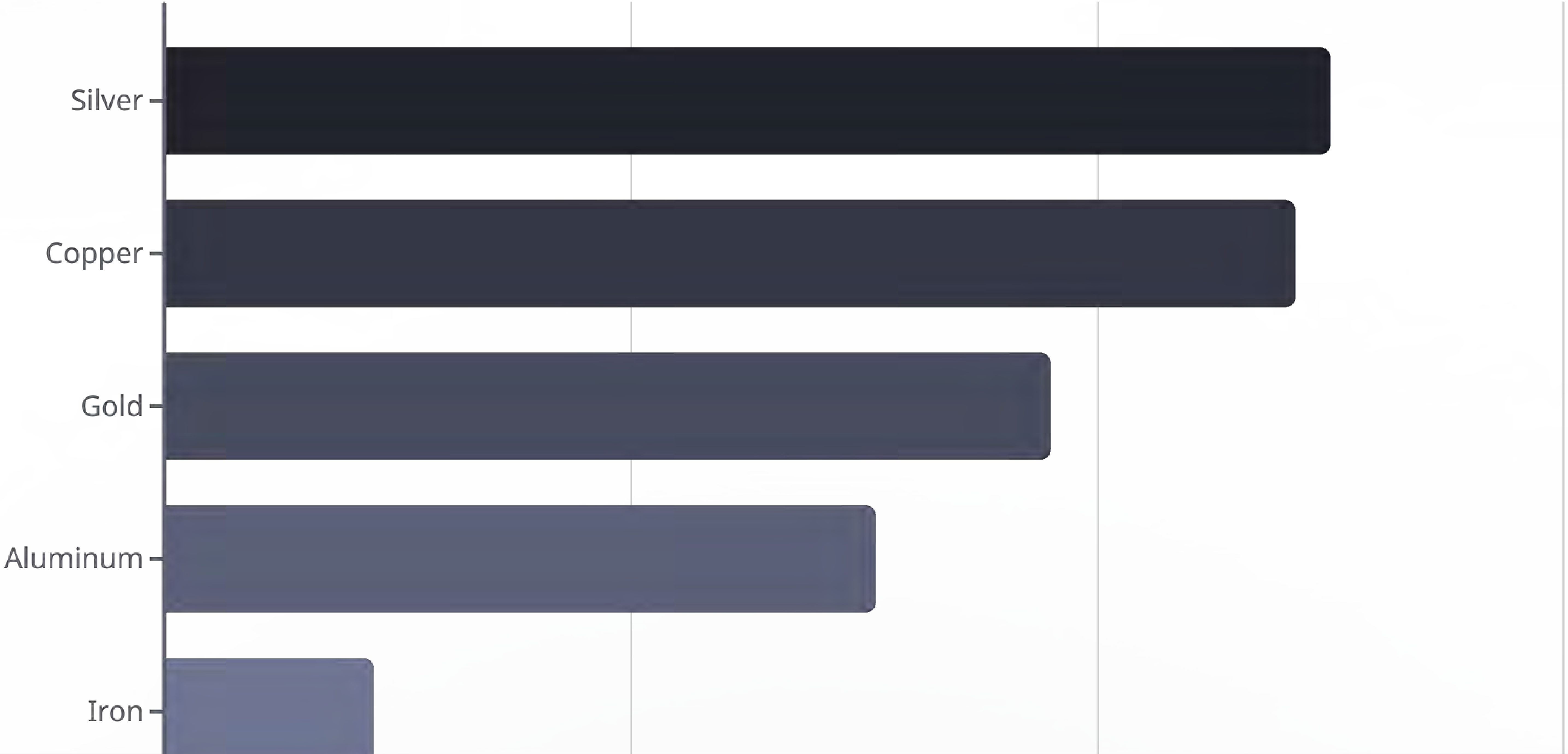
To use electrical energy to do work, set the electrons in directed motion. When you make electrons to move in the same direction, they produce an electric current.

The flow of electric current carries energy that can perform work. The more electrons that move in the same direction, the greater the flow of current and the greater the amount of available energy.


4. The electric curren
the direction from
Find out the direct
current in the meta
the wire as shown
A
5. Two spherical bobs

Conducting Materials

Materials that conduct electricity well and have low electrical resistance are conductors. Most metals are good conductors, but some are better than others.



Aluminum as a Conductor

Lightweight

Technicians use aluminum for high-voltage transmission lines because it is much lighter than copper.

Cost-Effective

Aluminum is cheaper than copper, making it economical for large-scale applications.

Structural Challenges

Pure aluminum is weak and could not support its own weight in transmission lines.

Reinforced Design

Transmission conductors are made with one or more core strands of steel cable, with strands of aluminum cable wrapped around them.

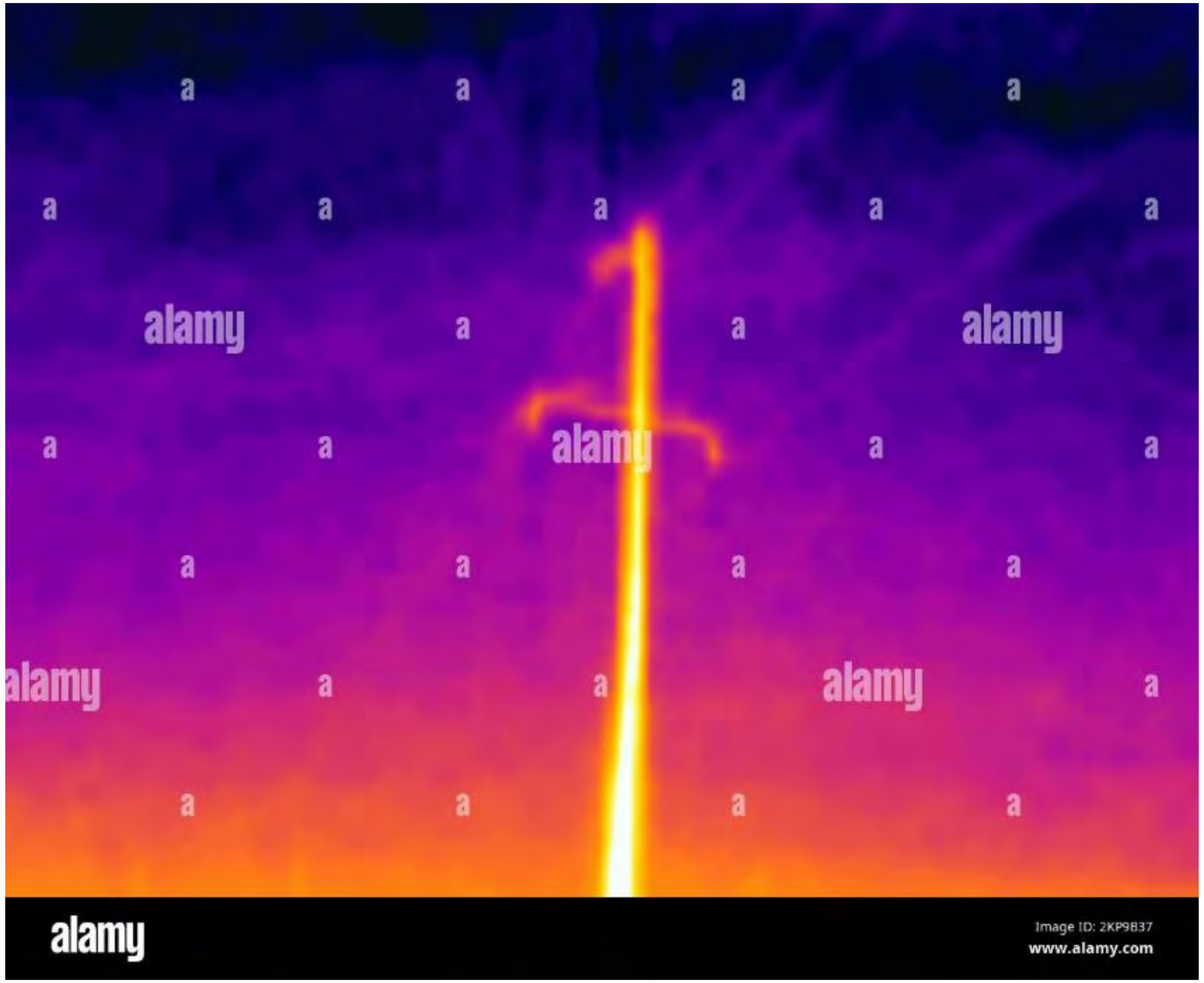
Conductor Heating

Heating Elements

Conductors heat up when current is flowing through them. This is a good thing in the case of conductors that work as heating elements.

Transmission Conductors

Heating is not a good thing in the case of using conductors in electrical transmission, as it represents energy loss and can damage insulation.



Insulating Materials

Plastic

Extensively used as electrical insulation for household wiring. Lower voltages require less insulation, so relatively thin plastic can be used.

Glass

Good insulator for very high voltages. In long lengths, it provides adequate insulation for transmission lines.

Porcelain

Poor conductor of electricity, extensively used as electrical insulator for high voltage applications.

Air

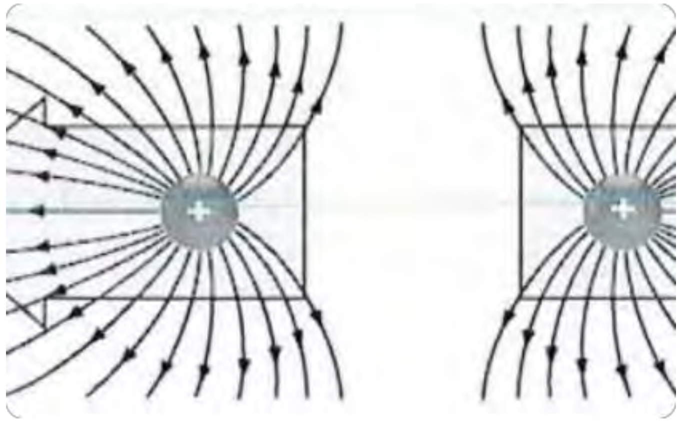
Functions as an insulator for very high voltages when sufficient distance is maintained.

Oil

Used as an insulator in high voltage applications such as transformers.

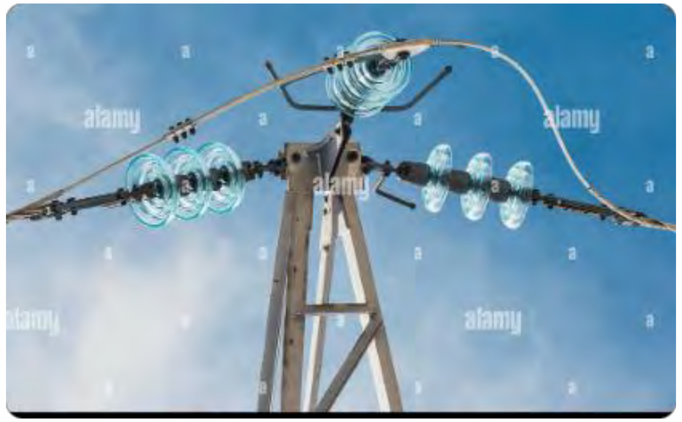
Transmission Line Insulators

For very high voltages, plastic is not an adequate insulator. At very high voltages, porcelain, glass, air, or oil function as insulators.



Transmission Tower

A transmission tower supporting a single conductor. A long glass holds away the conductor from the metal of the transmission tower.



Glass Insulators

Glass is a good insulator and, in long lengths, it provides adequate insulation for very high voltages.

Voltage and Insulation Breakdown

Insulator Effectiveness

If the voltage is high enough, electricity can pass through almost any insulator.

Lightning Example

Lightning is an electric current that passes through long distances of air, which is normally a poor conductor (a good insulator). To do this requires billions of volts of electrical pressure.

Arcing Phenomenon

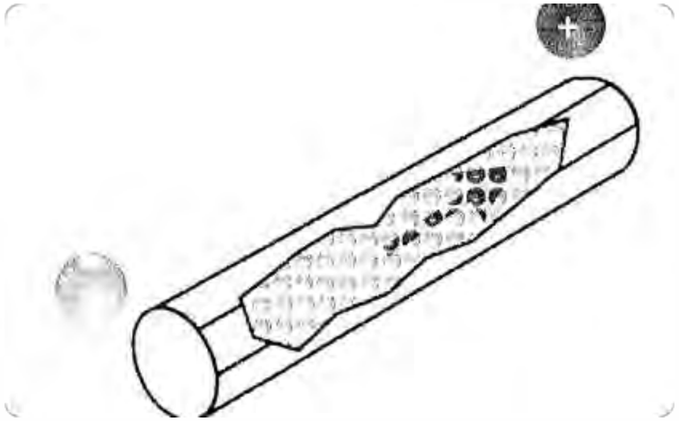
High-voltage electricity can arc or jump across an air gap from one point to another if the voltage between the two points is strong enough.

Safety Precaution

For this reason, personnel must remain well clear of high-voltage equipment.

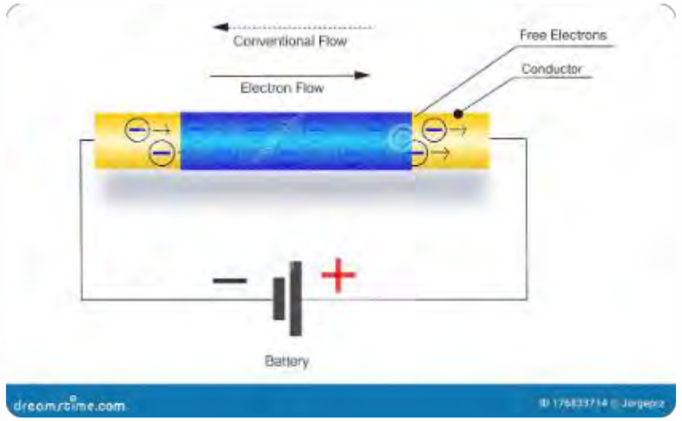
Current Flow in a Conductor

To produce a flow of electricity or current in a conductor, make the electrons move in a direction along the conductor by placing opposite (positive and negative) charges on the ends of the conductor. The free negative electrons move toward the positive charge and away from the negative charge.



Free Electrons Flow

Free electrons flow in the same direction in a conductor to produce electric current.



Electron Movement in Copper

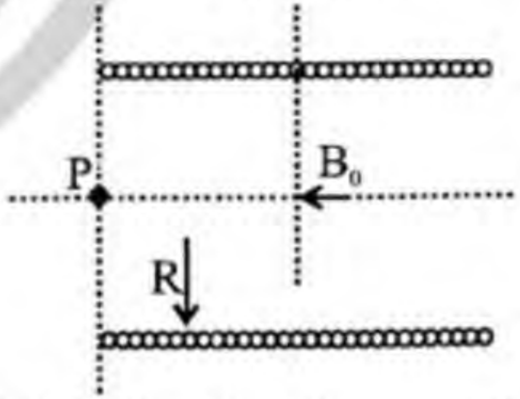
Copper's abundance of free electrons makes it an excellent conductor for electric current.

Types of Current

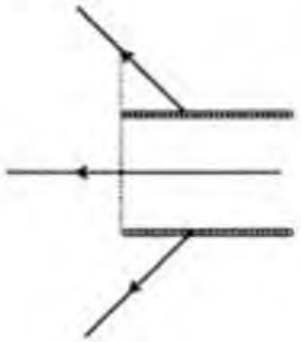
Direct Current (DC)

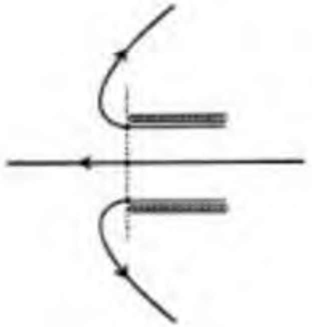
When current flows in a constant direction, it is a direct current (dc).

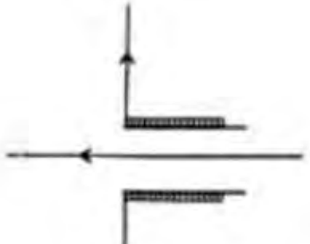
8. A direct current flows in a solenoid of length L and radius $R, (L >> R)$, producing a magnetic field of magnitude B_0 inside the solenoid.

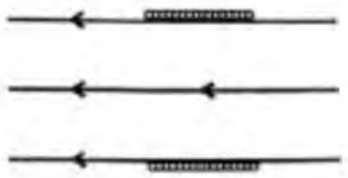


Which of the following diagrams best describes the magnetic field lines in the vicinity of P at the end of the coil

(1) 

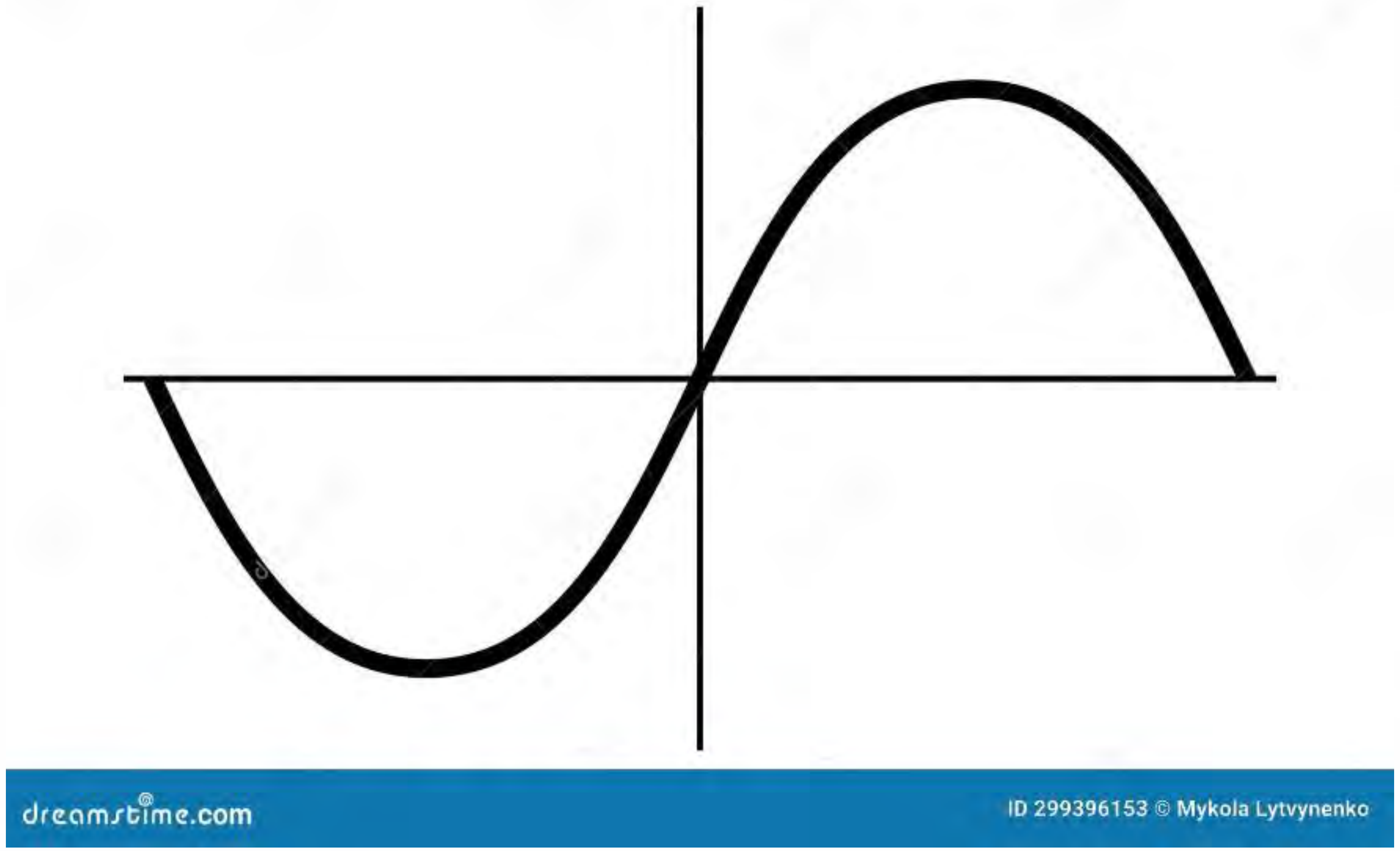
(2) 

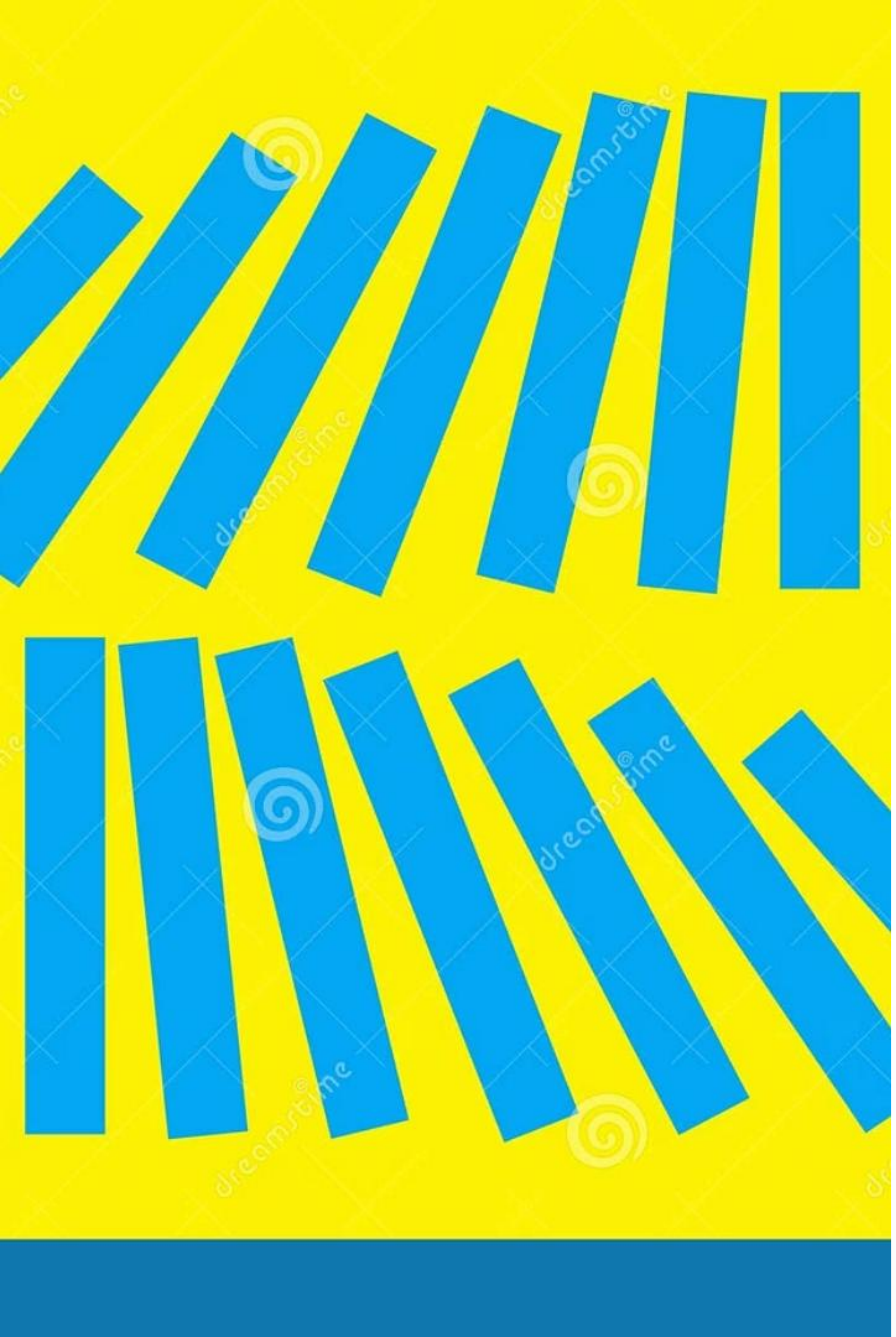
(3) 

(4) 

Alternating Current (AC)

Alternating current (ac), on the other hand, regularly reverses direction and occurs during reversal of the polarity of each end of the conductor, which is always the case with house current.





Speed of Electric Current

Light Speed Propagation

The effect of electric current moves down the conductor at the speed of light (297,600 km per second).

Limited Electron Movement

Individual electrons do not move very far in the conductor.

Domino Effect

As each electron leaves its own orbit and enters another, it repels another electron out of orbit, and so on.

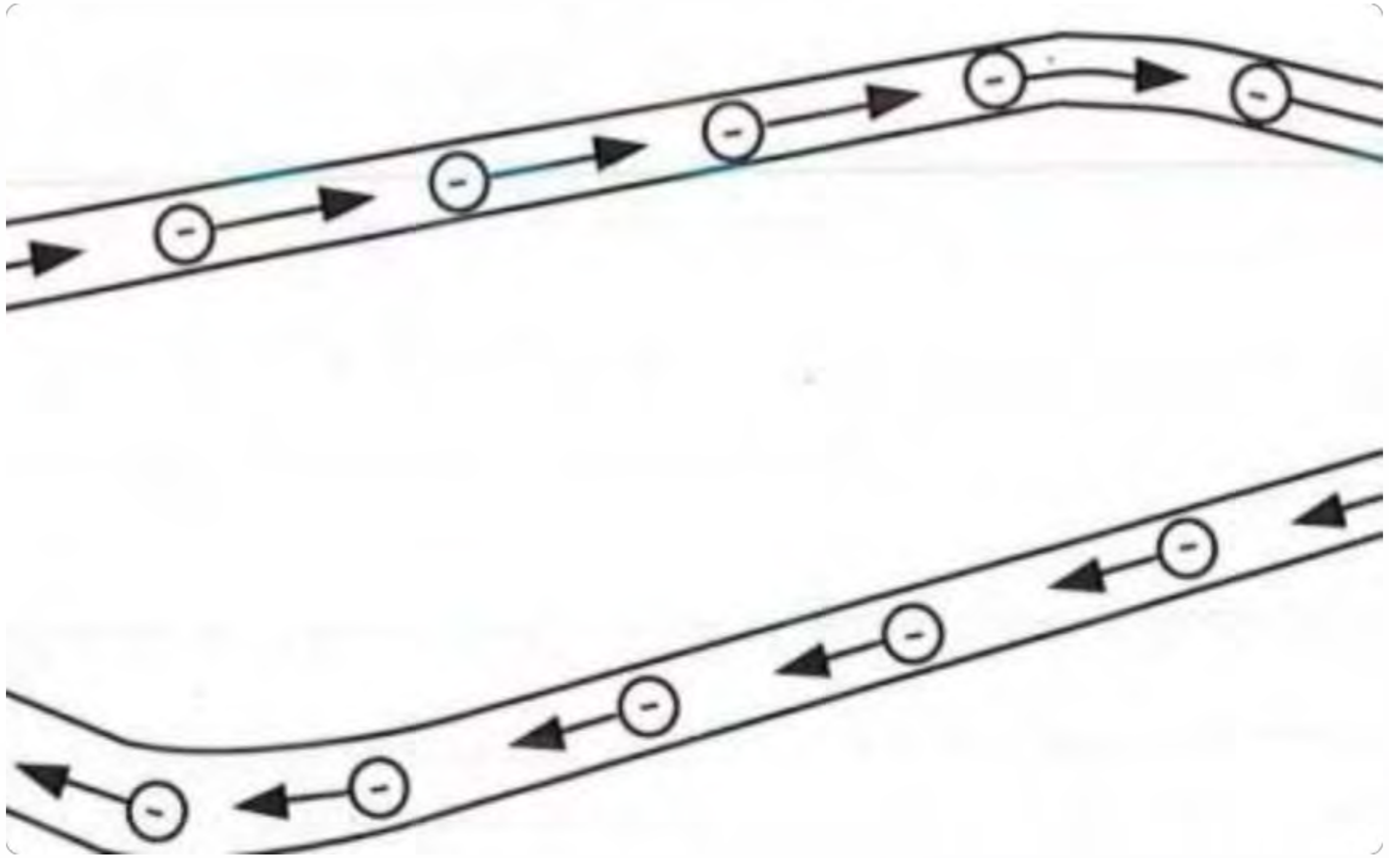
Wave-Like Propagation

The rapidly moving current is the impulse of these changes moving along the length of the conductor.

This is similar to the impulse of falling dominoes moving the length of the row, while each domino makes only a slight movement.

Closed and Open Circuits

Placing a negative charge at one end of the wire repel away electrons to the other end of the wire. Current flows only until enough electrons accumulate at the other end to produce an equal charge. At that point, no further current flows, and there is static electric charge on the conductor.



Complete or Closed Circuit

For electric current to flow, there must be opposite charges at the ends of the conductor. Some kind of electrical energy source, such as a battery or generator, supplies these charges.

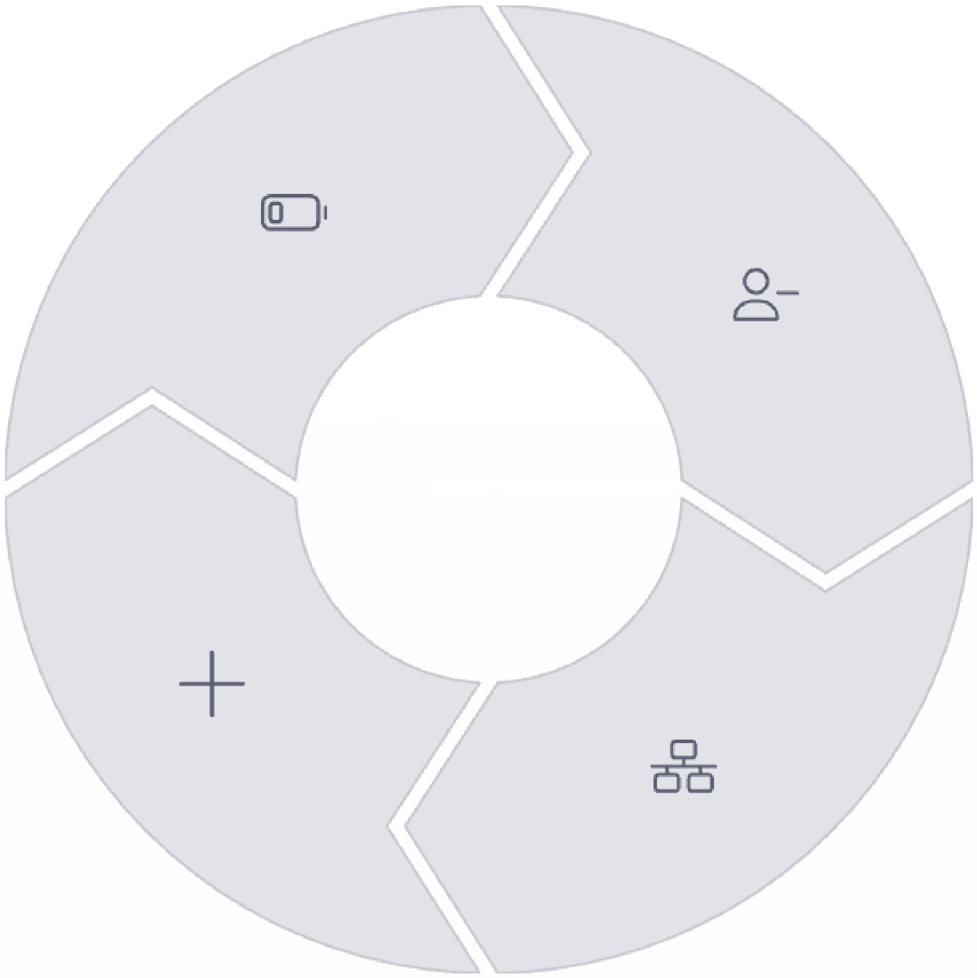
Open Circuit

If the circuit breaks (opens) at any point, current stops flowing. An open circuit can accidentally result from breaks or intentionally from switches or disconnection.

How a Closed Circuit Works

Energy Source

Battery or generator provides opposite charges



Negative Terminal

Electrons are repelled into the wire

Conductor

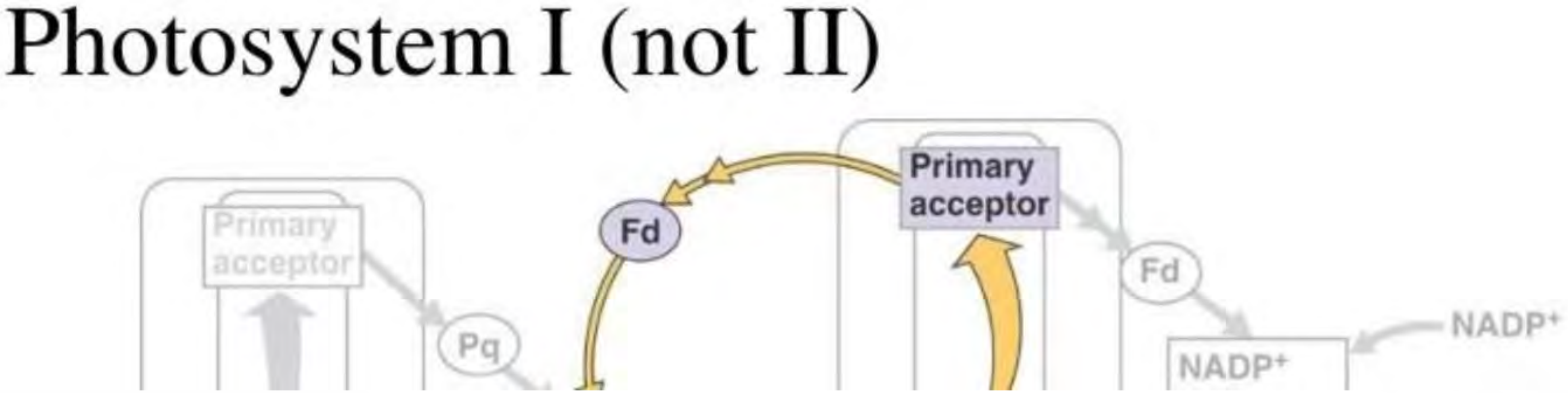
Electrons flow through the wire

Positive Terminal

Electrons are attracted to this end

At the negative side of the electrical energy source, electrons are repelled in the wire. At the positive side, the source attracts electrons.

While current flows in the circuit, electrical energy can do work-for example, heating a lamp filament to give light. If the circuit breaks (opens) at any point, current stops flowing.



Conventional Flow

Historical Assumption

Traditional current flows from positive to negative

Conventional Flow

This direction is still commonly used

Electromagnetism Rules

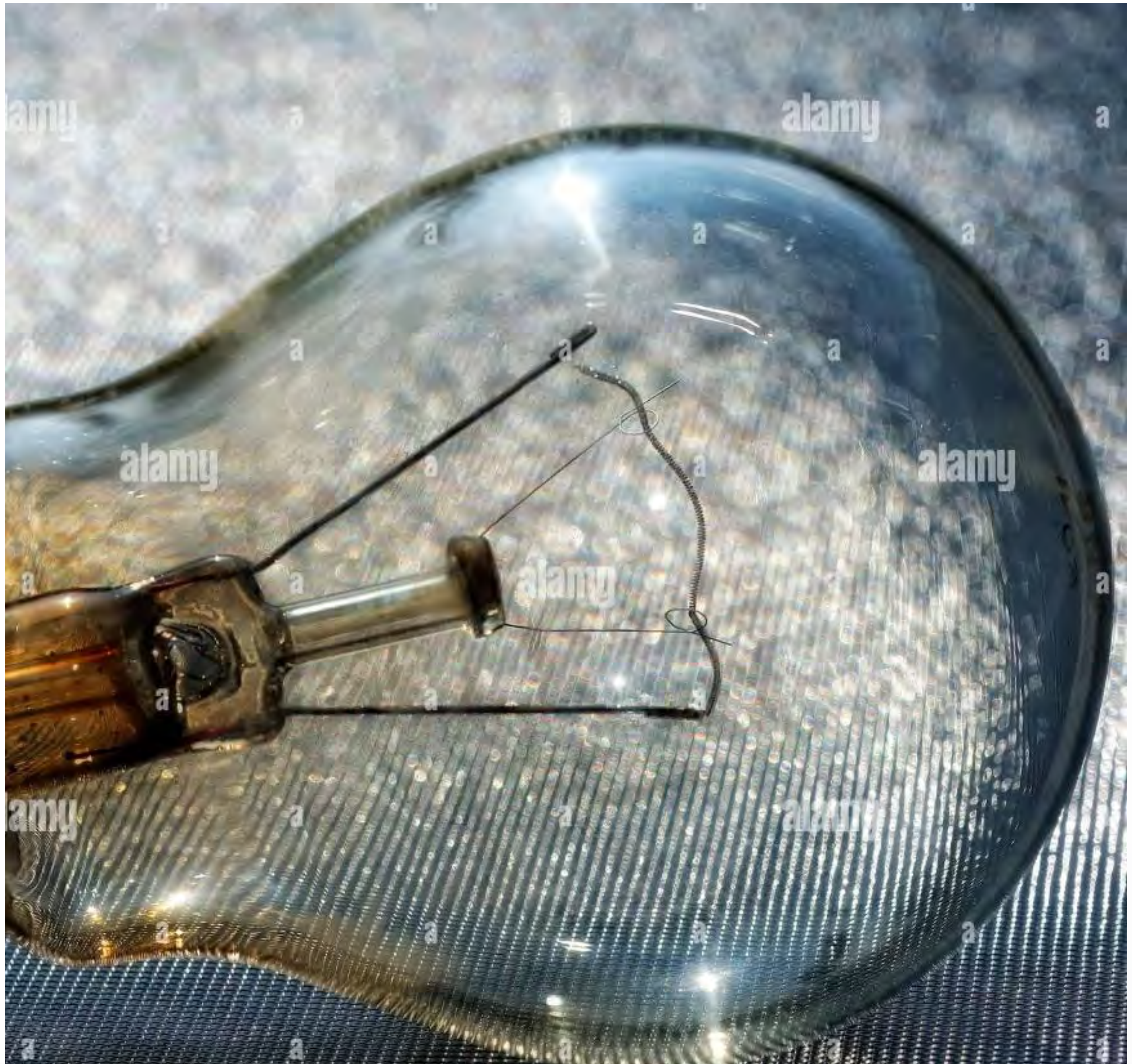
Based on conventional flow direction

Despite present knowledge about electron-flow, there has been an assumption that traditional current flows from positive to negative. This direction is conventional flow and is still common. For example, the rules for electromagnetism, a topic for later discussion, are based on conventional flow.

Open Circuit Examples

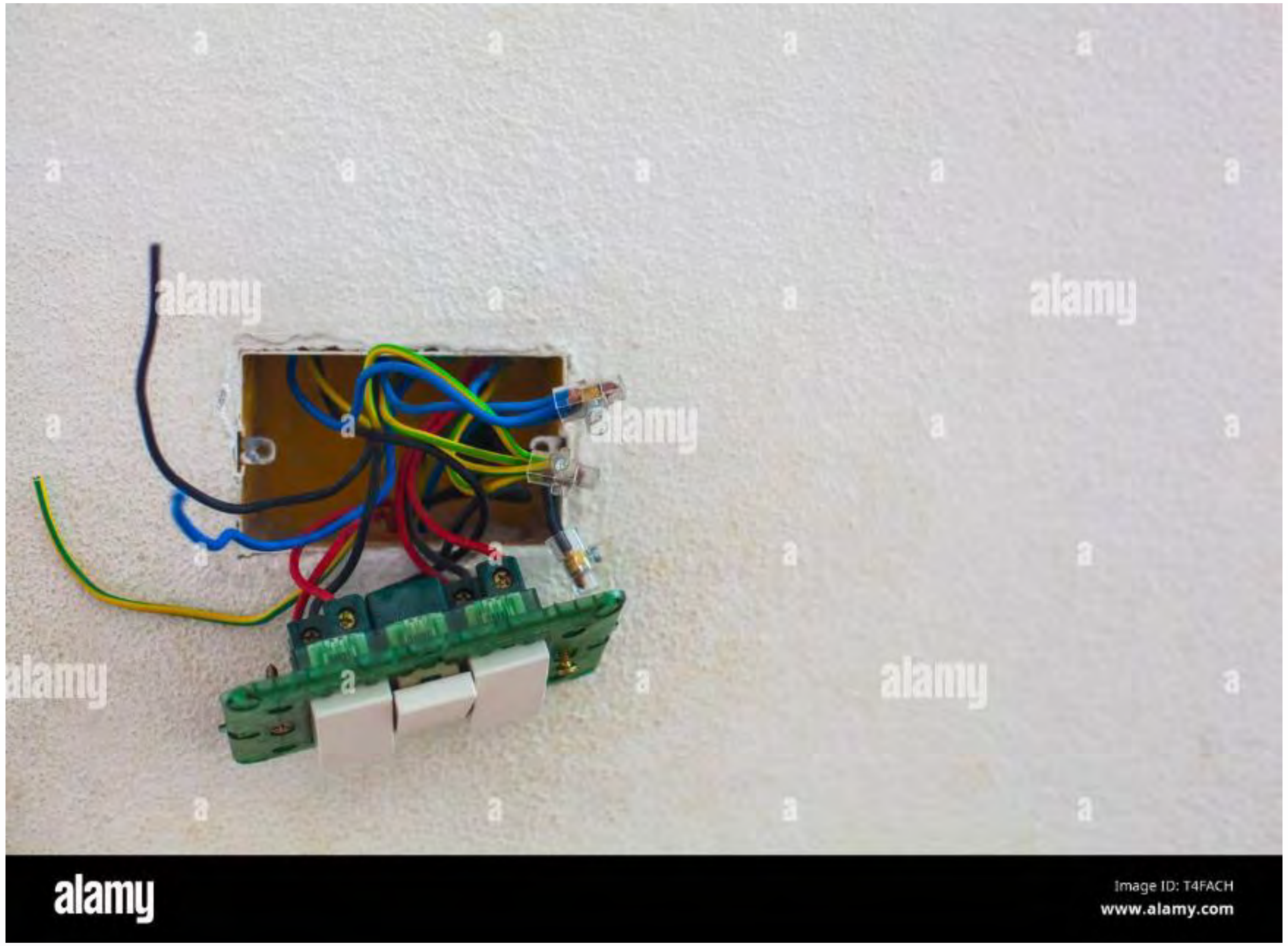
Broken Filament

When the filament in a lamp breaks, the lamp no longer lights because the circuit is open.



Light Switch

When the light switch is in the open position, the lamp no longer lights because the circuit is intentionally opened.



Useful Effects of Electricity: Heat

When electric current passes through a wire, the temperature of the wire rises, and heat transfer gives off energy. Many household appliances, such as toasters and electric heaters, use this effect.

Good conductors such as copper produce less heat, while poor ones such as tungsten produce a lot of heat when they conduct current.

Toaster

Electric toasters use resistive heating elements that glow red-hot to toast bread.

Space Heater

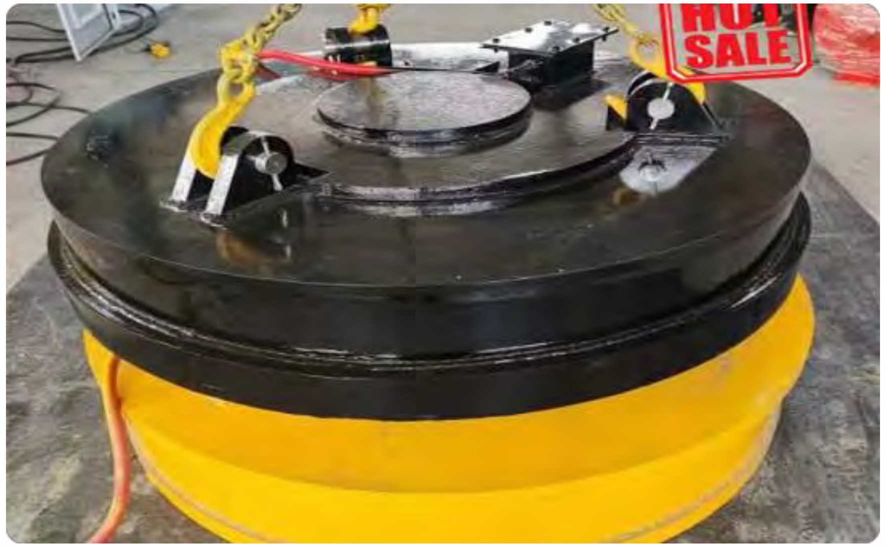
Electric heaters convert electrical energy into heat energy for warming spaces.

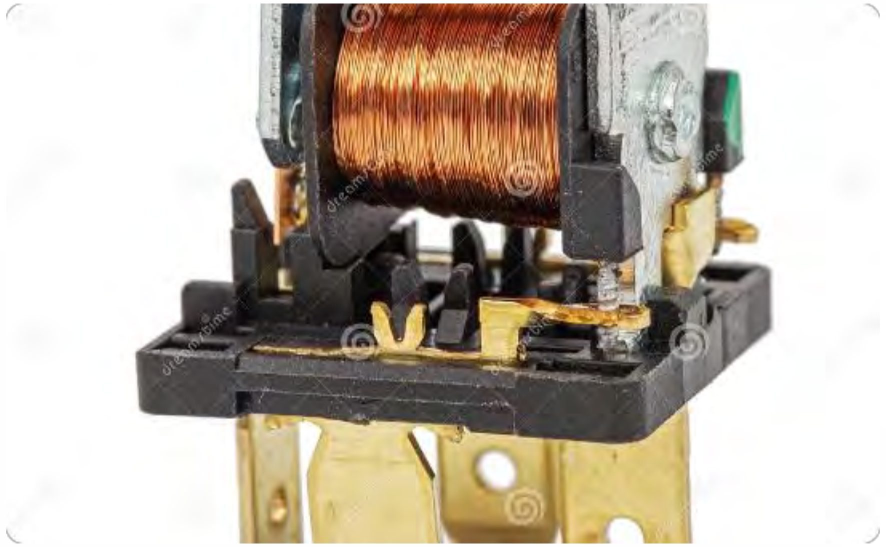
Light Bulb

Incandescent bulbs use tungsten filaments that heat up to produce light.

Useful Effects of Electricity: Magnetism

Any conductor of electric current acts like a magnet. This interaction between electricity and magnetism is called electromagnetism. When the current stops flowing, the conductor no longer acts as a magnet.





Electromagnet

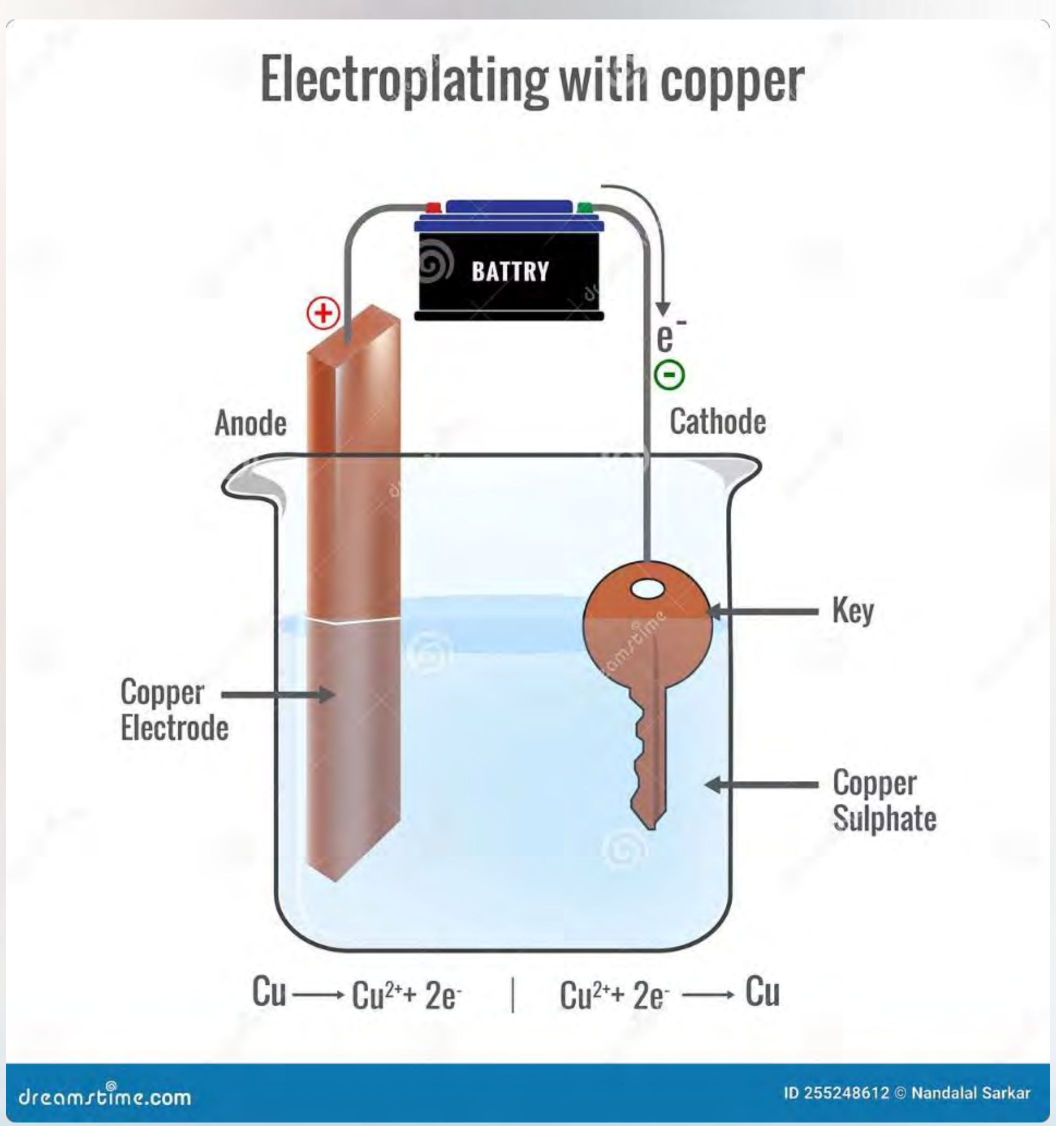
An electromagnet is a type of magnet in which the magnetic field is produced by an electric current.

Electric Motor

Electric motors use electromagnetism to convert electrical energy into mechanical motion.

Relay

Relays use electromagnets to mechanically operate switches, allowing a low-power signal to control a high-power circuit.



Useful Effects of Electricity: Chemical Changes

The electroplating process uses an electric current to produce a metallic coating on a surface. The electric current acts on a chemical solution, the electrolyte, to deposit coating metal from the electrolyte onto the surface to be plated.

Preparation

Object to be plated is connected to negative terminal (cathode)

Electrolyte Bath

Object is immersed in solution containing metal ions

Current Application

Electric current causes metal ions to deposit on the object

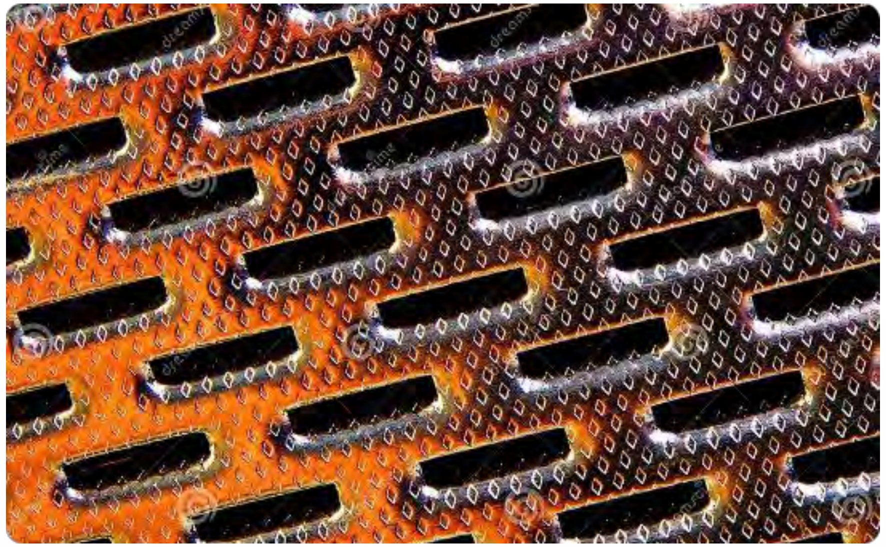
Finished Product

A thin, even layer of metal coats the original object

Electroplating Applications

Jewelry

Gold plating provides a precious metal finish at a fraction of the cost of solid gold.



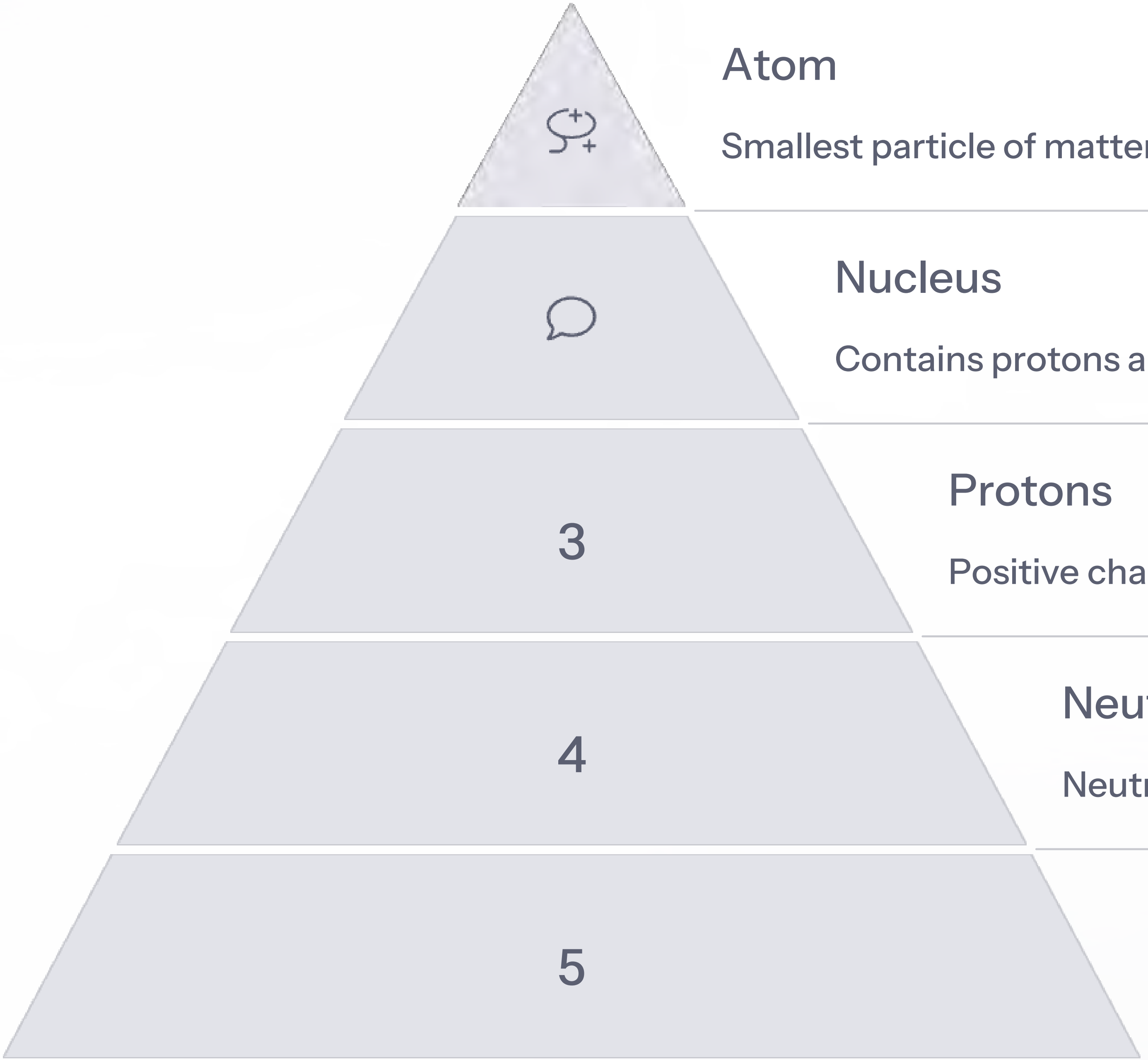
Automotive Parts

Chrome plating provides corrosion resistance and an attractive finish to metal components.

Electronics

Nickel plating improves conductivity and corrosion resistance in electronic components.

Atomic Structure Review



Atom

Smallest particle of matter in a chemical reaction

Nucleus

Contains protons and neutrons

Protons

Positive charge, in nucleus

Neutrons

Neutral charge, in nucleus

Electrons

Negative charge, orbit nucleus

Electrical Charges Review

Positive Charge

Fewer electrons than protons

Negative Charge

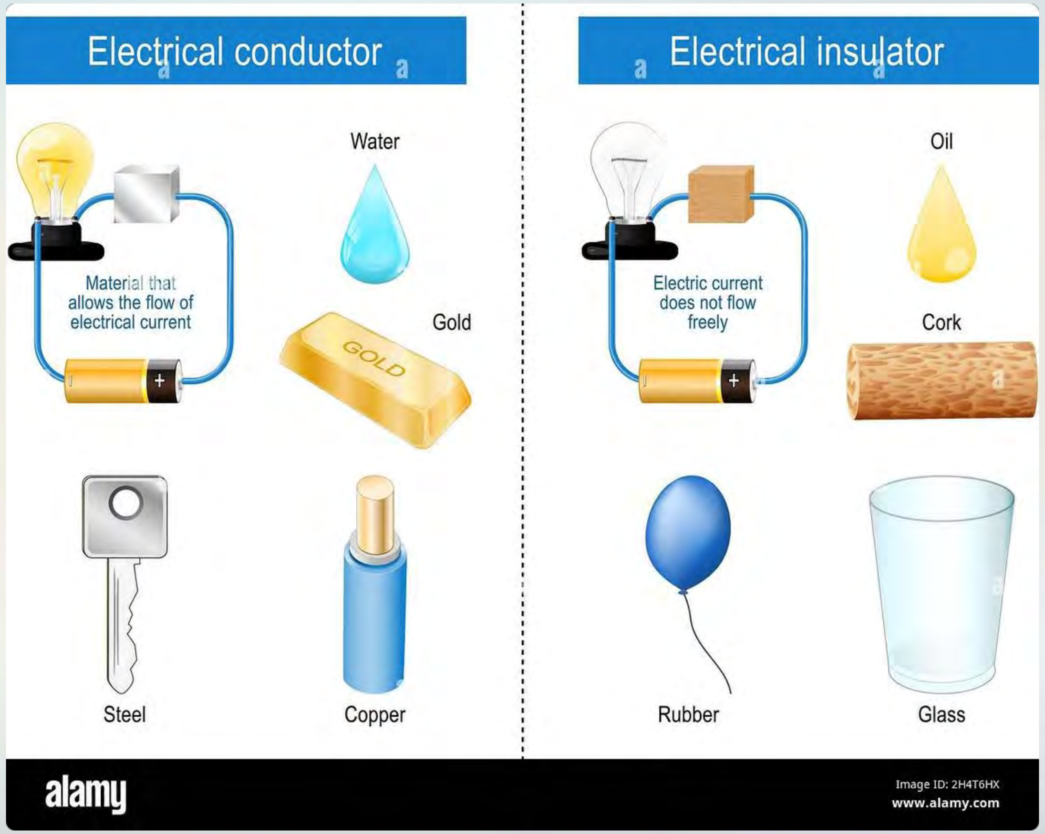
More electrons than protons

Attraction/Repulsion

Like charges repel, unlike attract

Neutral

Equal electrons and protons



Conductors vs. Insulators Review

Property	Conductors	Insulators
Free Electrons	Many	Few
Electrical Energy Transfer	Easy	Difficult
Examples	Copper, Aluminum	Glass, Rubber
Application	Wires, Terminals	Wire Coating, Supports
Heat Production	Less (good conductors)	More (poor conductors)

Electricity Production Methods Review

Thermoelectricity

Heat application to joined different metals

Electromagnetism

Conductor moving through magnetic field

Electrochemistry

Chemical reactions in batteries

Piezoelectricity

Pressure applied to certain crystals

Photoelectricity

Light striking photosensitive materials

Current Flow Review

Energy Source

Provides opposite charges at conductor ends

2

Electron Movement

Electrons move from negative to positive

3

Complete Circuit

Path must be complete for current to flow

To produce a flow of electricity or current in a conductor, make the electrons move in a direction along the conductor by placing opposite (positive and negative) charges on the ends of the conductor. The free negative electrons move toward the positive charge and away from the negative charge.

Useful Effects of Electricity Review

Heat

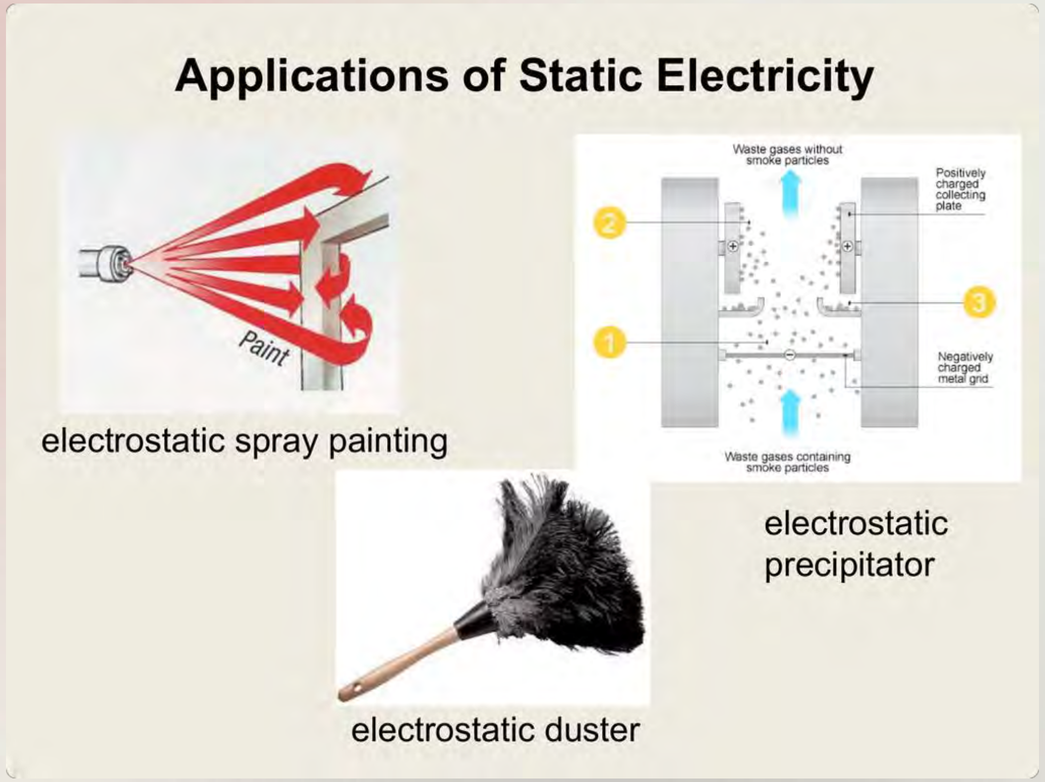
Current passing through a wire raises its temperature, transferring heat energy. Used in toasters, heaters, and incandescent bulbs.

Magnetism

Current-carrying conductors act as magnets (electromagnetism). Used in motors, generators, and relays.

Chemical Changes

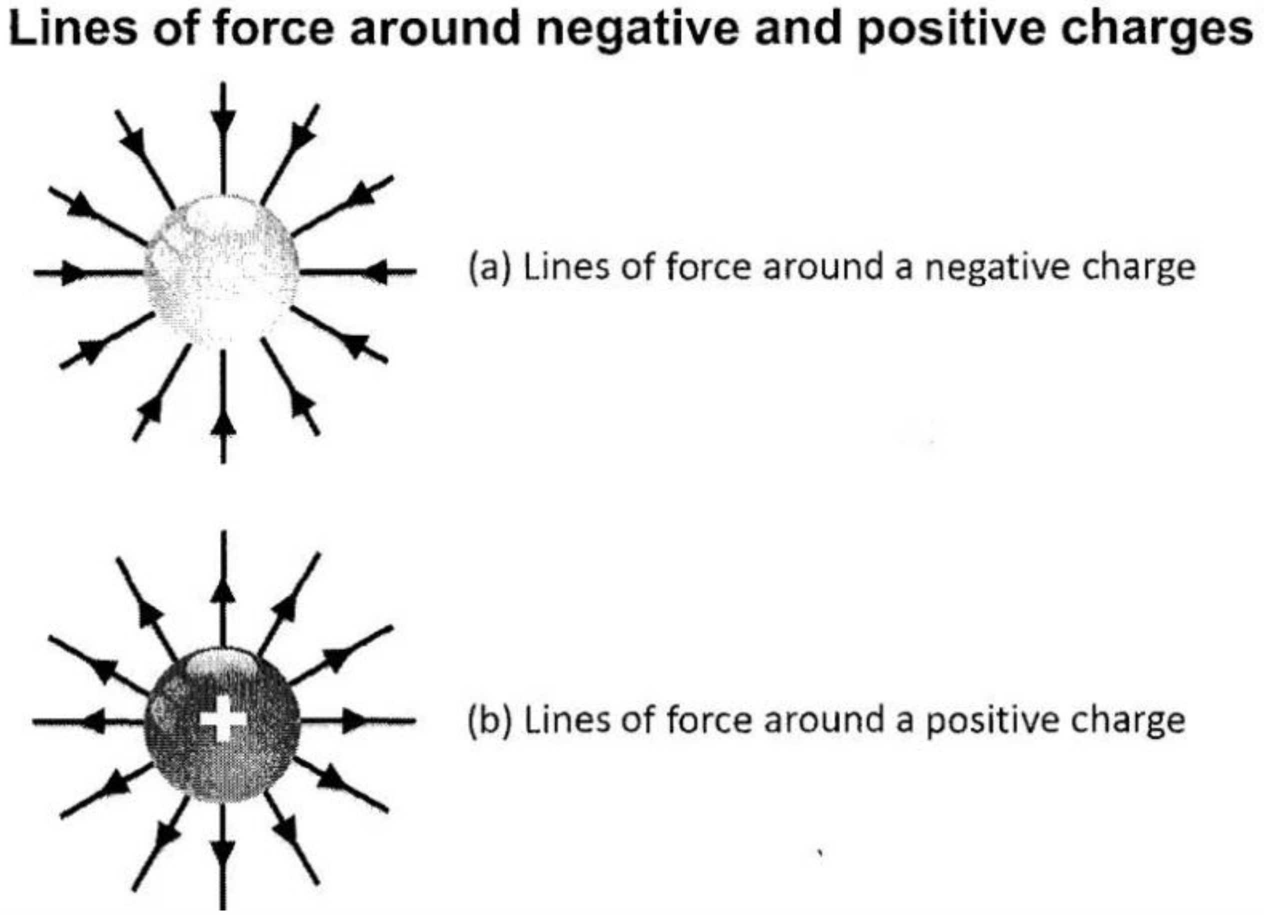
Electric current can produce chemical reactions. Used in electroplating and battery charging.



Electrostatic Fields Review

Negative Charge Fields

Lines of force point toward the negative charge.



Positive Charge Fields

Lines of force radiate outward from the positive charge.

A point positive charge is brought near an isolated conducting sphere (Fig. 1.2). The electric field is best given by

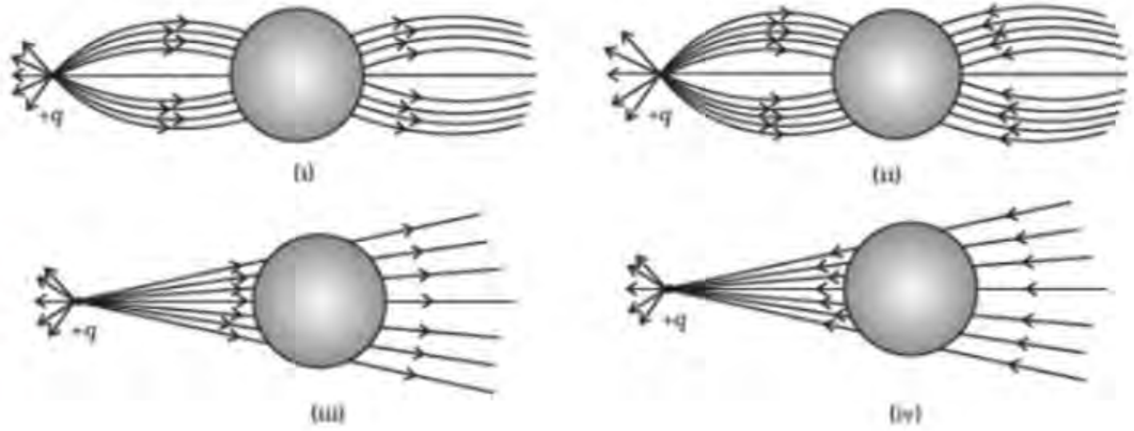
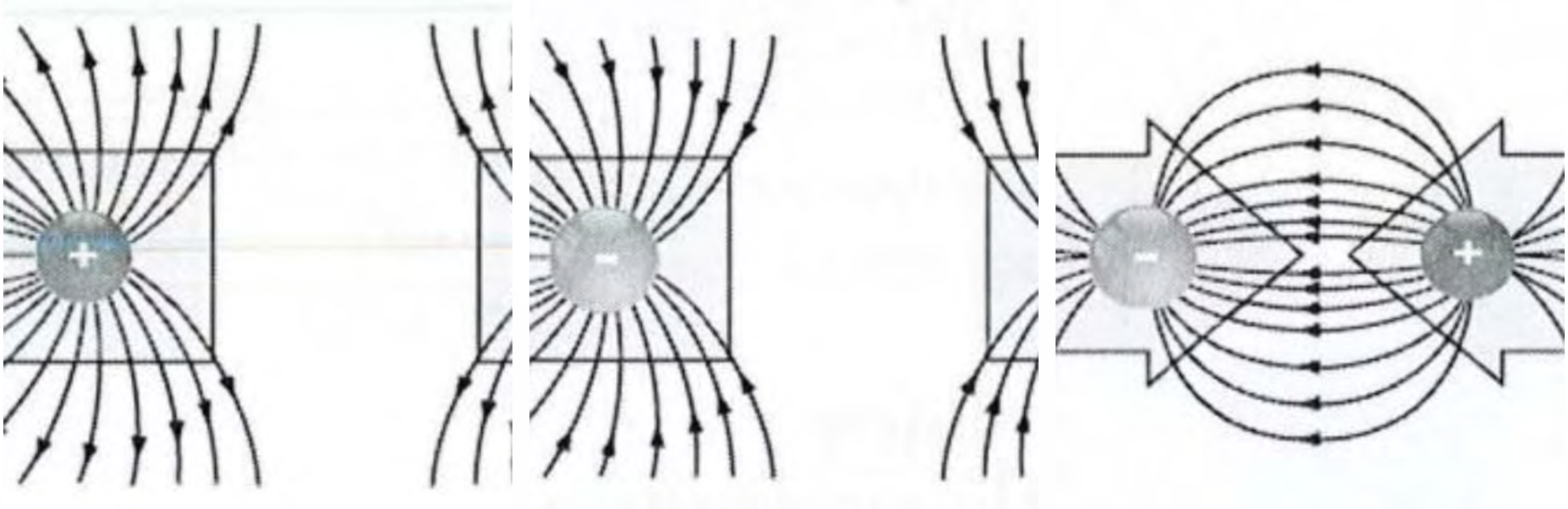


Fig. 1.2

(a) Fig (i) (c) Fig (iii) (b) Fig (ii) (d) Fig (iv)

Attraction and Repulsion Review



The fundamental law of electrical charges states that like charges repel and unlike charges attract.

- Positive charges repel other positive charges
- Negative charges repel other negative charges
- Positive and negative charges attract each other

The strength of these forces depends on the amount of charge and the square of the distance between the charged objects.

Battery Operation Review

Different Metal Electrodes

Two different metals are used as electrodes

Electrolyte Solution

Electrodes are immersed in chemical solution

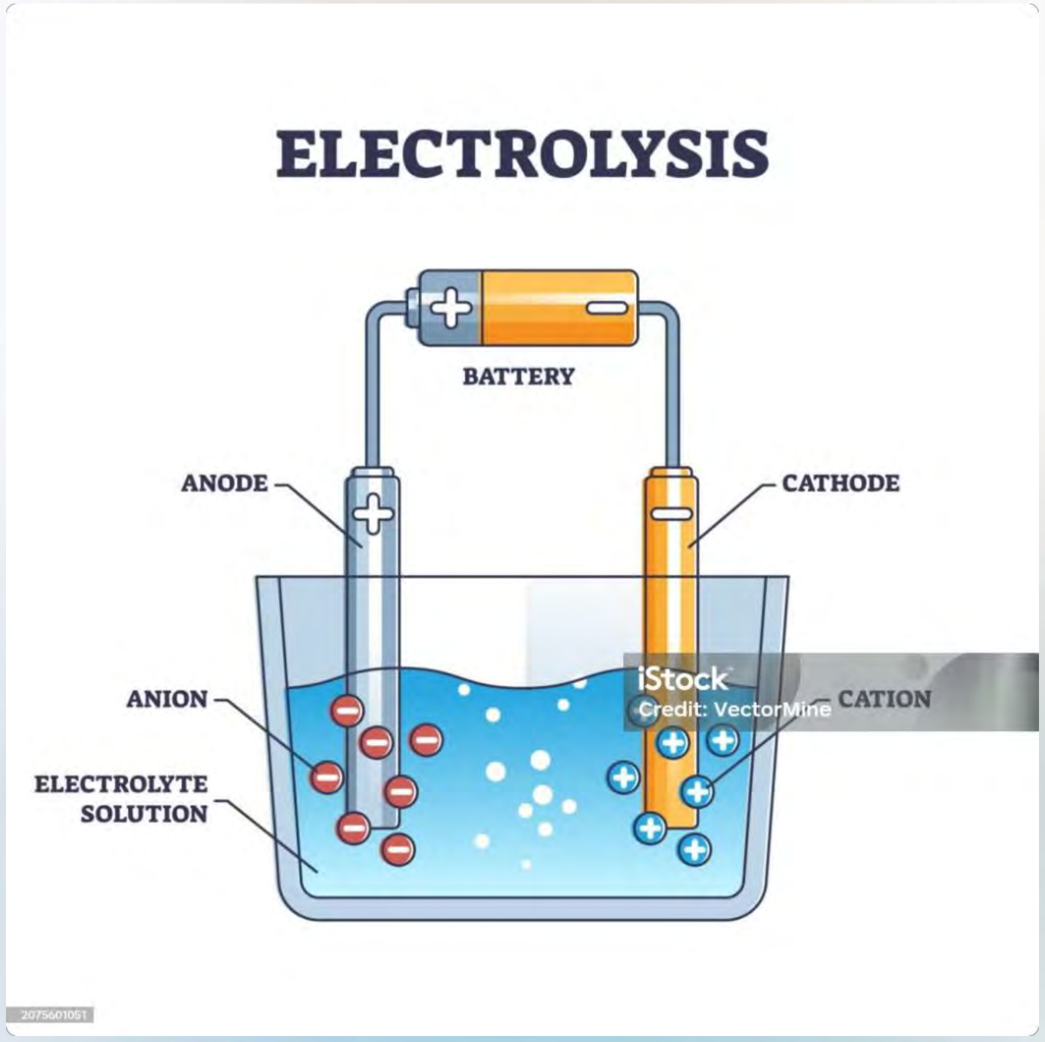
Electron Transfer

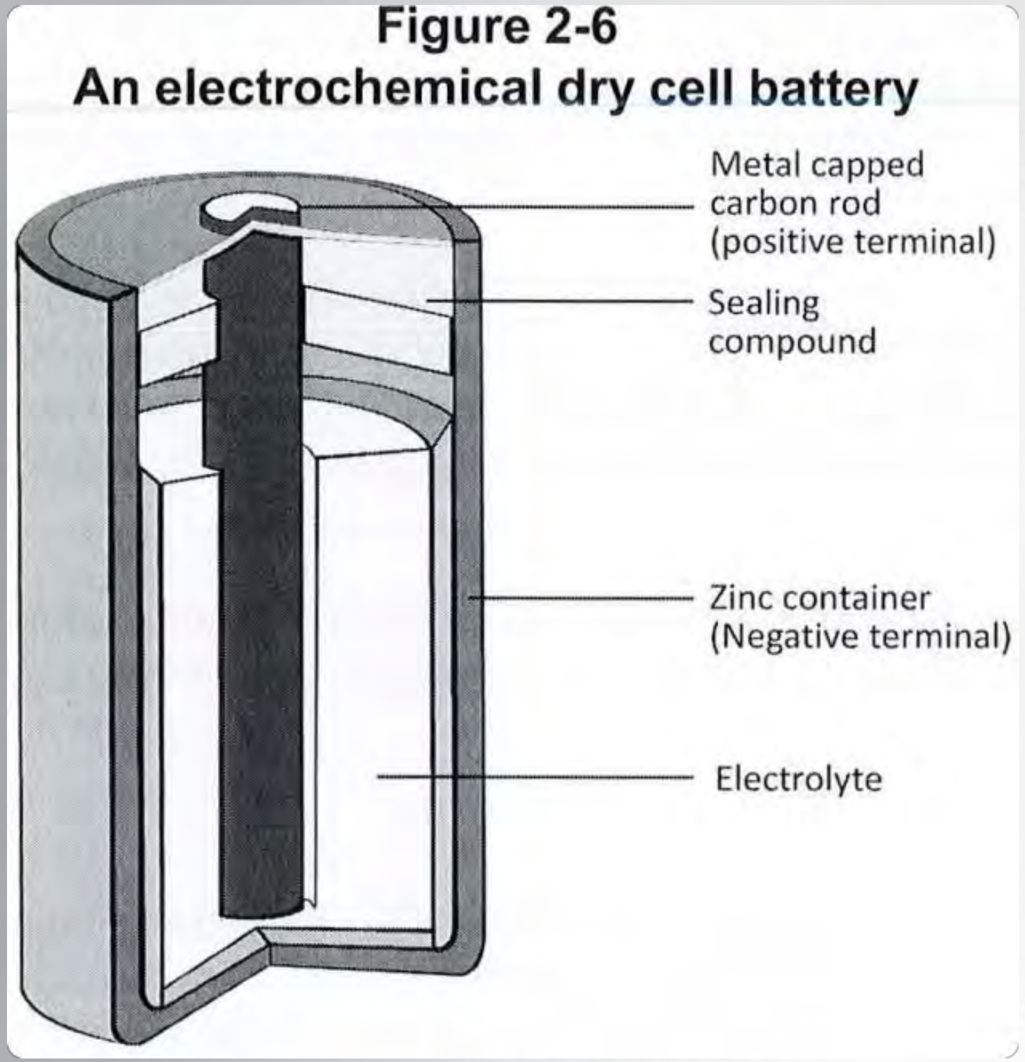
Chemical action transfers electrons between electrodes

4

Potential Difference

Creates voltage between positive and negative terminals





Dry Cell Structure Review

Flashlight batteries are dry cells with these components:

Negative Electrode

The zinc battery container serves as the negative electrode

Positive Electrode

A carbon rod in the center of the cell is the positive electrode

Electrolyte Mixture

The space between electrodes contains carbon, manganese dioxide, and electrolyte

Protective Seal

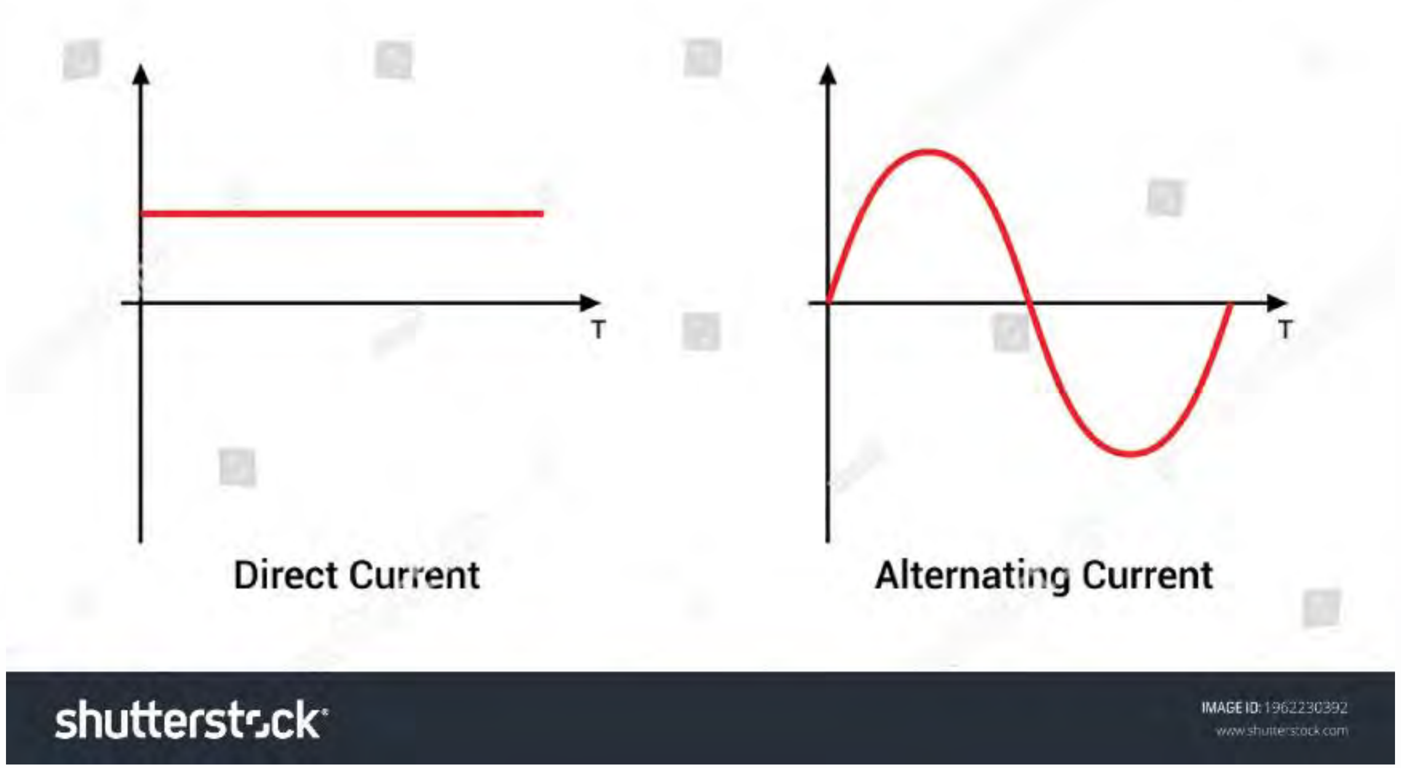
The top has a seal to prevent evaporation of the electrolyte

Direct vs. Alternating Current Review

Direct Current (DC)

Current flows in a constant direction

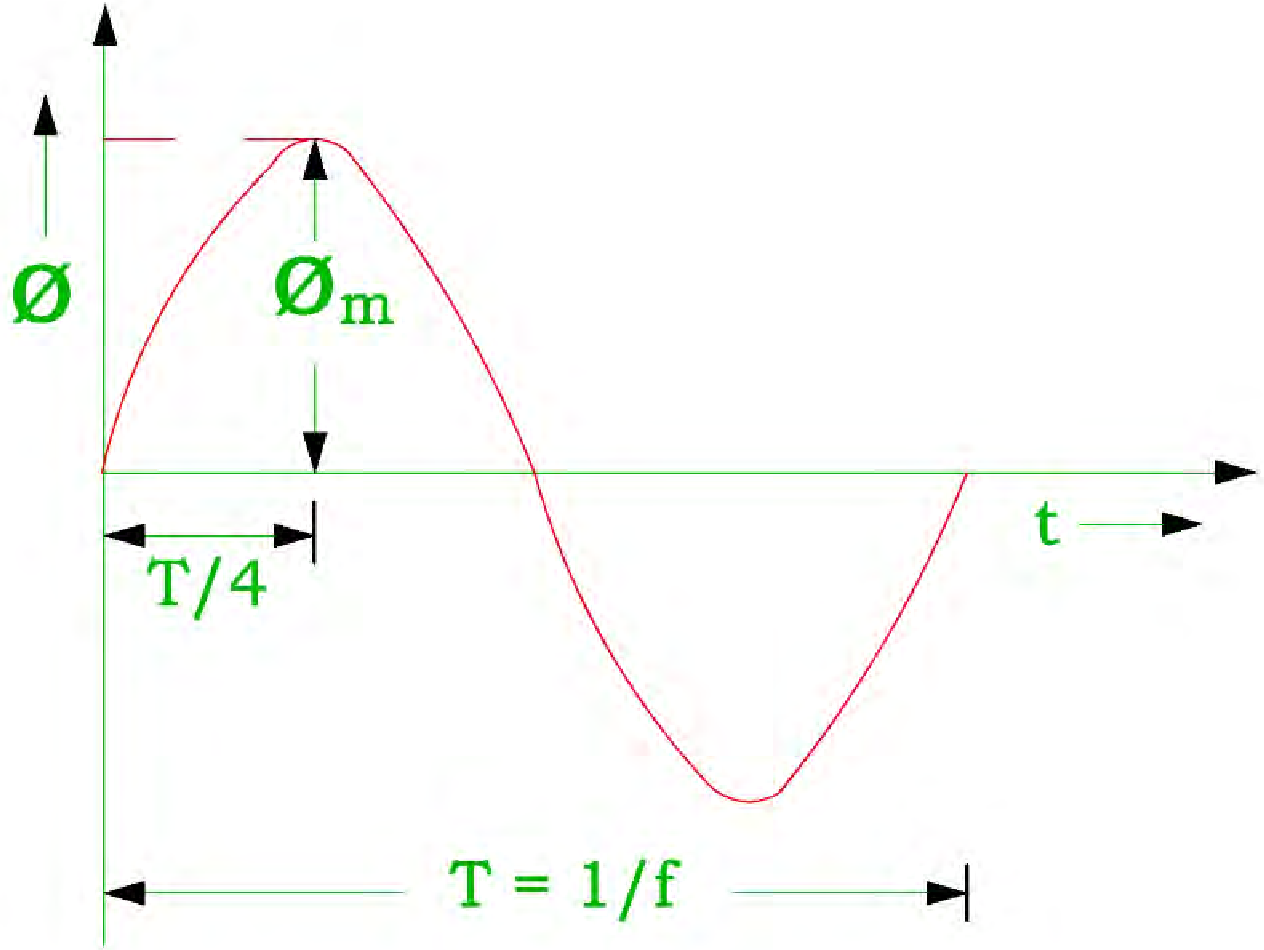
- Produced by batteries
- Used in electronics
- Constant polarity

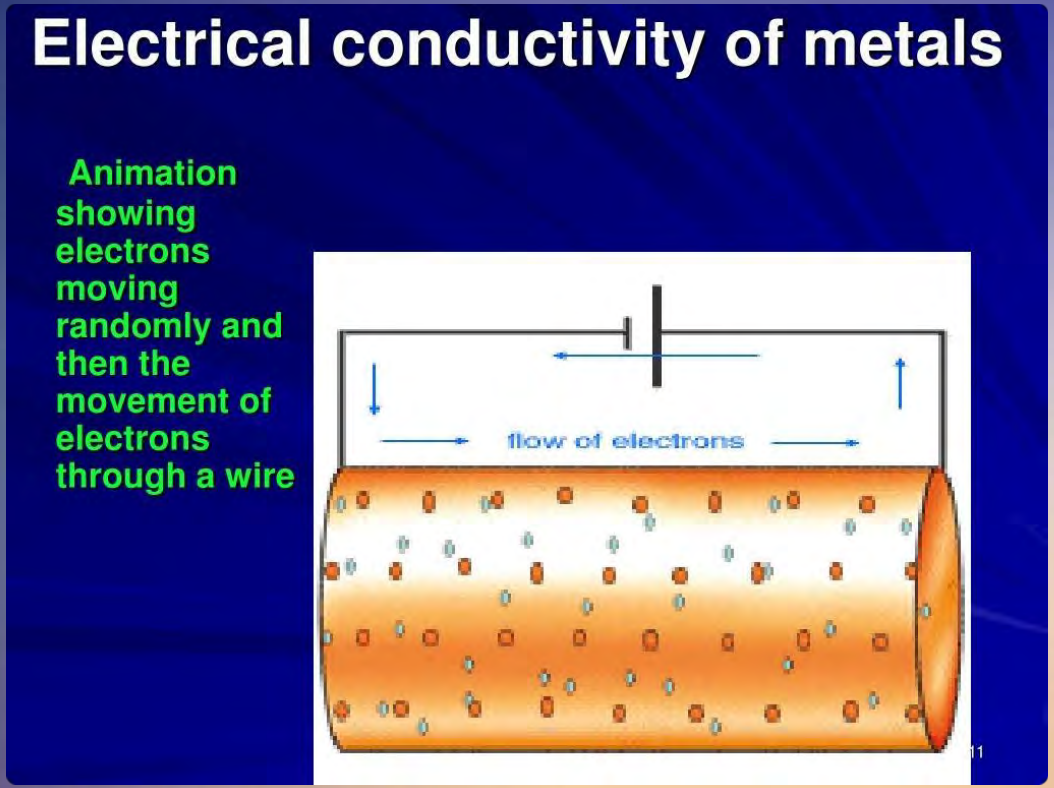


Alternating Current (AC)

Current regularly reverses direction

- Standard house current
- Efficient for power transmission
- Polarity constantly reverses





Electron Movement in Conductors Review

Random Motion

Free electrons move randomly in a conductor with no applied voltage

2

Voltage Application

Opposite charges are placed at the ends of the conductor

Directed Movement

Electrons move toward the positive charge and away from the negative charge

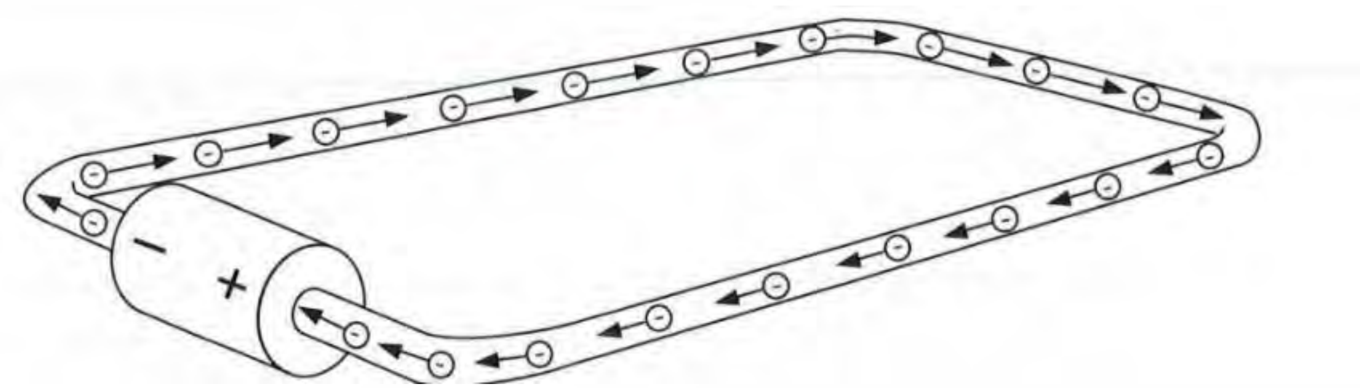
Current Flow

The directed movement of electrons creates electric current

Closed vs. Open Circuits Review

Closed Circuit

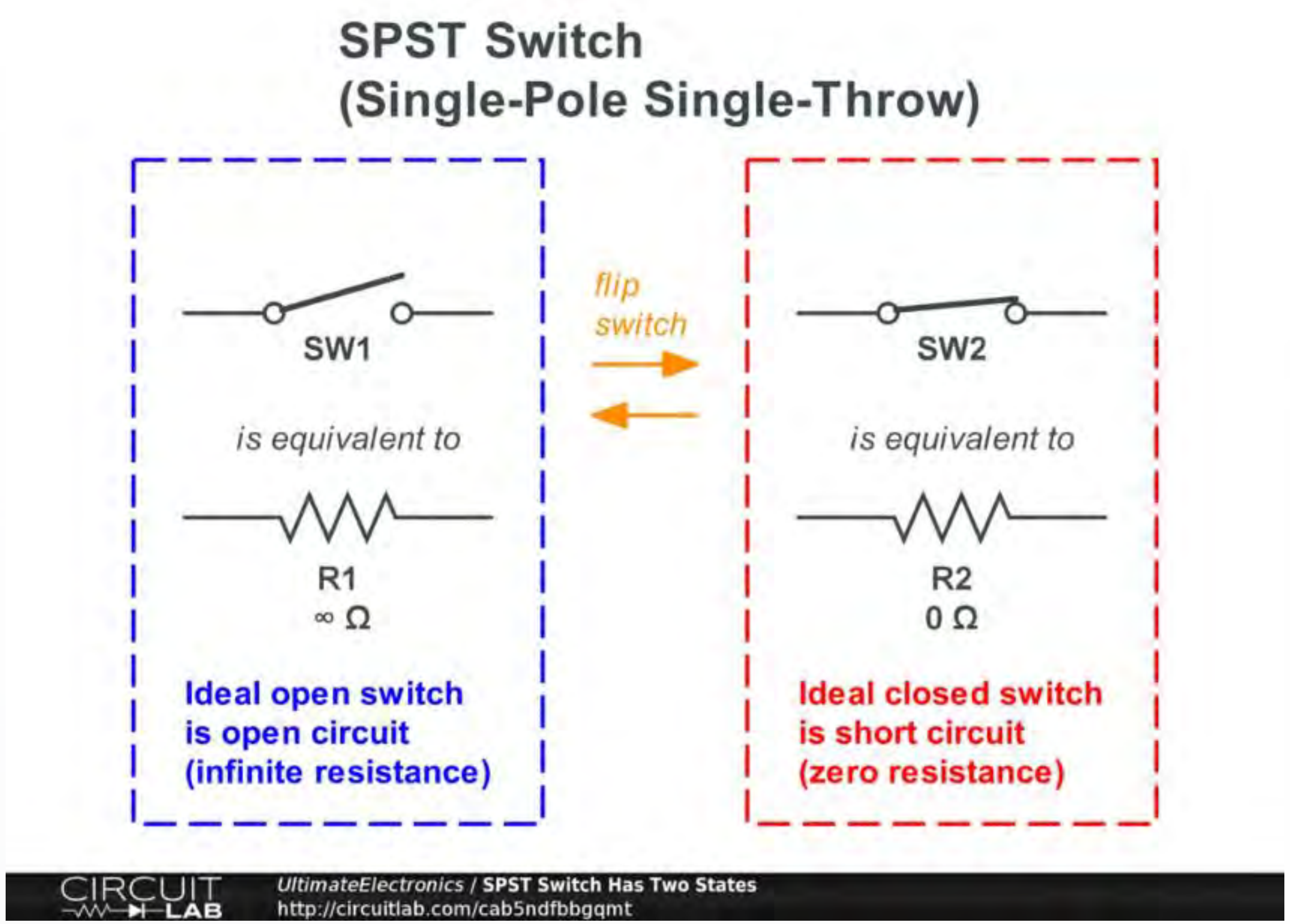
A complete path for current to flow from the negative terminal of the power source, through the load, and back to the positive terminal.



Open Circuit

A break in the path that prevents current from flowing. Can be intentional (switch) or unintentional (broken wire).

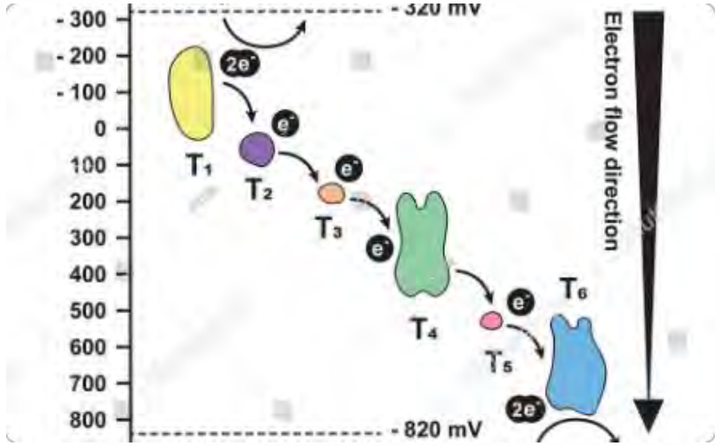
When a circuit is open, no current flows and electrical devices cannot operate.



Conventional vs. Electron Flow Review

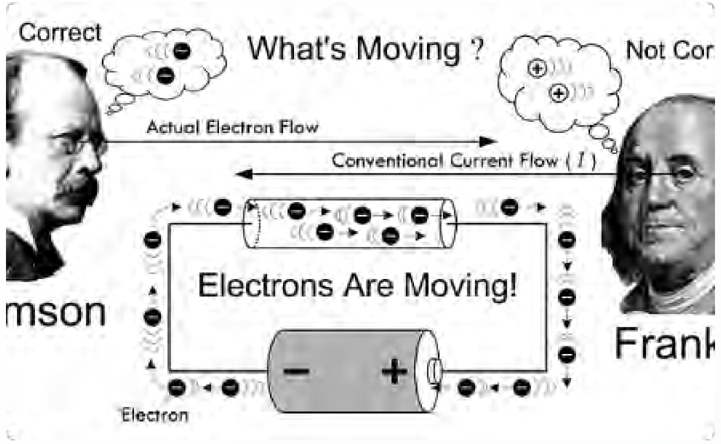
Conventional Flow

Historically assumed to flow from positive to negative. Still commonly used in many electrical diagrams and explanations.



Electron Flow

The actual movement of electrons from negative to positive. Represents the physical reality of current flow.



Comparison

Despite knowing about electron flow, conventional flow is still used for consistency, especially in electromagnetism rules.

Electrostatic Charges Review

2

Types of Charges

Positive and negative electrical charges

1840

Mass Ratio

Times lighter electrons are than protons

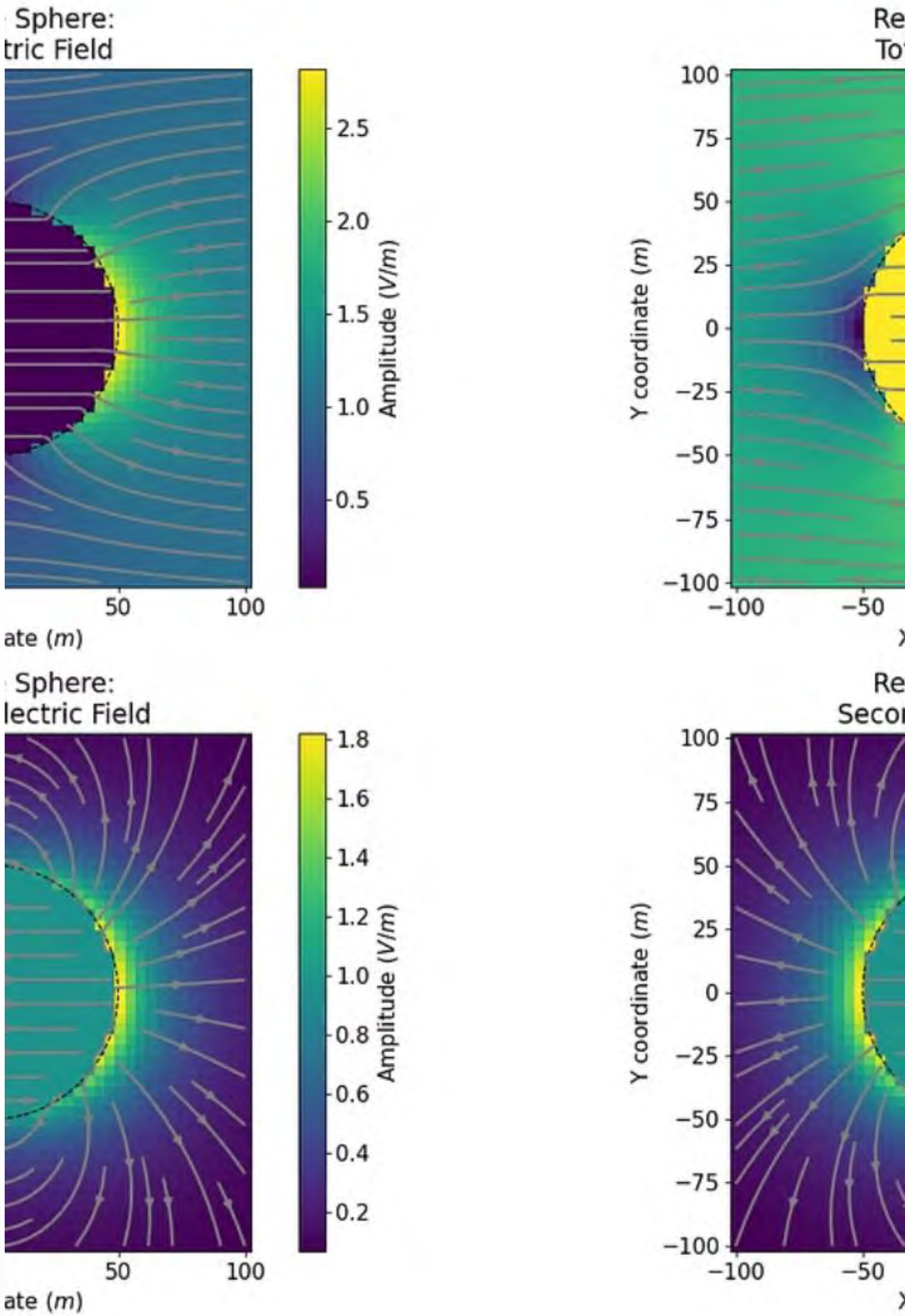
3

Size Comparison

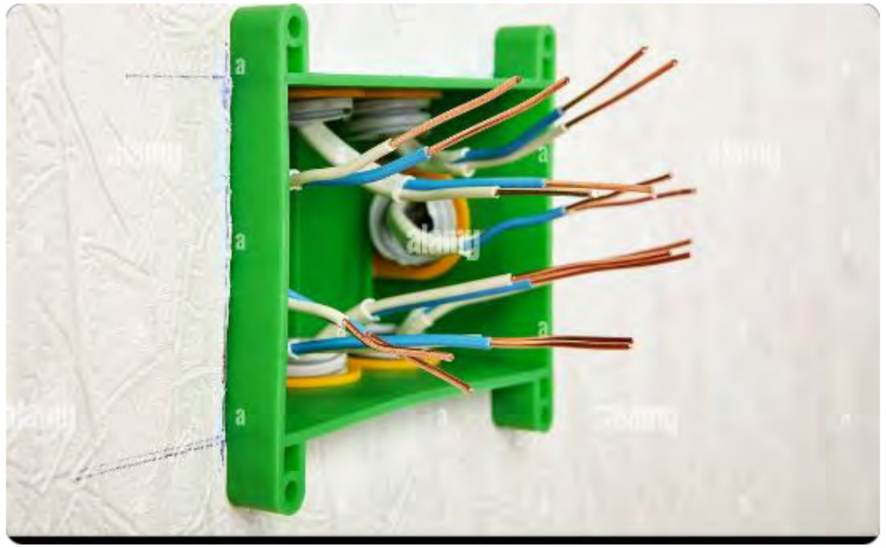
Times larger electrons are than protons

Electrostatic charges are stationary electric charges. They create electrostatic fields around them, with forces of attraction between unlike charges and repulsion between like charges.

The strength of these forces depends on the amount of charge and the square of the distance between the charged objects.



Insulator Applications Review



Household Wiring

Household wiring consists of pure copper conductors with a plastic layer of insulation. This insulation provides protection from electric shock and prevents short-circuiting of the system.

High Voltage Transmission

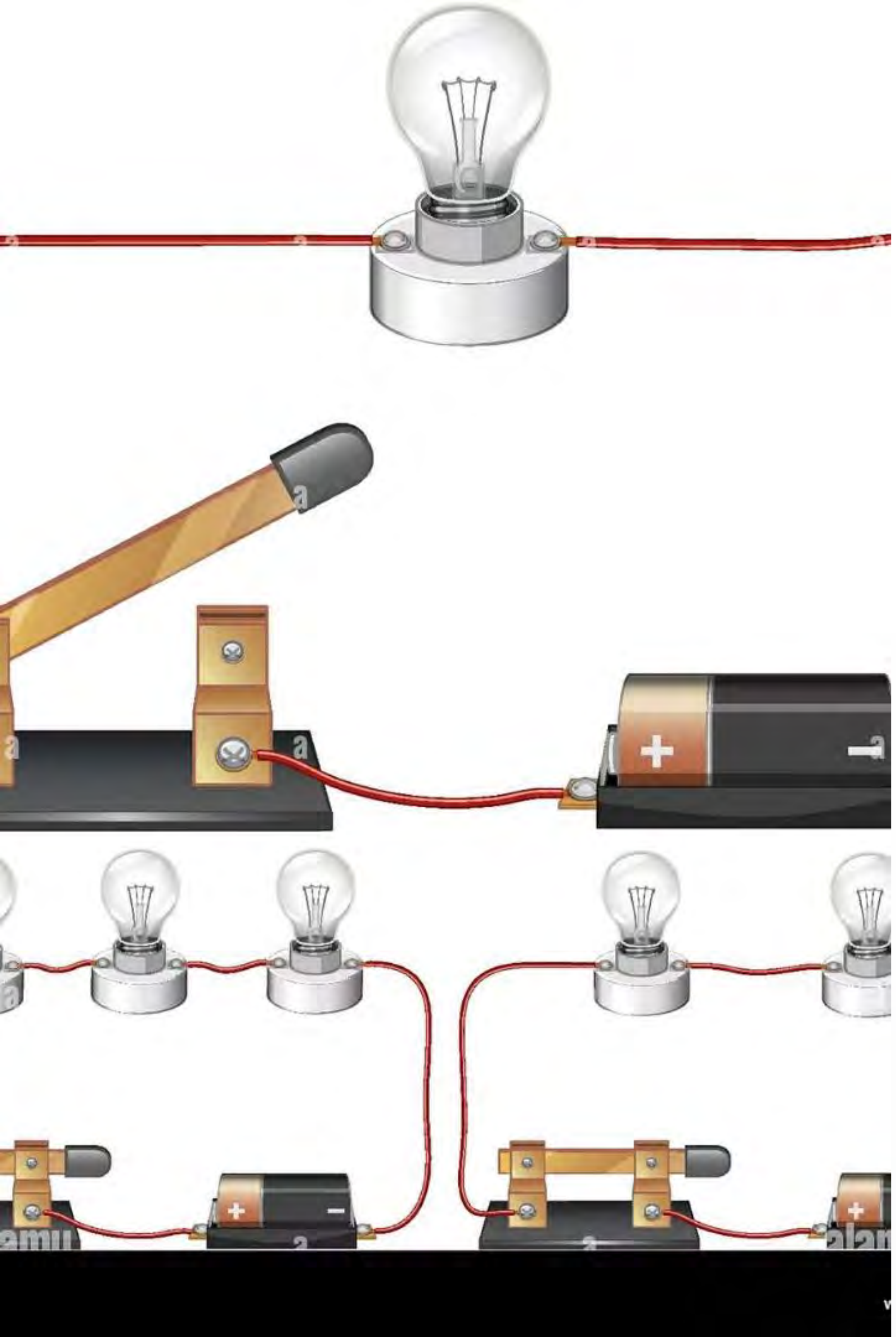
For very high voltages, porcelain, glass, air, or oil function as insulators. Glass insulators hold conductors away from metal transmission towers.

Safety Equipment

Insulated tools and protective gear prevent electrical shock when working with live circuits.

Useful Effects of Electricity Summary

Effect	Description	Applications
Heat	When electric current passes through a wire, the temperature of the wire rises, and heat transfer gives off energy. Good conductors such as copper produce less heat, while poor ones such as tungsten produce a lot of heat when they conduct current.	Toasters, electric heaters, incandescent lights
Magnetism	Any conductor of electric current acts like a magnet. This interaction between electricity and magnetism is electromagnetism. When the current stops flowing, the conductor no longer acts as a magnet.	Motors, generators, relays, speakers
Chemical changes	The electroplating process uses an electric current to produce a metallic coating on a surface. The electric current acts on a chemical solution, the electrolyte, to deposit coating metal from the electrolyte onto the surface to be plated.	Electroplating, battery charging, electrolysis



CSA Unit 5

Chapter 3
Components and Operation of a Simple Electrical Circuit

The gas technician/fitter requires a basic knowledge of the components and operation of simple electrical circuits in order to connect and troubleshoot the type of electrical equipment encountered in the gas industry. This presentation will explore the components of simple electrical circuits and explain their operation.

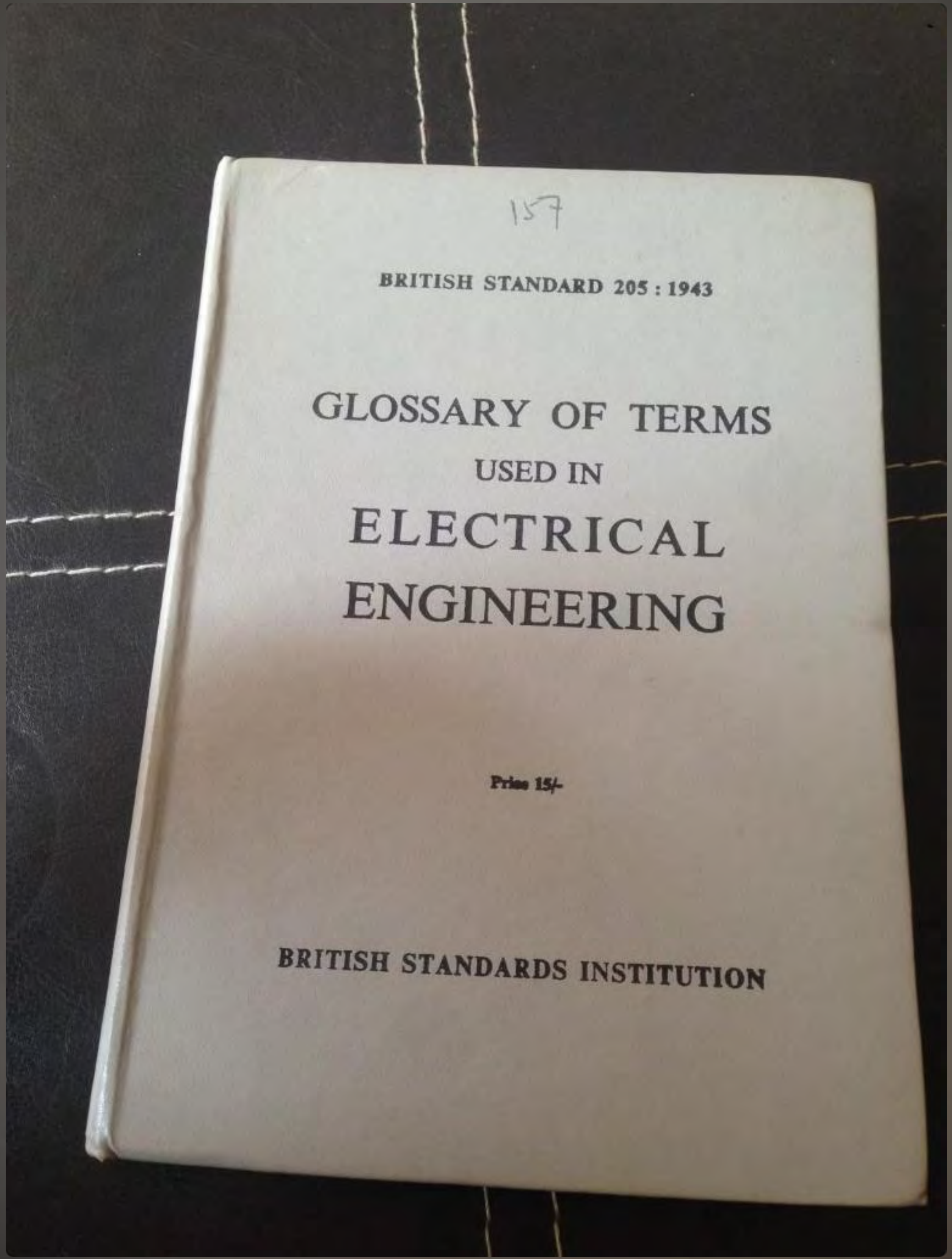
Purpose and Objectives

Purpose

The gas technician/fitter requires a basic knowledge of the components and operation of simple electrical circuits in order to connect and troubleshoot the type of electrical equipment he/she encounters in the gas industry.

Objectives

- Describe the components of a simple electrical circuit
- Describe the operation of a simple electrical circuit



Key Terminology

Term	Abbreviation (symbol)	Definition
Electromotive force	emf	Potential difference of an energy source (for example, battery or generator)
Ohm's law		States that the current flowing in an electrical circuit is directly proportional to the applied voltage
Potential		Positive or negative, measured at one point with respect to another
Potential difference		Difference in potential between any two points in a circuit
Resistance		Opposition that a material offers to the flow of current
Voltage		Alternative term for potential difference
Voltage drop		Potential difference across individual loads in a circuit

Components of a Simple Electrical Circuit

Energy Source

Such as a battery or a wall plug that provides electrical energy

Conductors

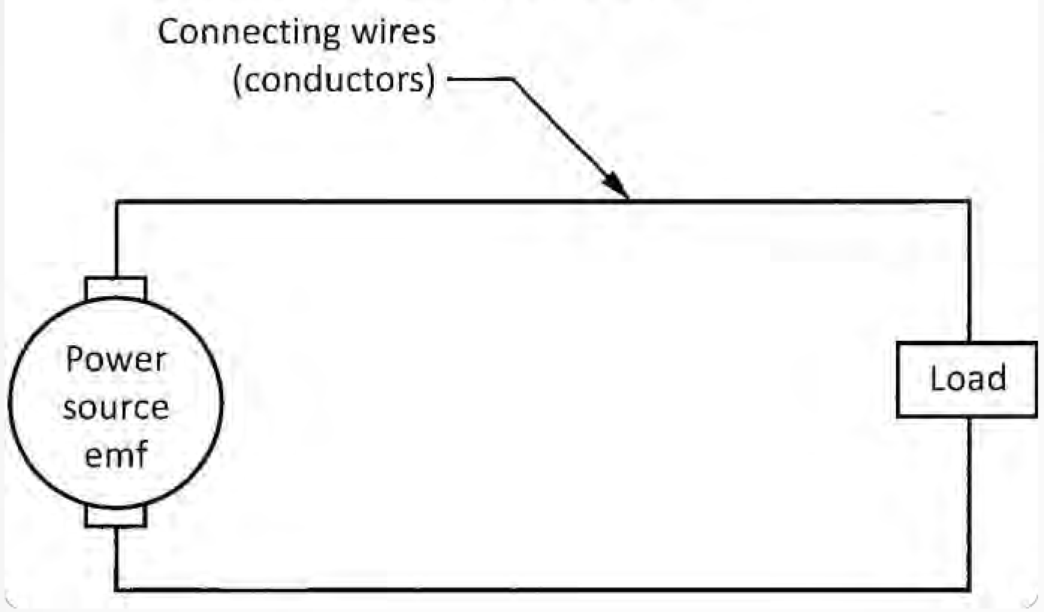
Connecting wires that provide a path for current flow

Load

A device that uses electrical energy to do work

A circuit often has a switch and an overcurrent protective device such as a fuse or circuit breaker.

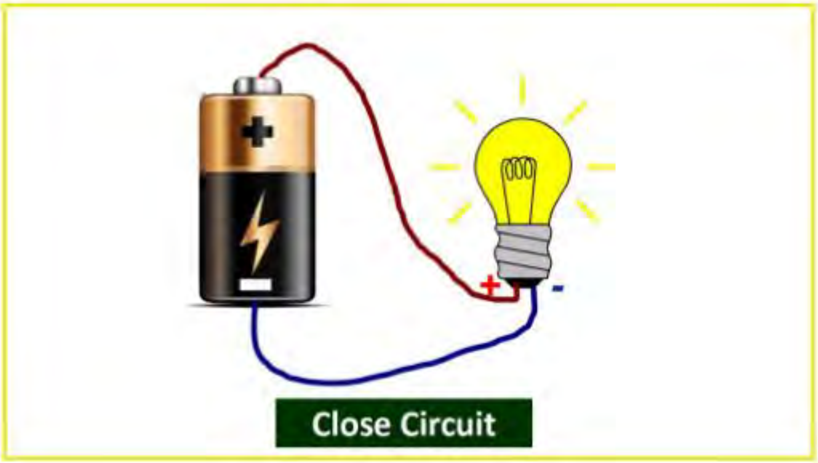
Figure 3-1
An electric circuit



Open vs. Closed Circuits

Closed Circuit

In a closed circuit, the path is complete and current can flow through the circuit.



Open Circuit

In an open circuit, the path is incomplete and current cannot flow.

Opening a circuit is possible through:

- Breakage
- Disconnection from an energy source
- Using a switch

Energy Sources and Potential

Electrical Energy Sources

Supply electrical energy in several ways (e.g., a wet-cell battery produces electrochemical energy)

Potential Difference

The measure of the ability (potential) of a unit of electric charge to do a certain amount of work

Electromotive Force (emf)

The force that drives the current, measured in volts (V)

The difference in potential between two terminals provides the force to drive the current, similar to high and low-pressure points in a fluid piping system.

Voltage Units

Voltage	Equivalent
1 volt (1 V)	1000 millivolts (= 10^3 mV) 1,000,000 microvolts (= 10^6 µV)
1 kilovolt (1 kV)	1000 volts (= 10^3 V)
1 megavolt (1 MV)	1,000,000 volts (= 10^6 V)

The sizes of voltages may vary a great deal, so the size of the units used can also vary.

Current Flow

Energy Source

Provides voltage (potential difference)

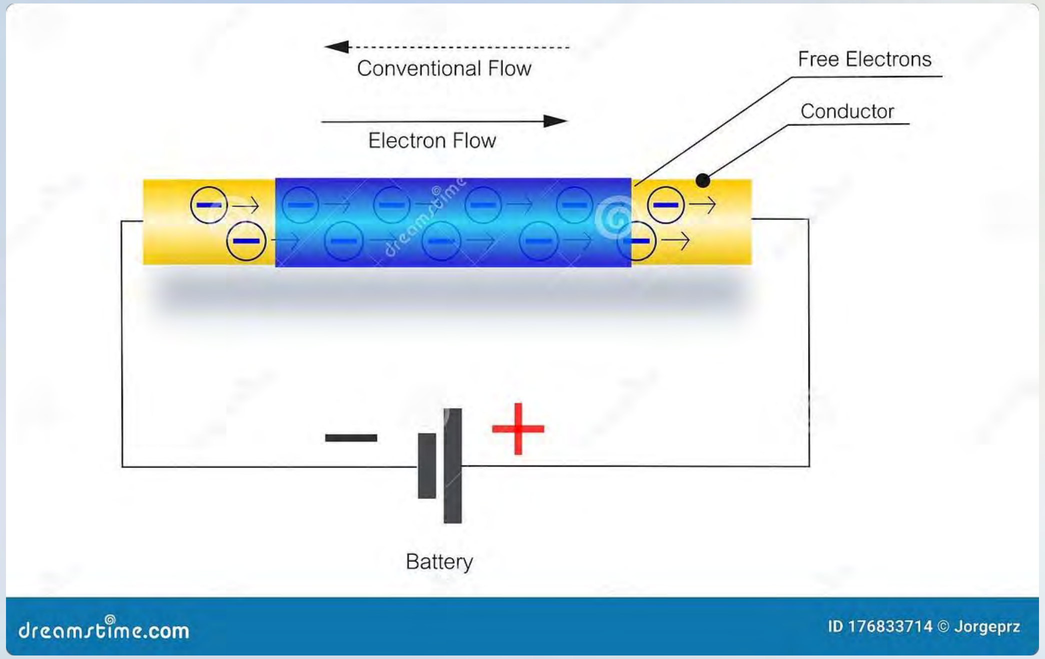
Current Flow

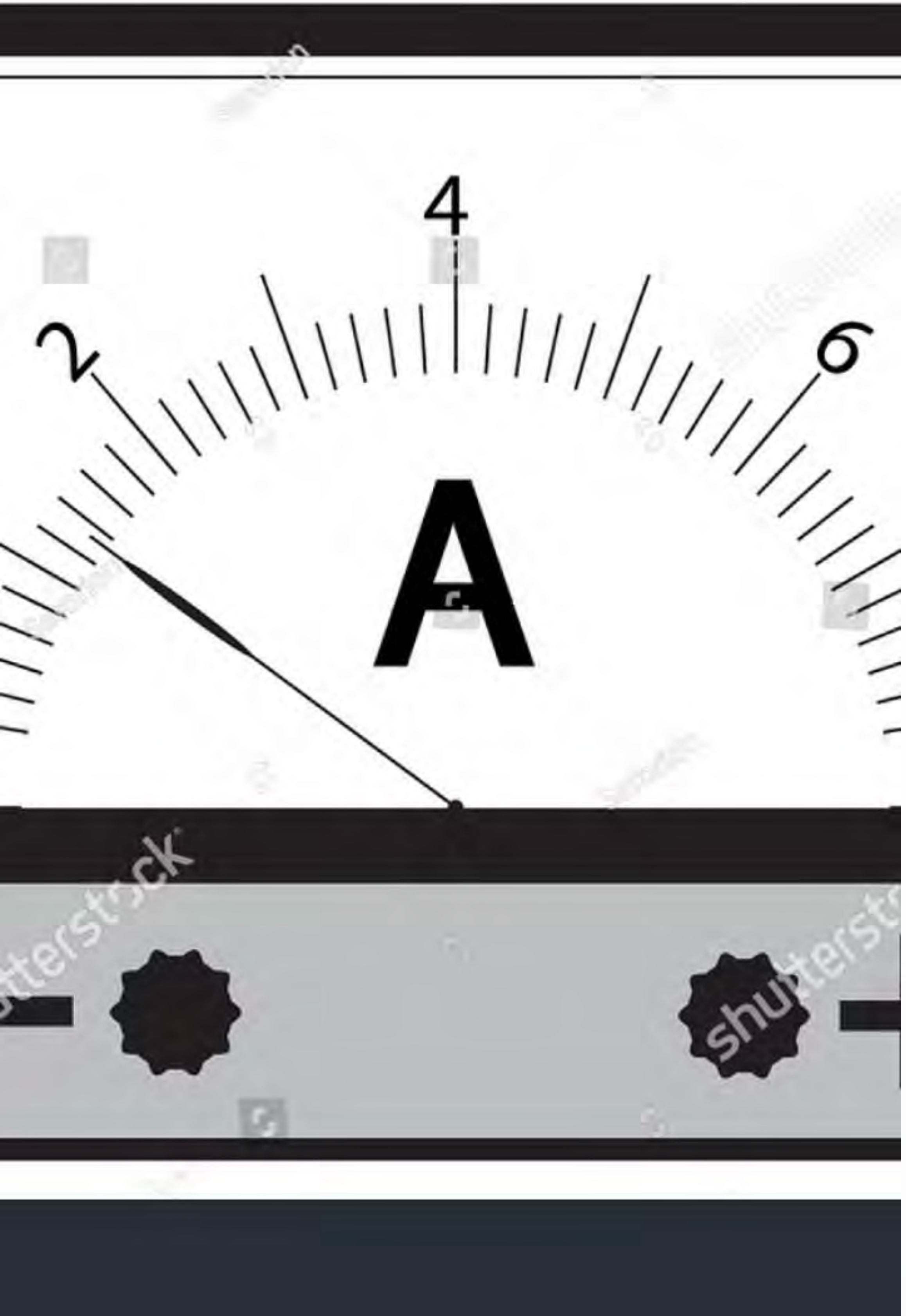
Electrons flow toward the positive terminal

Load

Uses electrical energy to do work

Electric current flows whenever there is a difference of potential across a circuit. The amount of voltage across the circuit determines how much current can flow through the load. The polarity of the source determines the direction of current flow.





Current Units

Current	Equivalent
1 ampere (1 A)	1000 milliamperes (= 10^3 mA) 1,000,000 microamperes (= 10^6 µA)
1000 amperes	1 kiloampere (= 1 kA)

Ampere (A) is a measure of current, which may be quite small or very large.

Conductors and Resistance

Conductors

The ease with which a current flows through a conductor varies. In DC circuits, the opposition that a material offers to the flow of current is called resistance.

A conductor in a circuit should have low resistance, allowing maximum current flow. Copper wire is the most commonly used conductor.

Resistance

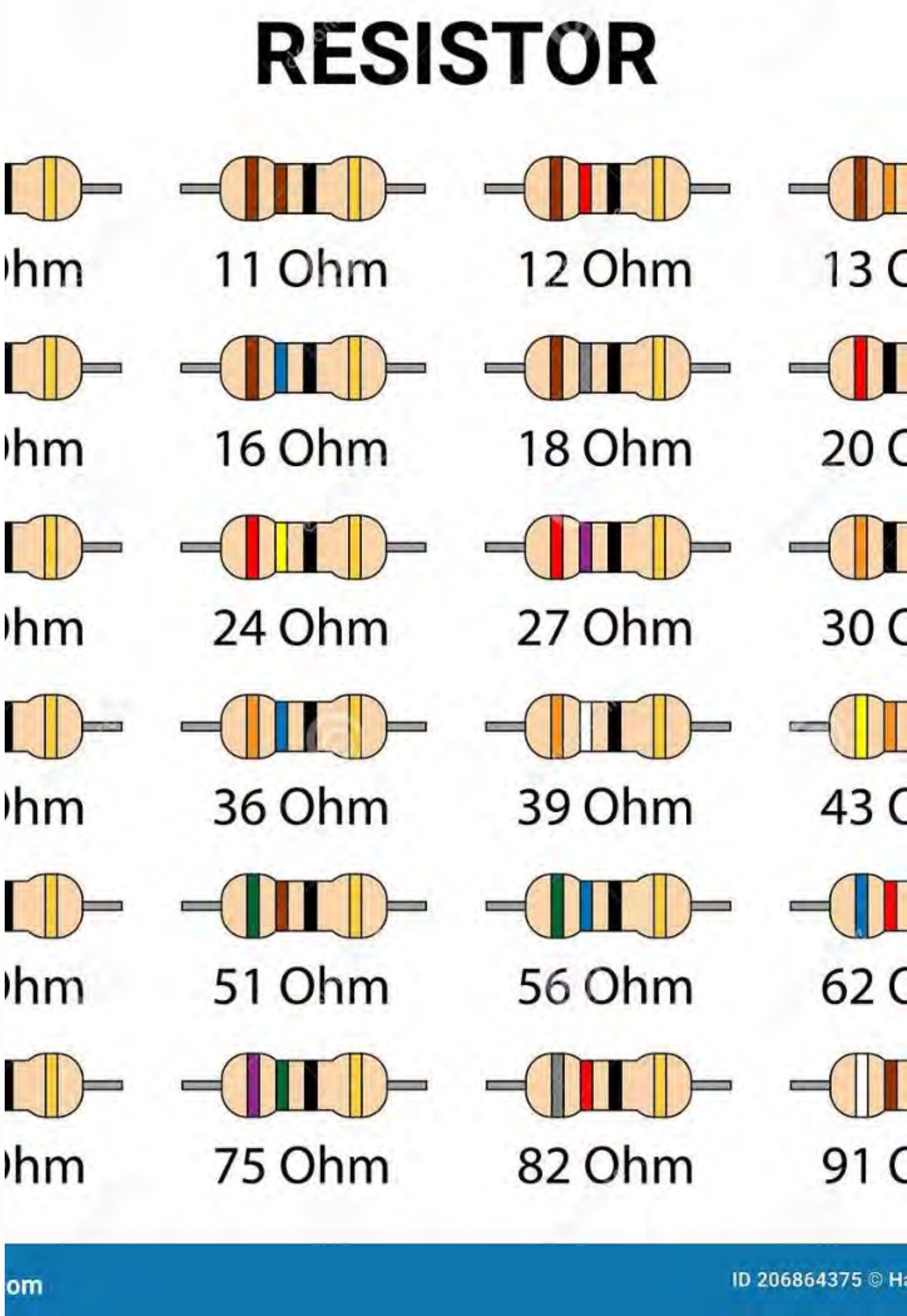
Materials with high resistance oppose the flow of current. The unit of measurement of resistance is the ohm (Ω).

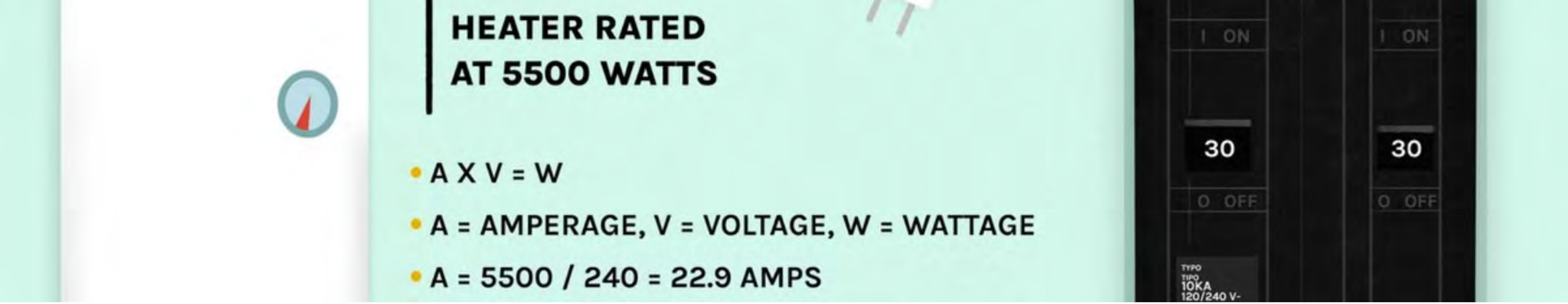
Some resistances are very large, requiring larger units like kilohm ($k\Omega$) or megohm ($M\Omega$).

Some are small, measured in milliohm ($m\Omega$) or microhm ($\mu\Omega$).

Resistance Units

Ohm (Ω)	Equivalent
1 kilohm (1 kΩ)	1000 ohms (= 10^3 Ω)
1 megohm (1 MΩ)	1,000,000 ohms (= 10^6 Ω)
1 milliohm (1 mΩ)	0.001 ohms (= 10^{-3} Ω)
1 microhm (1 $\mu\Omega$)	0.000001 ohms (= 10^{-6} Ω)





Load in Electrical Circuits

Definition

The load uses electrical energy to do useful work such as producing motion, light, or sound or providing heating.

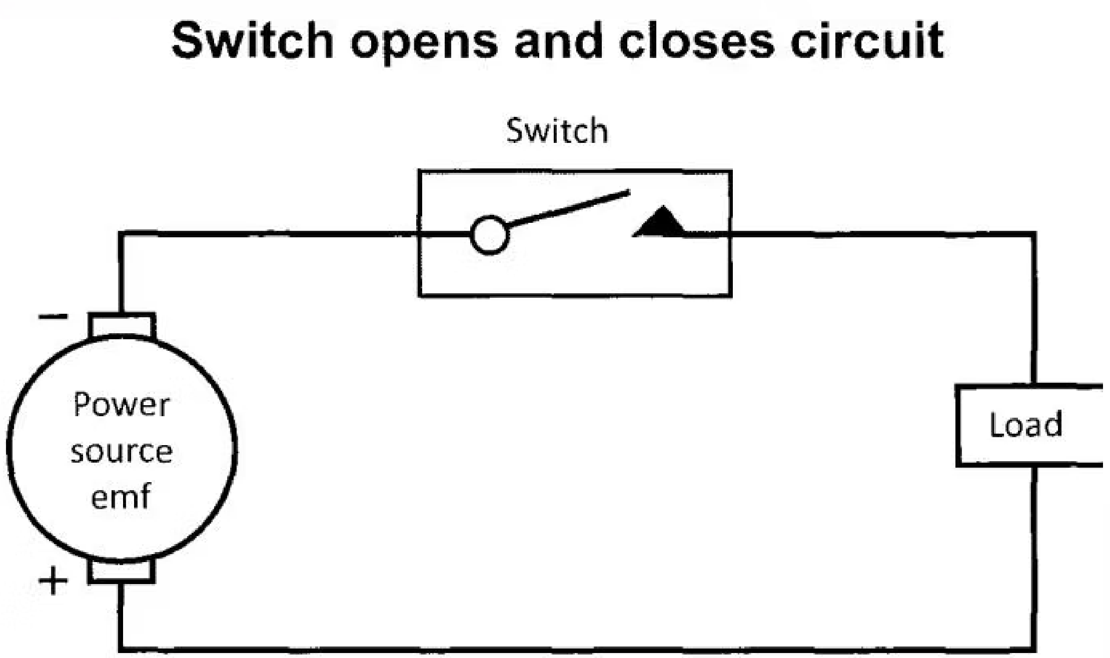
Resistance

The load usually has resistance in the electrical circuit. The energy source performs work by driving the current through the resistive load.

Energy Demand

The term load also refers to the amount of energy demanded from the source. For example, when you increase or decrease the load, it means that the energy source is supplying more or less energy.

Switches in Electrical Circuits



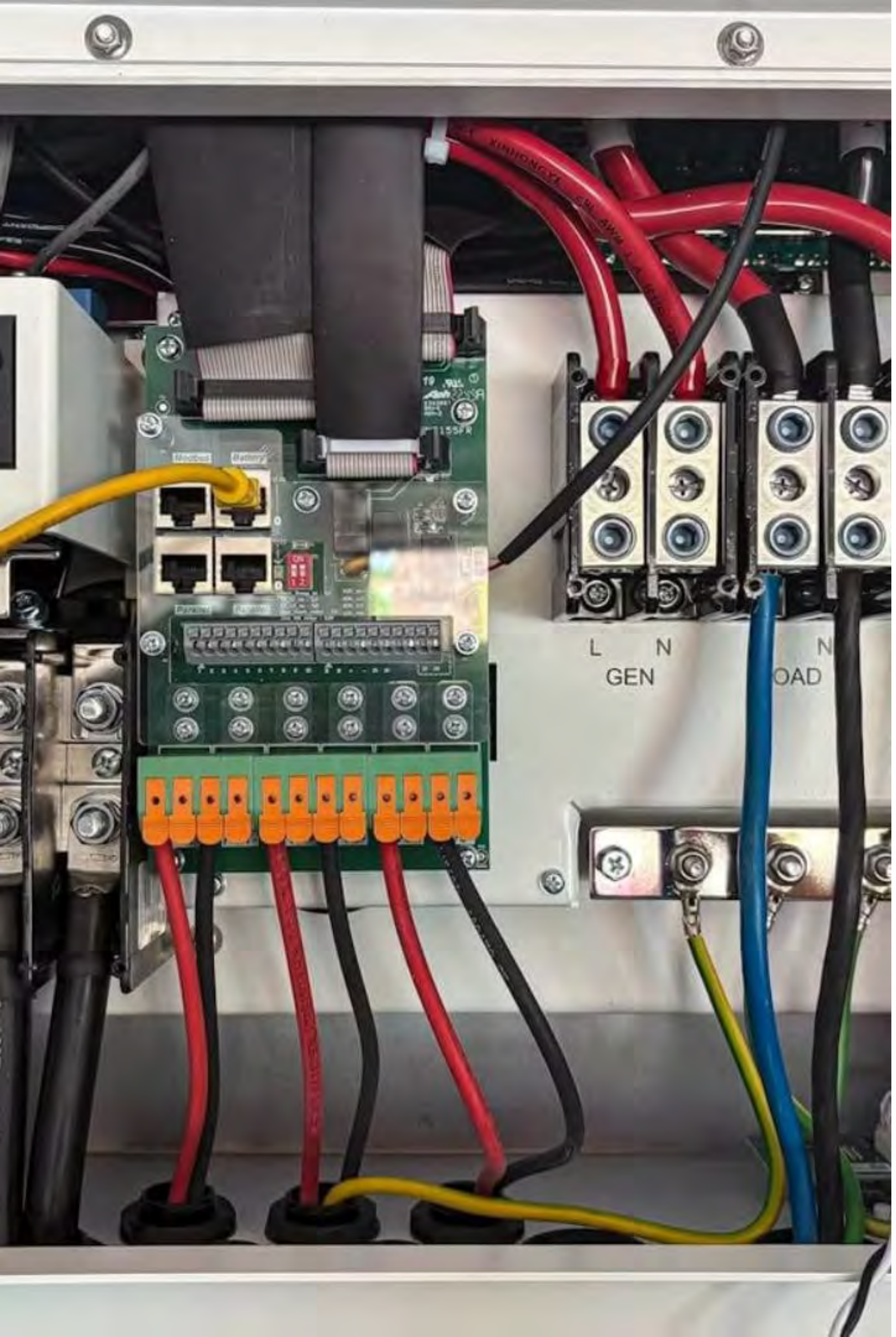
Function

A switch opens or closes an electric circuit as required. The simplest type has two pieces of conducting metal connected to the conductor of the circuit.

Relay Contacts

Contacts in an electrical relay function as switches in control circuits. These contacts are either normally closed (NC) or normally open (NO).

When you energize a relay, the contacts switch position to energize or de-energize circuits.



Circuit Protective Devices

Fuses

Melt when current exceeds rating, breaking the circuit

Circuit Breakers

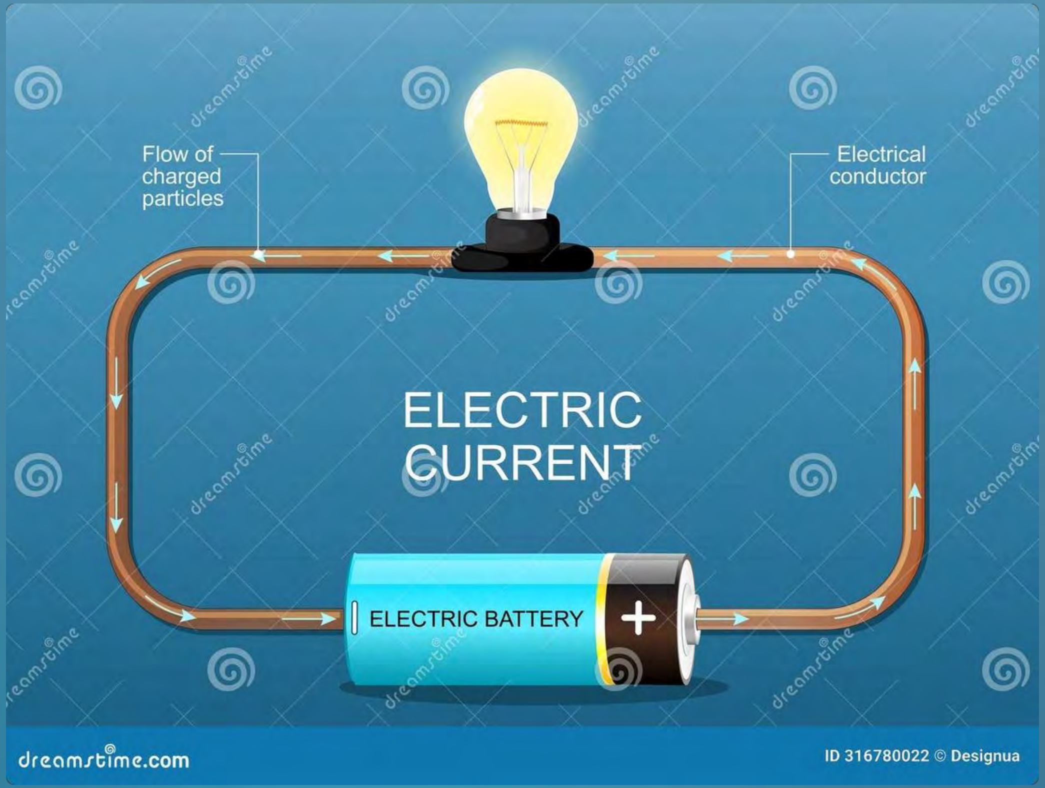
Mechanical switches that trip when overloaded

Thermal Overloads

Protect against excessive heat

Magnetic Overloads

Respond to current surges



Electron Flow in a Circuit

An electric current is the movement of electrons along a conductor. Electrons are extremely small atomic particles that have a negative electric charge.

Heating of the conductor

Resistance in the conductor creates heat as electrons flow

Chemical changes

Electron flow can cause chemical reactions

Production of a magnetic field

Current flow creates a magnetic field around the conductor

You can use these effects to power machinery and other devices.

Comparing Water Flow to Electrical Flow

Water Flow System

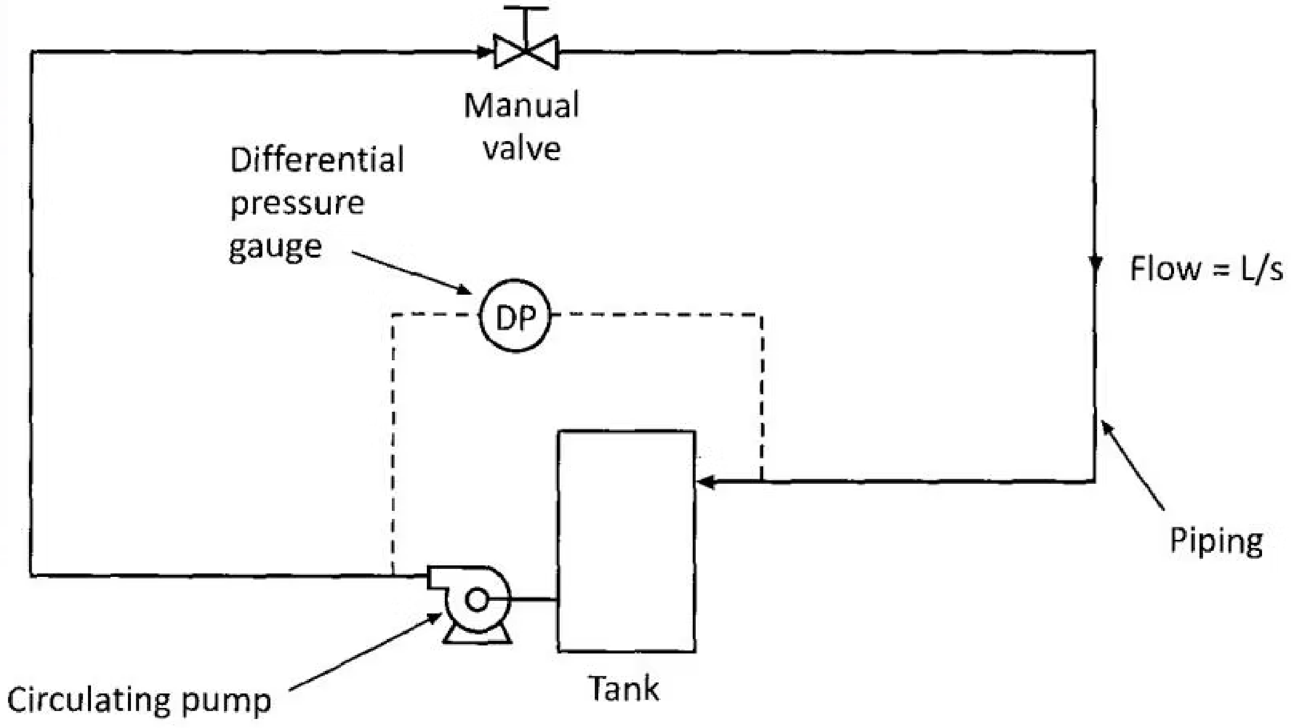
- Water pressure (psi or kPa)
- Water flow rate (gal/min or L/s)
- Pipe restrictions (diameter, fittings)
- Pump creates pressure difference

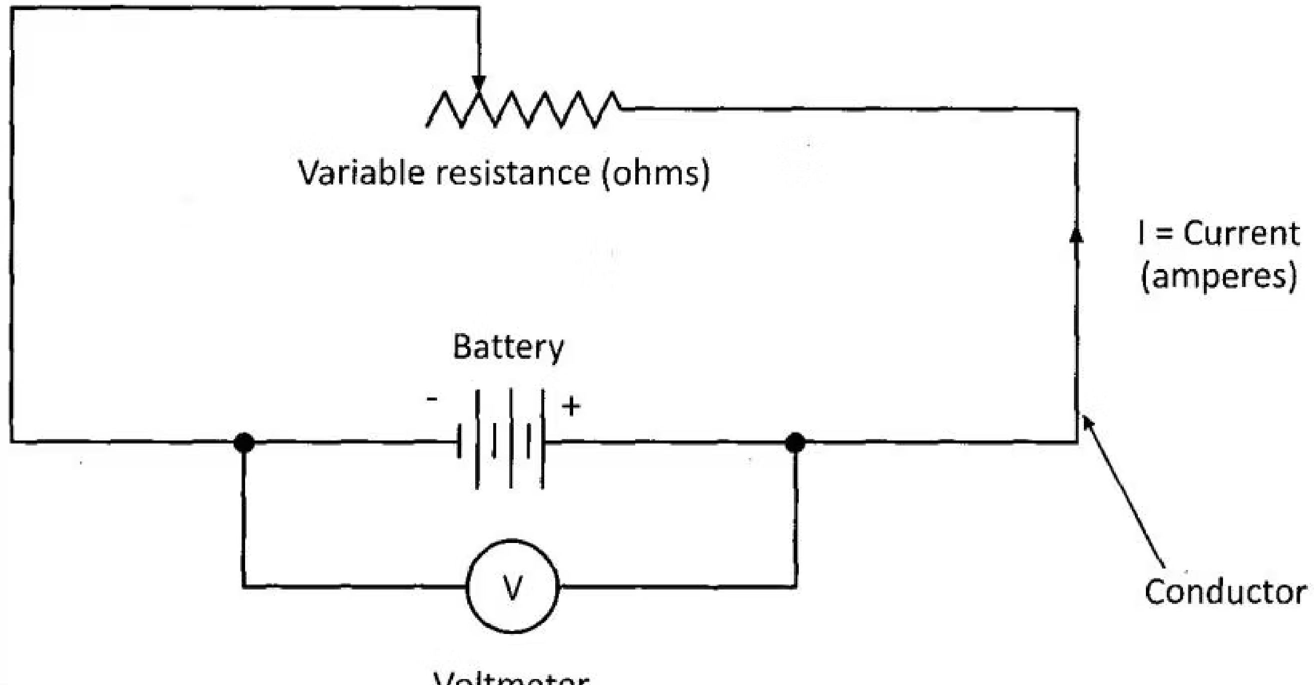
Electrical Circuit

- Electrical pressure (volts)
- Current flow (amperes)
- Conductor restrictions (resistance in ohms)
- Battery/generator creates potential difference

An electric circuit is like the flow of water through a piping system. For water to flow, there must be a pressure difference. Similarly, for electricity to flow, there must be a potential difference.

Water Flow vs. Electrical Flow





Factors Affecting Water Flow

1. ## Pressure Applied

   The greater the pressure applied to the system, the greater the water flow that will occur at a given resistance.

2. ## Pipe Restrictions

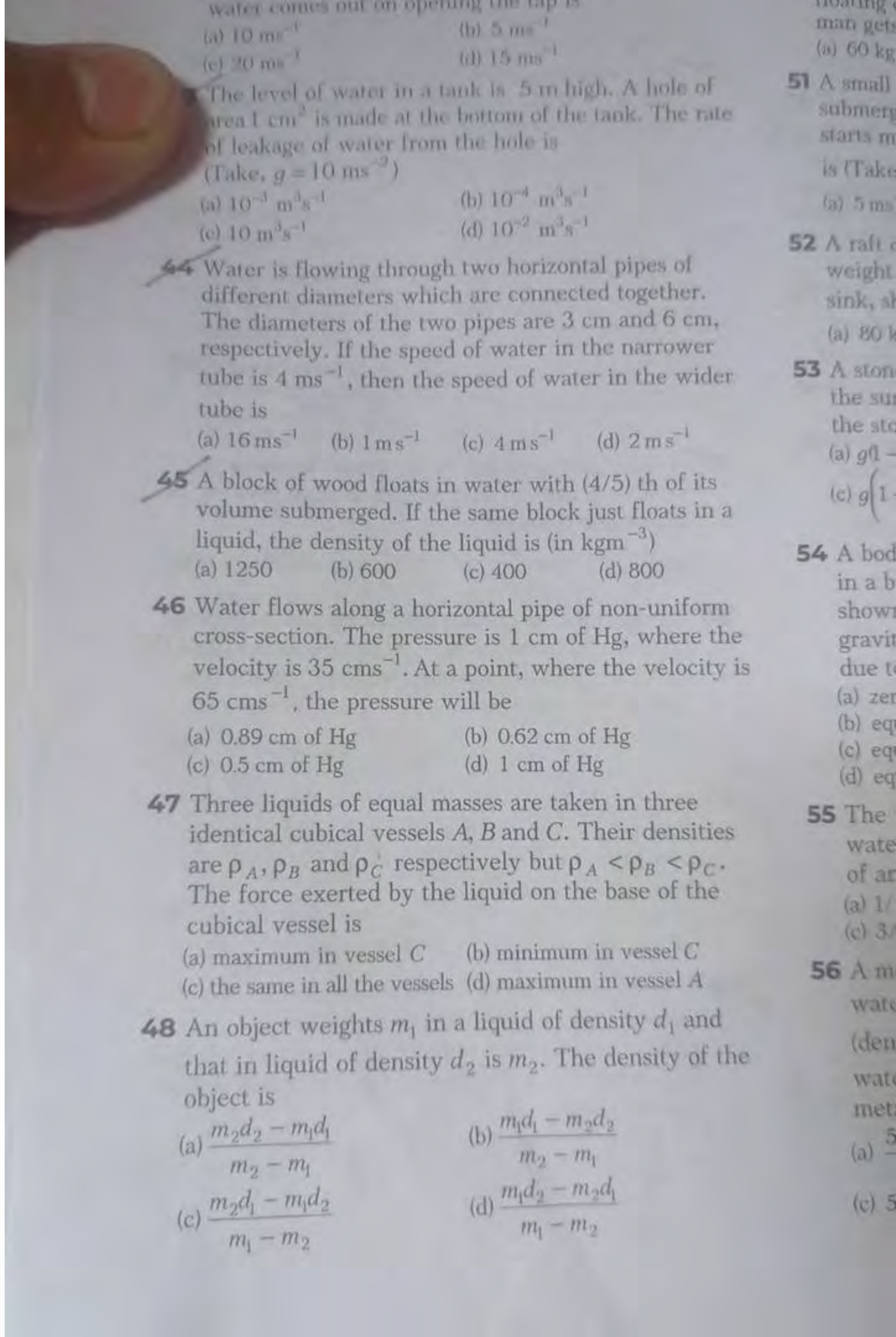
   Restrictions include length and diameter of pipe, as well as the number of fittings.

3. ## Pipe Diameter

   More water will flow through larger-diameter pipe when the same pressure is applied.

4. ## Pump Size

   Maintaining pressure difference with larger pipes requires a larger pump.



water comes out on opening the tap is
(a) $10\ ms^{-1}$ (b) $5\ ms^{-1}$
(c) $20\ ms^{-1}$ (d) $15\ ms^{-1}$

The level of water in a tank is 5 m high. A hole of area $1\ cm^2$ is made at the bottom of the tank. The rate of leakage of water from the hole is (Take, $g = 10\ ms^{-2}$)
(a) $10^{-3}\ m^3s^{-1}$ (b) $10^{-4}\ m^3s^{-1}$
(c) $10\ m^3s^{-1}$ (d) $10^{-2}\ m^3s^{-1}$

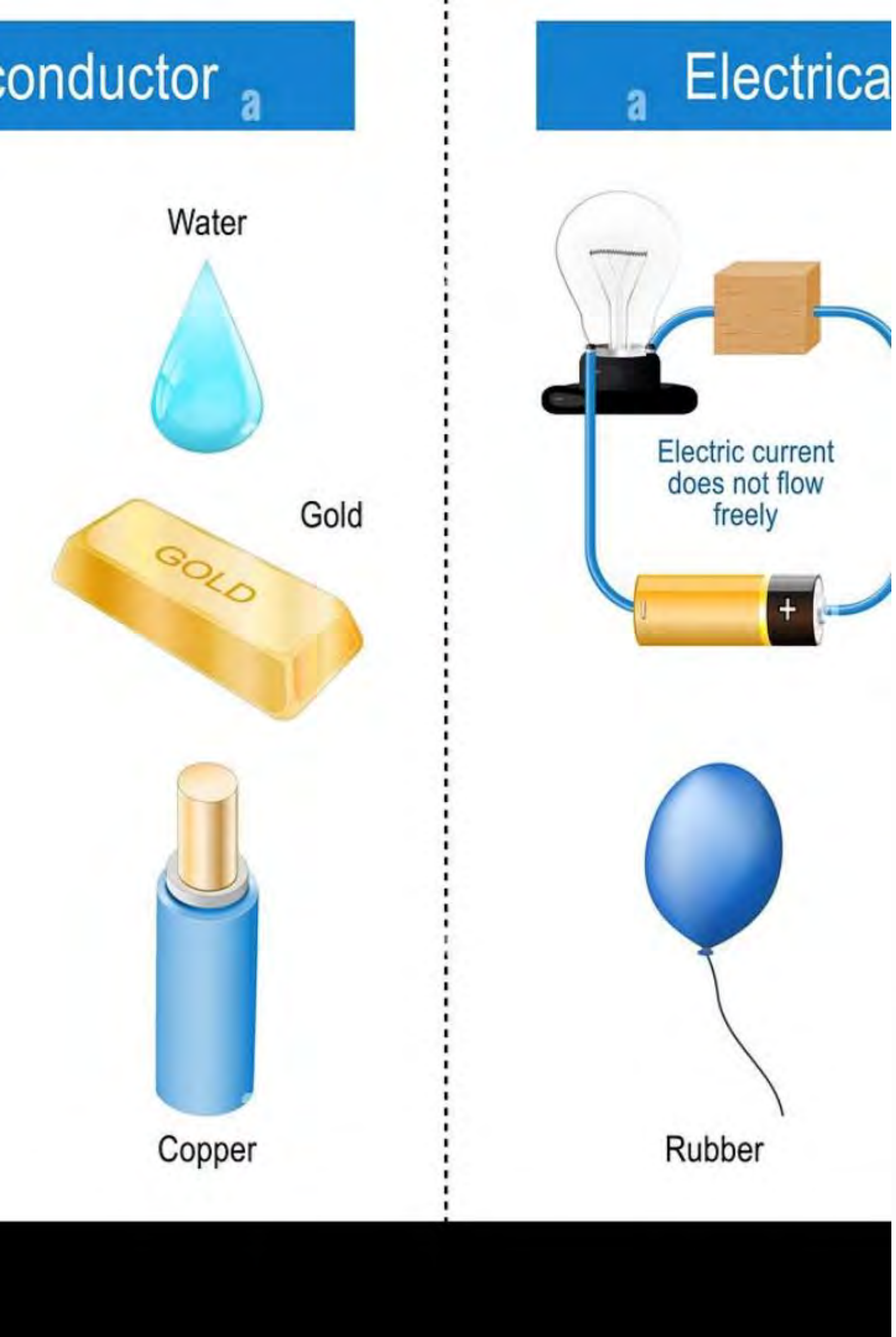
44 Water is flowing through two horizontal pipes of different diameters which are connected together. The diameters of the two pipes are 3 cm and 6 cm, respectively. If the speed of water in the narrower tube is $4\ ms^{-1}$, then the speed of water in the wider tube is
(a) $16\ ms^{-1}$ (b) $1\ ms^{-1}$ (c) $4\ ms^{-1}$ (d) $2\ ms^{-1}$

45 A block of wood floats in water with (4/5) th of its volume submerged. If the same block just floats in a liquid, the density of the liquid is (in kgm^{-3})
(a) 1250 (b) 600 (c) 400 (d) 800

46 Water flows along a horizontal pipe of non-uniform cross-section. The pressure is 1 cm of Hg, where the velocity is $35\ cms^{-1}$. At a point, where the velocity is $65\ cms^{-1}$, the pressure will be
(a) 0.89 cm of Hg (b) 0.62 cm of Hg
(c) 0.5 cm of Hg (d) 1 cm of Hg

47 Three liquids of equal masses are taken in three identical cubical vessels A, B and C. Their densities are ρ_A, ρ_B and ρ_C respectively but $\rho_A < \rho_B < \rho_C$. The force exerted by the liquid on the base of the cubical vessel is
(a) maximum in vessel C (b) minimum in vessel C
(c) the same in all the vessels (d) maximum in vessel A

48 An object weights m_1 in a liquid of density d_1 and that in liquid of density d_2 is m_2. The density of the object is
(a) $\frac{m_2d_2 - m_1d_1}{m_2 - m_1}$ (b) $\frac{m_1d_1 - m_2d_2}{m_2 - m_1}$
(c) $\frac{m_2d_1 - m_1d_2}{m_1 - m_2}$ (d) $\frac{m_1d_2 - m_2d_1}{m_1 - m_2}$



Factors Affecting Electrical Flow

1. ## Potential Difference (Voltage)

   The greater the voltage applied to the circuit, the greater the current flow at a given resistance.

2. ## Conductor Restrictions

   Restrictions include the cross-sectional area of the conductor and the type of material.

3. ## Conductor Size

   More current will flow through larger conductors when the same voltage is applied.

4. ## Power Source Capacity

   Maintaining voltage with larger conductors requires a more powerful energy source.

Electrical Pressure Terminology

Term	Definition
Potential	Positive or negative, measured at one point with respect to another
Potential difference	Difference in potential between any two points in a circuit
Voltage	Alternative term for potential difference
Electromotive force (emf)	Potential difference of an energy source (for example, battery or generator)
Voltage drop	Potential difference across individual loads in a circuit

Often, you use voltage interchangeably with potential difference and emf and never in place of the term potential.

Ohm's Law

Ohm's law defines the relationship between current flow (amperes), electrical pressure (volts), and resistance in a circuit (ohms):

Definition

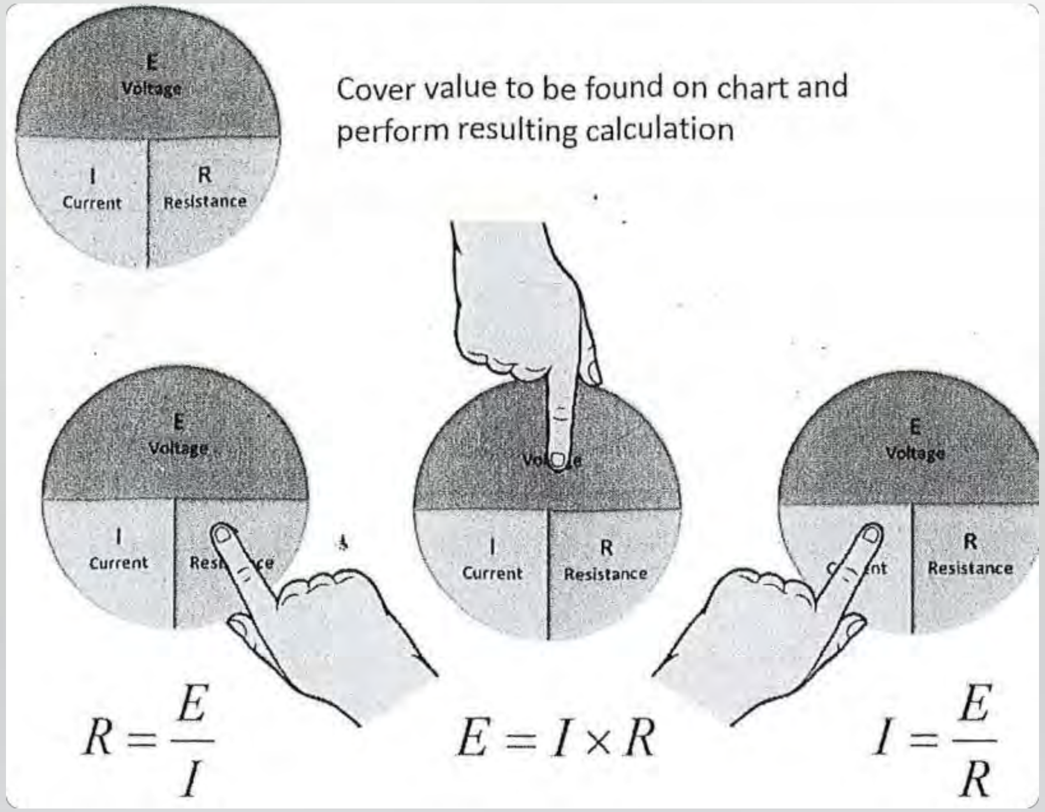
The current flowing in an electrical circuit is directly proportional to the applied voltage.

Relationship

As voltage increases, current increases. As resistance increases, current decreases, and vice versa.

Simple Expression

It takes an emf of 1 volt to push a current of 1 ampere through 1 ohm of resistance.



Ohm's Law Equations

Current (I)

I = E/R

Current equals voltage divided by resistance

Resistance (R)

R = E/I

Resistance equals voltage divided by current

Voltage (E)

E = I × R

Voltage equals current multiplied by resistance

When any two of these quantities are known, it is simple to calculate the third. These equations use amperes, volts, and ohms. If you use larger or smaller units, you must convert them first to these basic units.

Calculating Current Using Ohm's Law

Identify Known Values

In this circuit, we have a 20-volt source of emf and a resistor with resistance of 10 ohms.

Select the Appropriate Formula

To find current, use I = E/R

Substitute Values and Calculate

$I = 20V/10\Omega = 2A$

A current of 2 amperes flows in this circuit. You might need to use a calculation like this to see if the current in a circuit will exceed the safe current rating of a resistor.

Figure 3-5
A circuit with a 20-volt source of emf and a 10-ohm resistance

Calculating Resistance Using Ohm's Law

Identify Known Values

With a 60-volt source of emf and a current of 5 amperes flowing in the circuit.

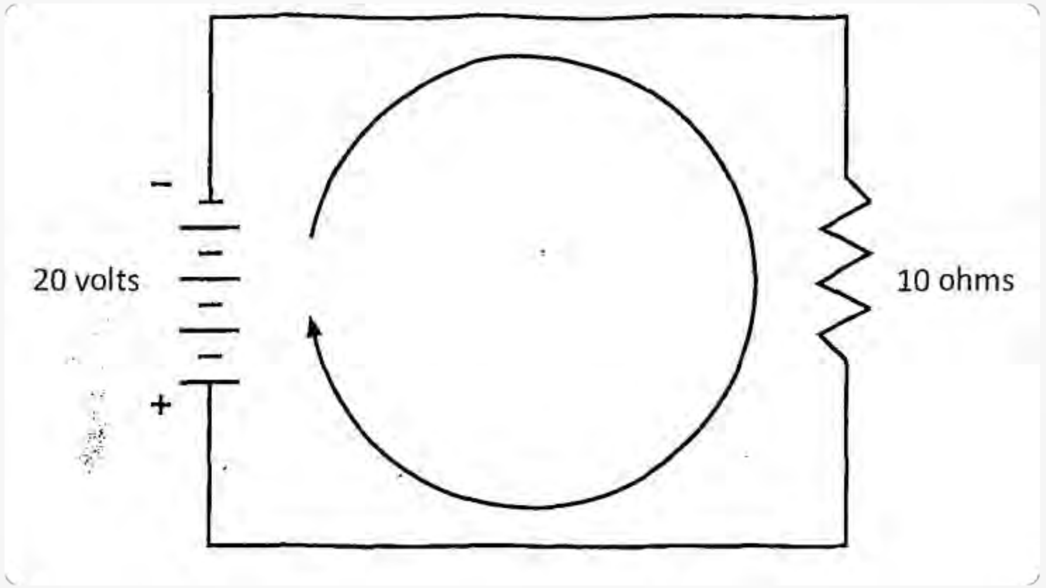
Select the Appropriate Formula

To find resistance, use $R = E/I$

Substitute Values and Calculate

$R = 60V/5A = 12\Omega$

The resistance in this circuit is 12 ohms. Resistance and current are inversely proportional. Therefore, to double the current to 10 amperes, halve the resistance by adjusting the rheostat to reduce resistance in the circuit to 6 ohms.



Work and Power in Electrical Circuits

Work

Work is the process of changing one form of energy into another. For example, a motor changes electrical energy into kinetic energy, so it is doing work.

The unit of electrical work is the joule (J). A more common unit of work is the kilowatt hour (kWh).

Power

Power is the rate at which work is done. The faster work is done, the greater the power.

The unit of power (P) is watts (W) or horsepower (hp). A watt is the consumed power when 1 ampere of current flows through a potential difference of 1 volt in 1 second.

Power Units

Power	Equivalent
1 watt (1 W)	1 joule/second (1 J/s) 0.00134 horsepower (0.00134 hp)
1 kilowatt (1 kW)	3413 Btu/h
1 hp	746 W
1 kilowatt (1 kW)	1000 W (= 10^3 W)
1 megawatt (1 MW)	1,000,000 W (= 10^6 W)

Power in Water and Electrical Systems

Water System Power

The power of a pump is a function of the pressure that the pump has developed and the flow of water.

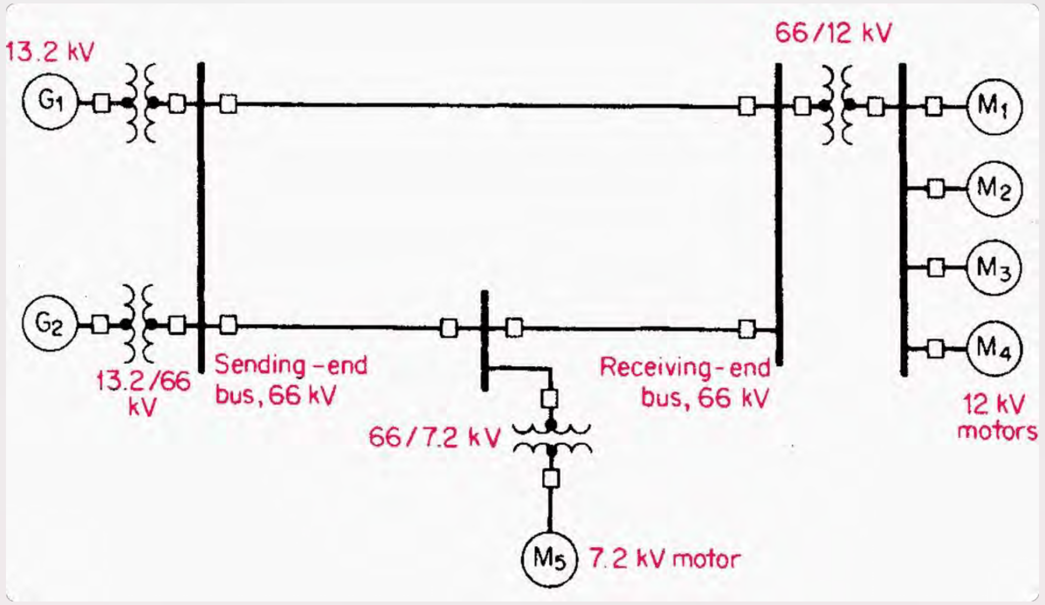
A more powerful pump is needed to develop higher pressure or to pump more water through the system.

Electrical System Power

In electric circuits, power is a function of current flow and applied voltage.

Power increases if you increase the current or voltage.

Maintaining flow with large conductors and low resistance requires a more powerful battery.



Power Calculation in DC Circuits

Basic Formula

Power in watts = (current in amperes) × (voltage in volts)

P = I × E

Derived Formulas

E = P/I

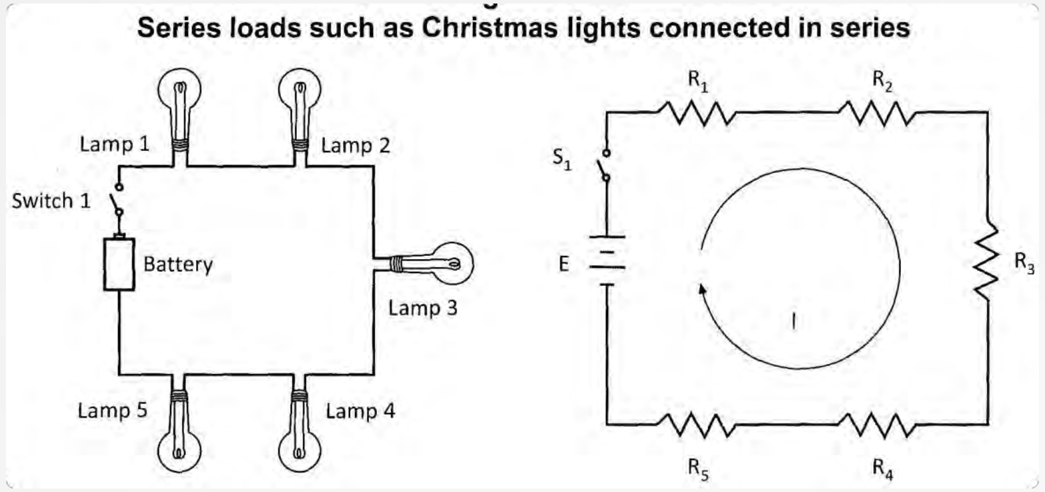
I = P/E

Example Calculation

If voltage is 60 volts and current is 5 amperes:

P = 5A × 60V = 300W

Therefore, the power of this circuit is 300 watts.



Series Circuits

Definition

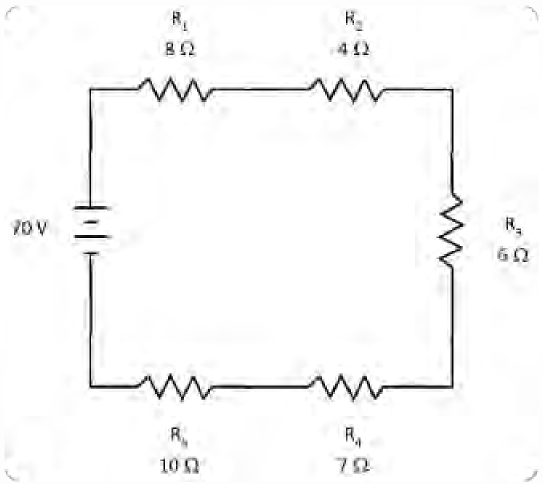
Circuits that have only one possible path for the current flow. The same amount of current flows through every part of the circuit.

Arrangement

The parts of the circuit follow one after the other in series in a single loop.

Example

Older forms of Christmas tree lights are connected in series. Each lamp is a resistive load. If one lamp burns out, the entire string goes out because the series circuit has been broken.



Voltage Drop in Series Circuits

Voltage Drop Definition

As electrons move from the negative to the positive terminal, they lose energy to the circuit resistance. This occurrence is voltage drop.

Total Voltage Drop

Total voltage drop in a circuit equals the applied voltage of the energy source. This is true for circuits with one load or 20 loads.

Multiple Loads

If there are several loads, some voltage drop occurs across each load. The same current passes through them all, so the voltage drop across each load is proportional to the resistance of that load.

Calculating Voltage Drop in Series Circuits

Identify Circuit Values

A series circuit has a total voltage of 48 volts and contains a 2-ohm resistor and a 4-ohm resistor.

Calculate Total Resistance

Total resistance is $2\Omega + 4\Omega = 6\Omega$

Calculate Current

$I = E/R = 48V/6\Omega = 8A$

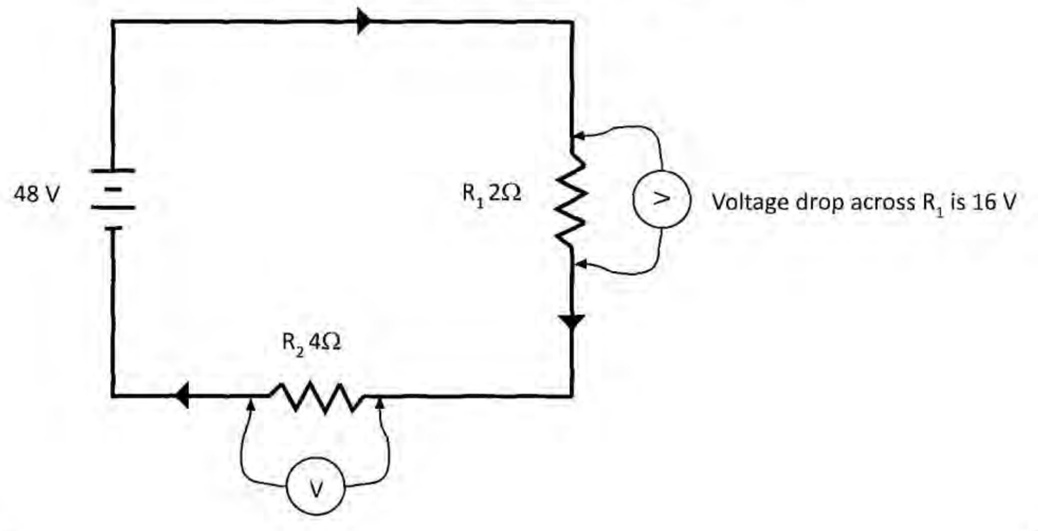
Calculate Individual Voltage Drops

Voltage drop across 2-ohm resistor: $E2 = I \times R = 8A \times 2\Omega = 16V$

Voltage drop across 4-ohm resistor: $E4 = I \times R = 8A \times 4\Omega = 32V$

Note: The total voltage drop in the series circuit (48V) is the sum of the voltage drops across the two resistors (16V + 32V).

Figure 3-9
Voltage drop in a series circuit



Parallel Circuits

Definition

If some parts of a circuit are connected in parallel, the current is not the same in all parts of the circuit.

Current Flow

Current flows through more than one complete path. These paths are called branches. The supply voltage is common to each branch.

Circuit Continuity

If one branch of a parallel circuit becomes open, current still flows through the other branches. For example, ordinary house lamps are connected in parallel; if one burns out, the rest stay lit.

Energy Sources

Energy sources as well as loads may be connected in parallel. Sources connected in parallel maintain the same terminal voltage, but supply greater amounts of current.

Current Flow in Parallel Circuits

Multiple Paths

In a parallel circuit, there are multiple possible complete paths for the current to flow through between the terminals.

Current Distribution

The sum of the currents in each branch equals the supply current.

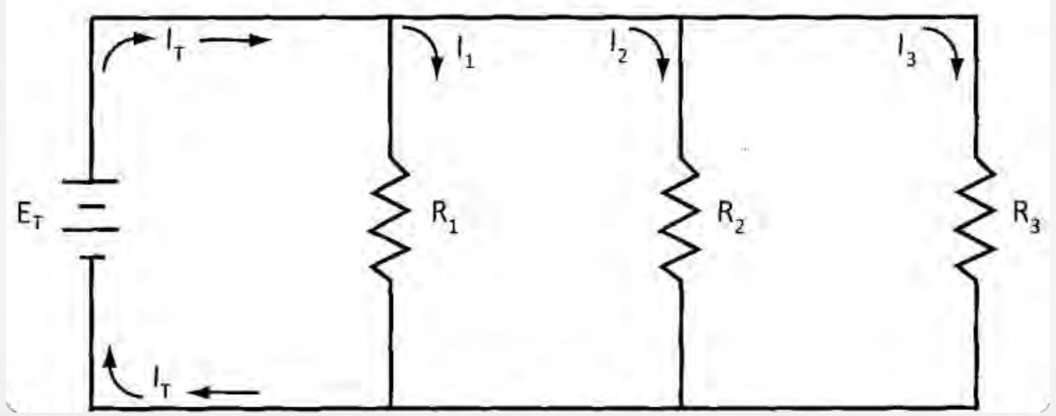
Branch Failure

If one load burns out, current can still flow through the other branches.

Source Disconnection

If the energy source is disconnected, no current flows in any of the branches.

Figure 3-12
Parallel circuit



Resistance in Parallel Circuits

Total Resistance Formula

In a parallel circuit, you can calculate the total resistance (RT) using the following formula:

1/RT = 1/R1 + 1/R2 + 1/R3 + ...

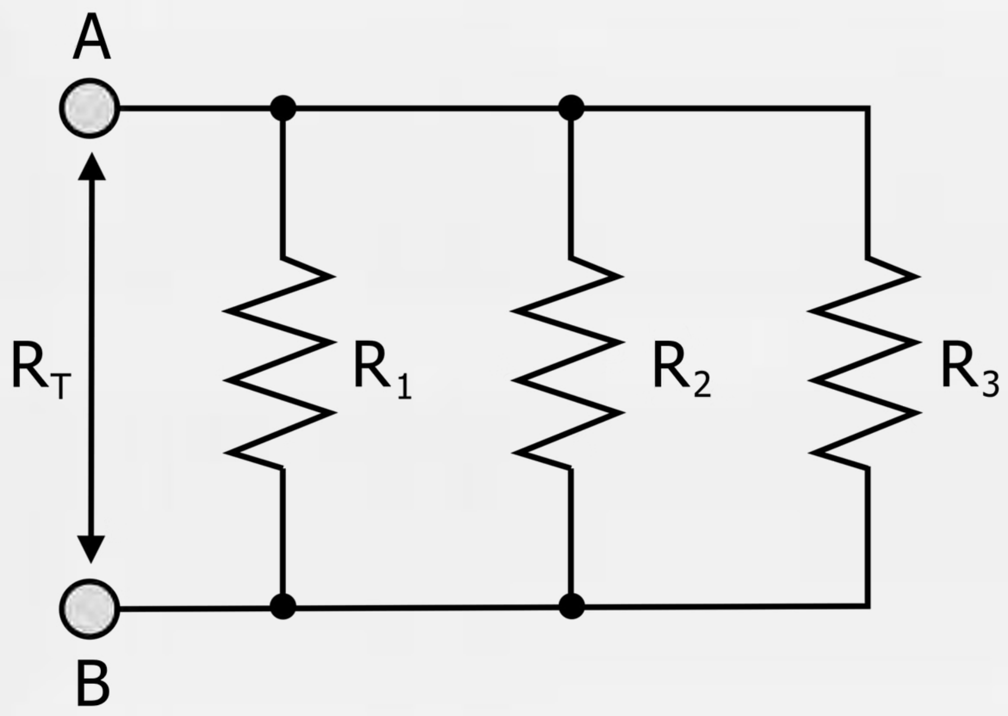
Alternative Calculation

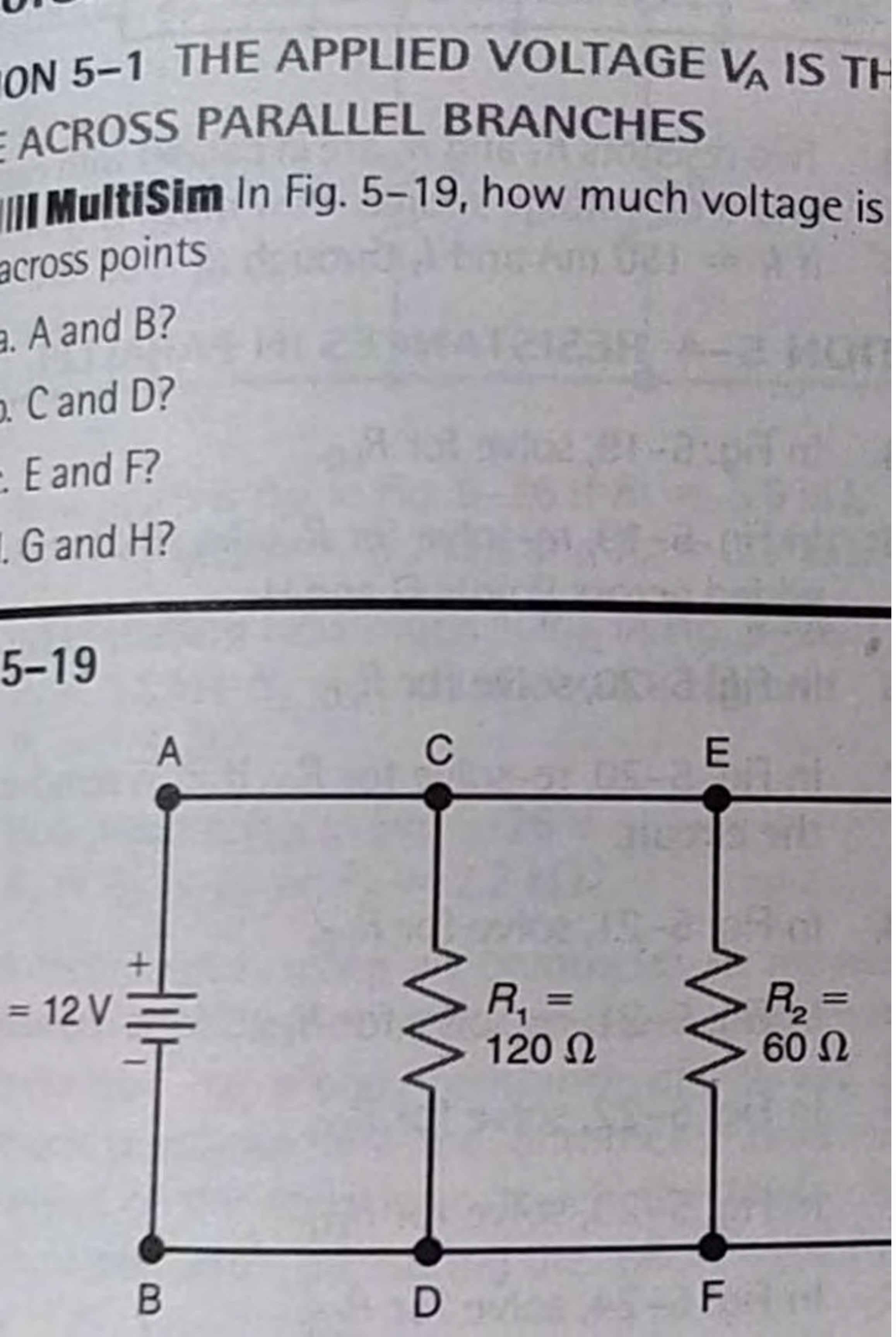
If the total current and voltage of a parallel circuit are known, you can calculate the total resistance from Ohm's law:

RT = ET/IT

Effect on Circuit

When resistances are connected in parallel, they reduce overall opposition to current flow.





Voltage in Parallel Circuits

Common Voltage

Parallel loads are connected directly across the same energy source. This means that, when loads are connected in parallel, the entire source voltage is applied across each branch.

Key Feature

This is the most important and useful feature of a parallel circuit, because all loads are supplied with a common voltage.

Current Distribution

The current in each branch is inversely proportional to the resistance of the load in the branch (Ohm's law). Branches with less resistance carry more current and vice versa.

Example of Parallel Circuit Calculation

Figure 3-13
Parallel circuit showing current flow through branches

Initial Circuit

In a simple circuit with a 6-volt power source and a resistance of 3 ohms, a current of 2 amps flows.

Adding Parallel Resistance

Another load, with a resistance of 4 ohms, is connected in parallel with the first one.

Current Through First Resistor

A current of 2 amperes still flows through the 3-ohm resistor.

Current Through Second Resistor

A current of 1.5 amperes now also flows through the 4-ohm resistor.

Total Current

Total current flow (IT) in the circuit has increased to 3.5 amperes.

Series-Parallel Circuits

Definition

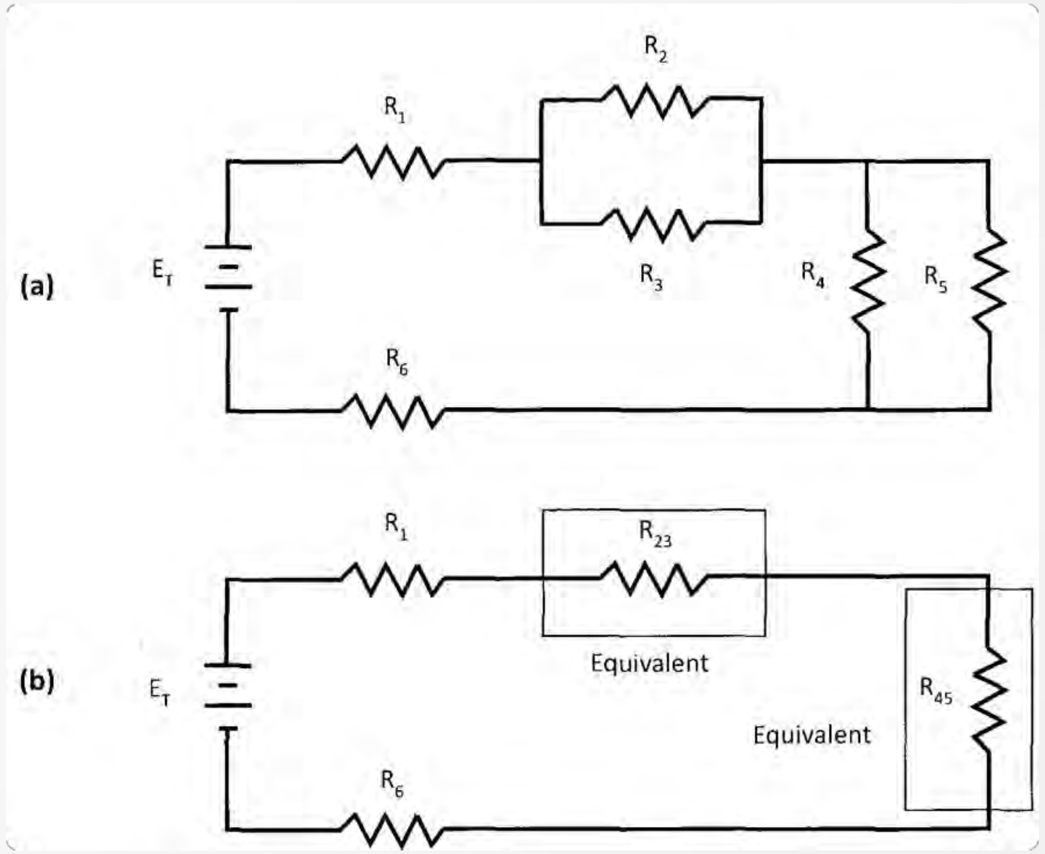
Circuits that combine series and parallel connections are called series-parallel circuits.

Analysis Approach

You can systematically break down series-parallel or combination circuits into series and parallel components.

Applicable Laws

The same laws that apply to individual series and parallel circuits are applicable to the analysis of series-parallel circuits.



Example of Series-Parallel Circuit

Circuit Structure

In the series-parallel circuit in Figure 3-14a:

- Resistors R2 and R3 (the first parallel component) are in parallel, but only with each other.
- Resistors R4 and R5 (the second parallel component) are also in parallel, but only with each other.
- These two parallel components of the circuit are in series with one another and with resistors R1 and R6.

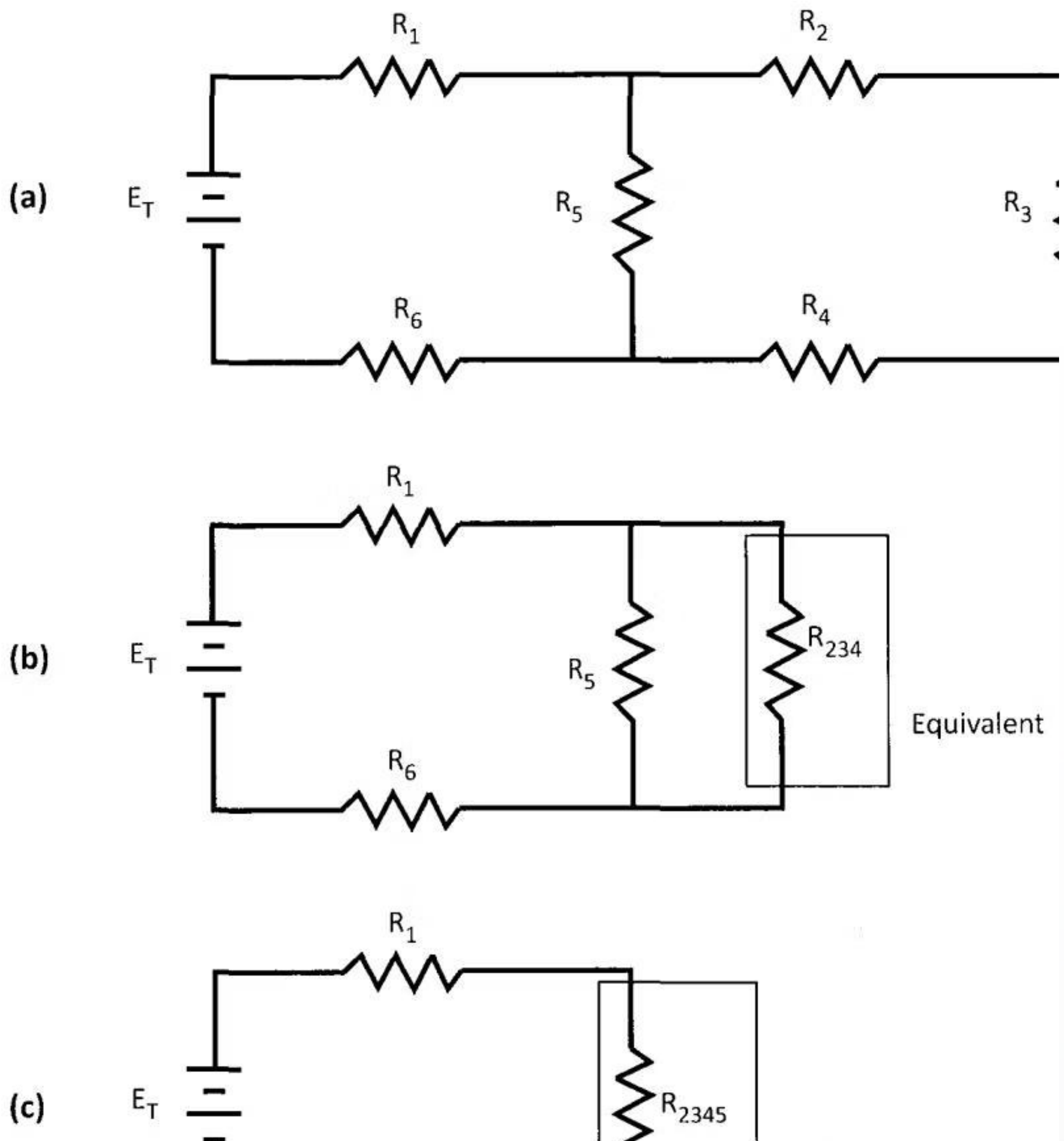
Equivalent Circuit

To analyze this circuit:

- Calculate parallel resistors R2 and R3 as an equivalent single resistance (R23).
- Calculate the other parallel component (R4 and R5) as a single equivalent resistance (R45).
- After substituting the two pairs of parallel resistances with their equivalent resistances, you have a simple series circuit.

Calculating Circuit Resistance in Series-Parallel Circuits

Figure 3-15
Calculating values in series-parallel circuits



Calculating Current in Series-Parallel Circuits

Determine Total Resistance

Once you determine the total circuit resistance, you can calculate the total line current by using Ohm's law (I = E ÷ R).

Calculate Voltage Drops

Calculate the individual voltage drops across the resistances using the following equations:

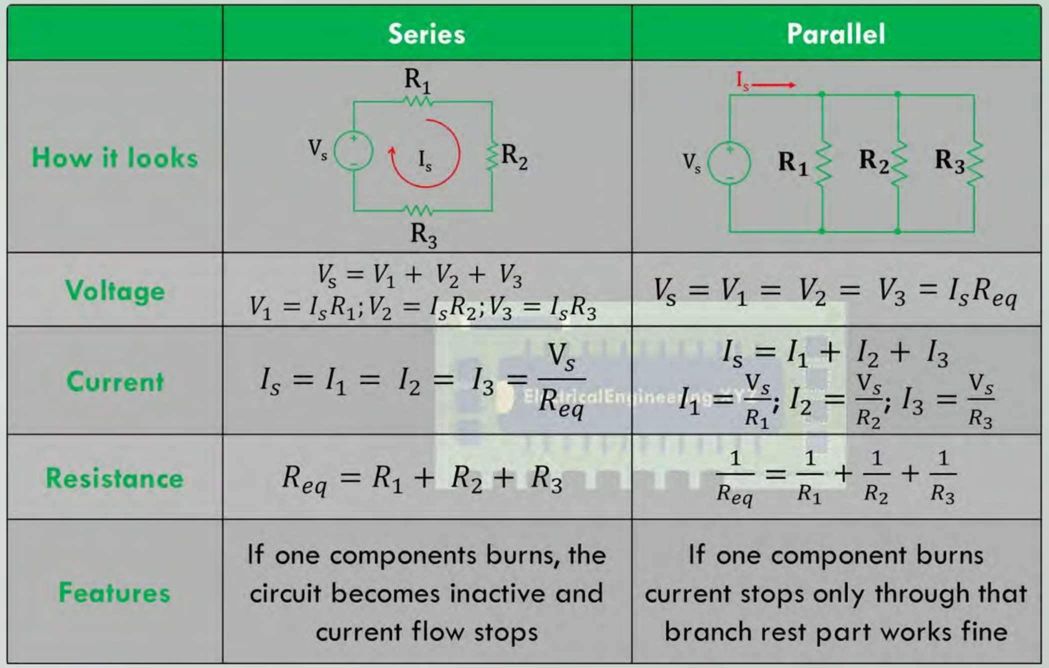
E1 = IT × R1

E2345 = IT × R2345

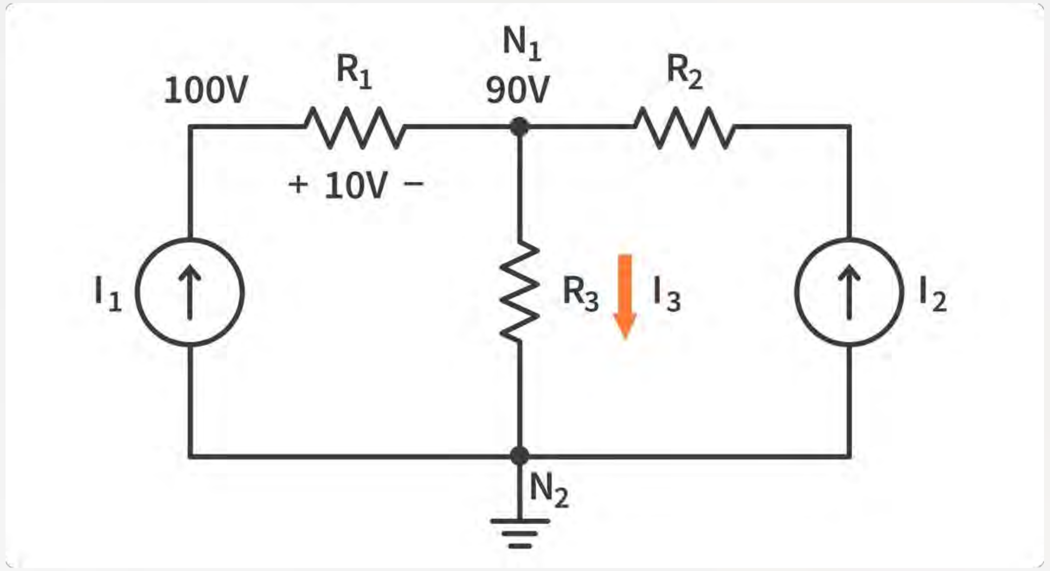
E6 = IT × R6

Verify Total Voltage

The sum of E1 + E2345 + E6 = ET.



	Series	Parallel
How it looks		
Voltage	$V_s = V_1 + V_2 + V_3$ $V_1 = I_sR_1; V_2 = I_sR_2; V_3 = I_sR_3$	$V_s = V_1 = V_2 = V_3 = I_sR_{eq}$
Current	$I_s = I_1 = I_2 = I_3 = \frac{V_s}{R_{eq}}$	$I_s = I_1 + I_2 + I_3$ $I_1 = \frac{V_s}{R_1}; I_2 = \frac{V_s}{R_2}; I_3 = \frac{V_s}{R_3}$
Resistance	$R_{eq} = R_1 + R_2 + R_3$	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
Features	If one components burns, the circuit becomes inactive and current flow stops	If one component burns current stops only through that branch rest part works fine



Calculating Branch Currents in Series-Parallel Circuits

Use Voltage Drop

You can use the voltage drop E2345 to calculate the branch currents.

Equal Voltage in Parallel Branches

For the parallel component of this series-parallel circuit, the voltage drops across the two branches are the same.

Calculate Branch Currents

I234 = E2345 ÷ R234

I5 = E2345 ÷ R5

Verify Total Current

IT = I5 + I234 for the parallel portion.

Practical Application: Electrical Circuits in Gas Equipment

Gas Furnaces

Modern gas furnaces use electrical circuits for ignition, fan control, and safety systems.

Gas Water Heaters

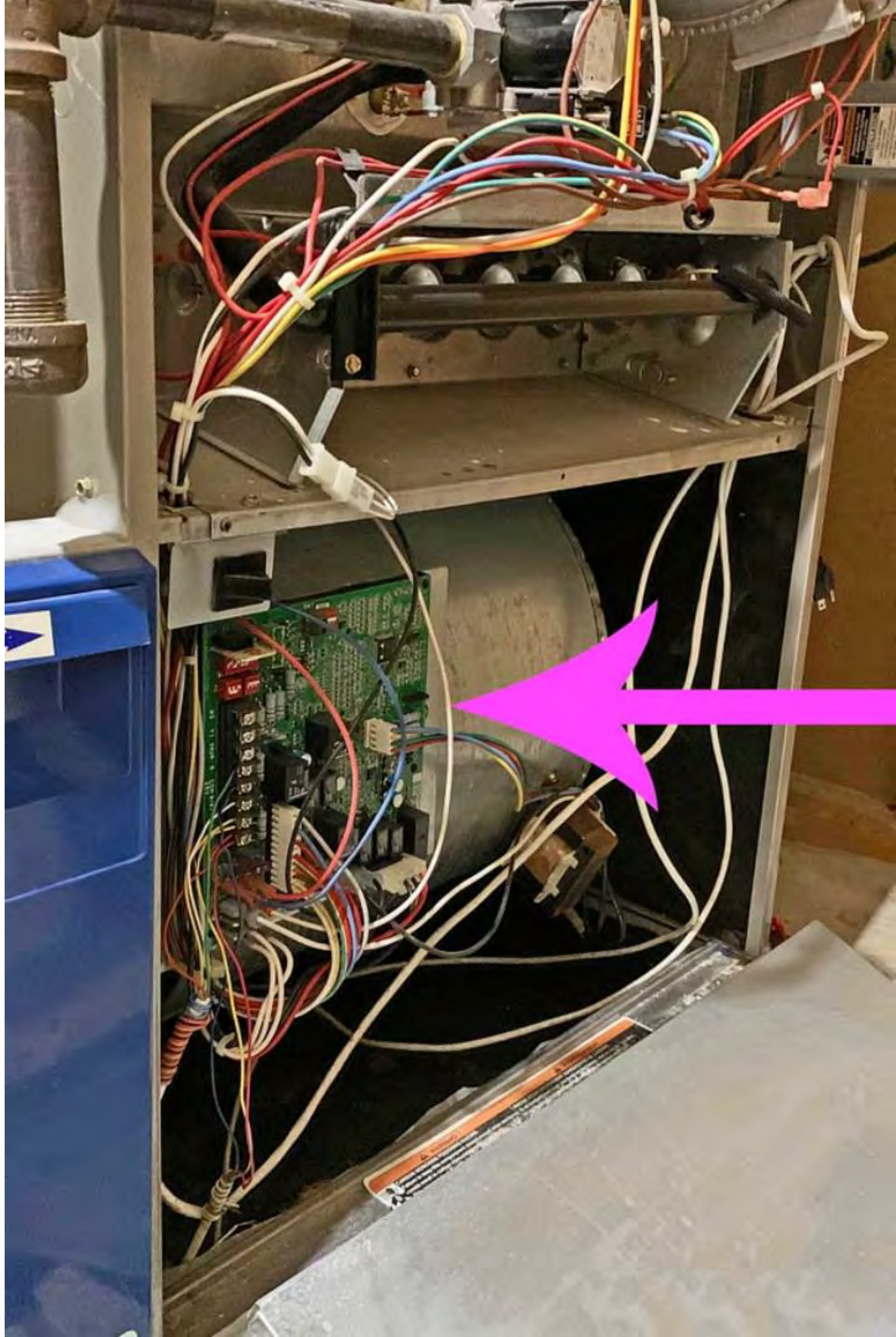
Electronic ignition systems and temperature controls use simple electrical circuits.

Gas Stoves

Electronic ignition, timers, and temperature controls all rely on electrical circuits.

Gas Detectors

Safety devices that detect gas leaks use electrical circuits to trigger alarms.



Troubleshooting Electrical Circuits in Gas Equipment

Verify Power Supply

Check that the equipment is receiving proper voltage

Inspect for Visible Damage

Look for burned components, loose connections, or damaged wires

Test Components

Use a multimeter to test resistance, voltage, and continuity

Repair or Replace

Fix connections or replace faulty components

Verify Operation

Test the equipment to ensure proper function

Safety Considerations When Working with Electrical Circuits

Disconnect Power

Always disconnect the power source before working on any electrical circuit.

Use Proper Tools

Use insulated tools and appropriate test equipment when working with electrical circuits.

Wear Protective Equipment

Use safety glasses and insulated gloves when appropriate.

Follow Codes and Standards

Adhere to local electrical codes and manufacturer's specifications.

Proper Training

Ensure you have the proper training and certification before working on electrical systems.

Common Electrical Problems in Gas Equipment

Faulty Ignition Systems

Electronic ignition systems may fail due to worn electrodes, damaged wiring, or control board issues.

Thermostat Problems

Thermostats can develop open circuits, short circuits, or calibration issues.

Fan Control Failures

Fan motors and control circuits may develop open circuits or short circuits.

Safety Circuit Malfunctions

Flame sensors, limit switches, and pressure switches can fail, causing the equipment to shut down.

Testing Electrical Components in Gas Equipment

Continuity Testing

Used to check if a circuit is complete or if there is a break in the circuit.

1. Disconnect power to the circuit
2. Set multimeter to continuity or resistance mode
3. Connect probes to the component terminals
4. A reading of zero or near-zero ohms indicates continuity

Voltage Testing

Used to verify if the correct voltage is present at various points in the circuit.

1. Set multimeter to AC or DC voltage mode
2. Connect probes to test points
3. Compare reading to expected voltage
4. Significant deviations indicate problems

Resistance Testing in Gas Equipment

Disconnect Power

Always ensure the circuit is de-energized before testing resistance.

Set Multimeter

Set the multimeter to the appropriate resistance range (ohms).

Isolate Component

Disconnect at least one end of the component from the circuit to get an accurate reading.

Measure Resistance

Connect the multimeter probes to the component terminals and read the resistance value.

Compare to Specifications

Compare the measured resistance to the manufacturer's specifications to determine if the component is functioning properly.

Electrical Diagrams for Gas Equipment

Types of Diagrams

- Wiring diagrams show the actual wire connections
- Schematic diagrams show the electrical function using symbols
- Ladder diagrams show the control circuit in a simplified format

Reading Diagrams

- Identify components using the legend
- Trace circuits from power source to load
- Understand the function of switches and controls
- Identify potential points of failure

Electrical Components in Gas Equipment

Thermostats

Control temperature by opening or closing circuits based on temperature changes

Fan Motors

Provide air circulation for combustion and heat distribution

Ignition Systems

Generate sparks or heat to ignite gas

Safety Controls

Monitor operation and shut down equipment if unsafe conditions occur

Relays and Contactors in Gas Equipment

Relays

Electromechanical switches that use a small current to control a larger current.

Components:

- Coil - Electromagnet that creates magnetic field when energized
- Contacts - Normally open (NO) or normally closed (NC)
- Armature - Moves contacts when coil is energized

Applications in Gas Equipment

Relays are used in gas equipment for:

- Fan control
- Ignition sequence control
- Safety circuit operation
- Valve operation

Transformers in Gas Equipment

Function

Transformers convert high voltage (typically 120V or 240V) to lower voltages (typically 24V) for control circuits.

Components

Primary winding, secondary winding, and iron core.

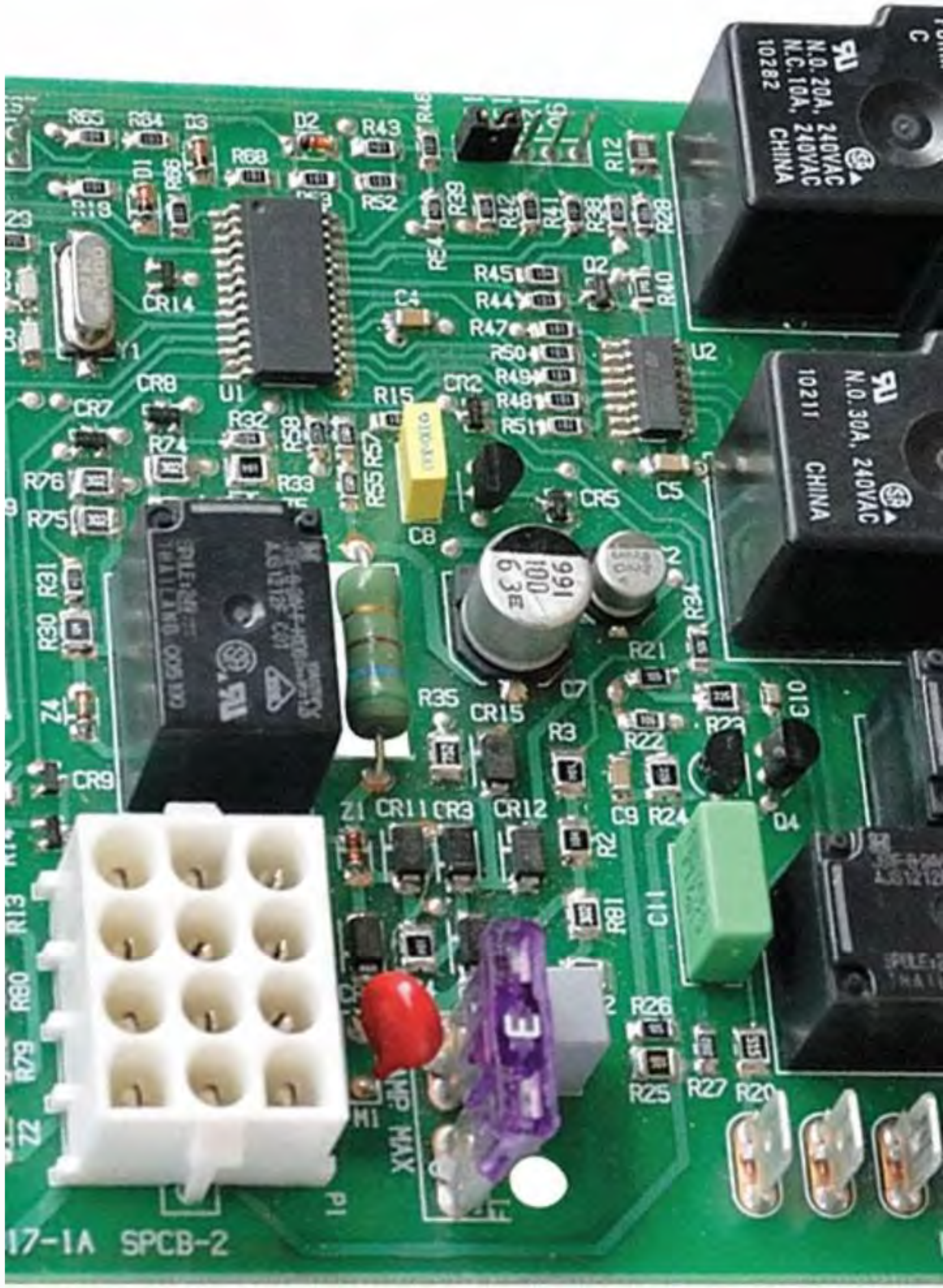
Applications

Used to power thermostats, control boards, and other low-voltage components in gas equipment.

Testing

Check input and output voltages with a multimeter to verify proper operation.

Control Boards in Modern Gas Equipment



Function

Electronic control boards manage the operation of modern gas equipment, controlling ignition, monitoring safety systems, and regulating performance.

Components

Microprocessors, relays, transistors, capacitors, resistors, and integrated circuits.

Diagnostics

Many control boards have LED indicators or digital displays that provide error codes to help diagnose problems.

Testing

Testing control boards often requires specialized knowledge and equipment. Many technicians replace the entire board rather than attempting to repair individual components.

Sensors in Gas Equipment

Temperature Sensors

Monitor temperature at various points in the system

Flame Sensors

Detect the presence of a flame to ensure safe operation

Pressure Switches

Monitor air or gas pressure to ensure proper combustion

Gas Detectors

Detect gas leaks and trigger safety shutdowns

Electrical Safety Devices in Gas Equipment

High Limit Switches

Shut down equipment if temperature exceeds safe limits

Pressure Switches

Ensure proper air flow for combustion

Flame Rollout Switches

Detect flames outside the combustion chamber

Timing Circuits

Control ignition sequence and ensure proper purge cycles

Fuses and Circuit Breakers

Protect against electrical overloads

Wiring Practices for Gas Equipment

Follow Manufacturer's Diagrams

Always refer to the manufacturer's wiring diagrams when installing or servicing equipment.

Use Proper Wire Gauge

Select wire size based on the current requirements and length of the run.

Secure Connections

Ensure all connections are tight and secure to prevent resistance and overheating.

Protect Wiring

Use conduit or other protection for wires that may be exposed to damage.

Label Wires

Clearly label wires to facilitate future troubleshooting and service.

Electrical Testing Equipment for Gas Technicians

Gas technicians should be familiar with various electrical testing equipment to diagnose and troubleshoot electrical problems in gas equipment.

Electrical Troubleshooting Procedure

Gather Information

Collect equipment history and symptoms

Visual Inspection

Look for obvious damage or loose connections

Test Components

Use appropriate test equipment to check circuits

Analyze Results

Compare findings to expected values

Repair or Replace

Fix the identified problems

Summary: Components and Operation of Simple Electrical Circuits

Energy Source

Provides the electromotive force (voltage) to drive current through the circuit

Conductors

Provide a path for current flow with minimal resistance

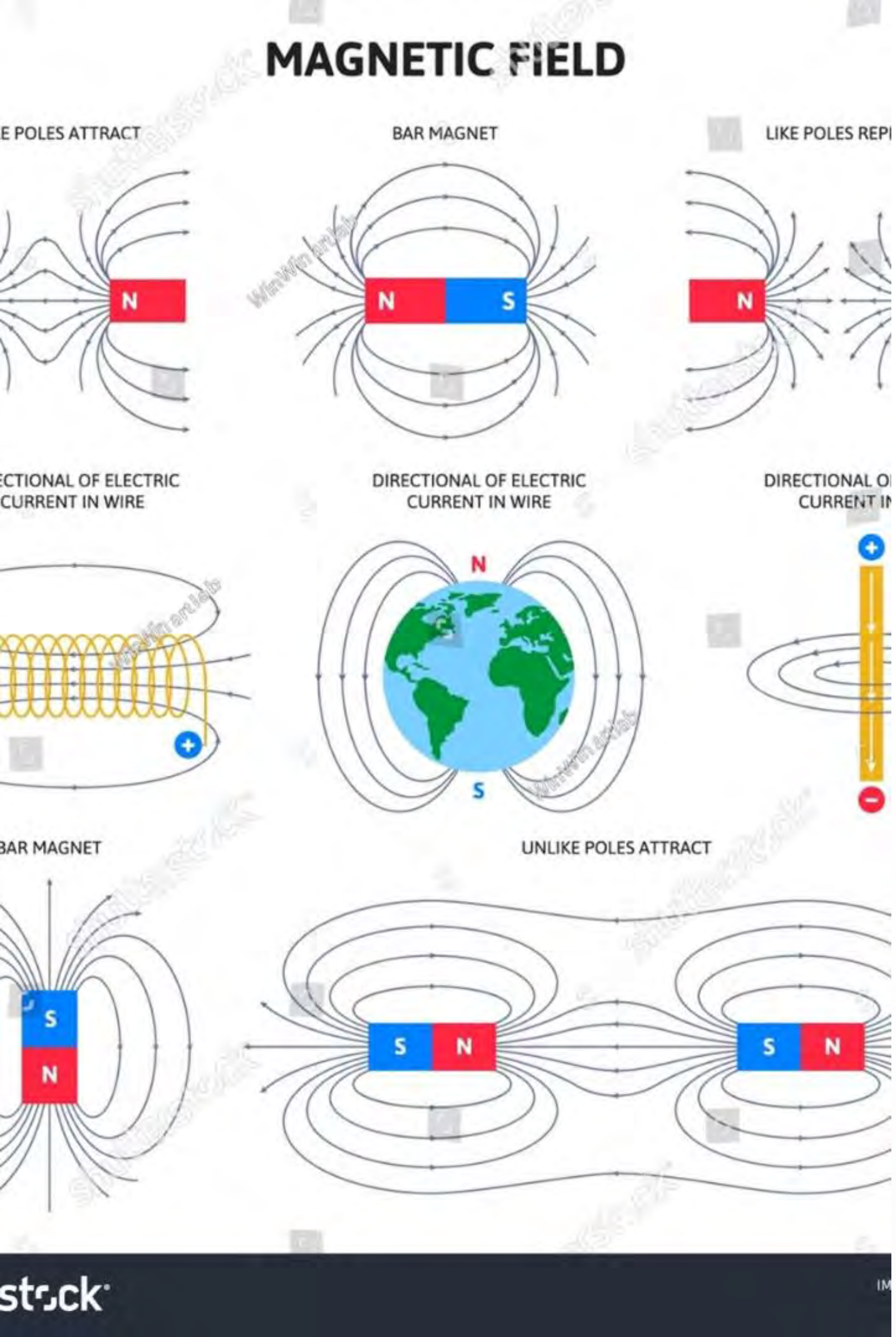
Controls

Switches and protective devices that manage circuit operation

Load

Uses electrical energy to perform useful work

Understanding these components and how they work together in series and parallel circuits is essential for gas technicians to effectively troubleshoot and maintain the electrical systems in gas equipment.



CSA Unit 5

Chapter 4 Principles of Basic Magnetism and Electromagnetism

Gas technicians/fitters require knowledge of the principles of magnetism and electromagnetism to understand the operation of electric motors, solenoid switches, and valves and relay Units in control circuits.

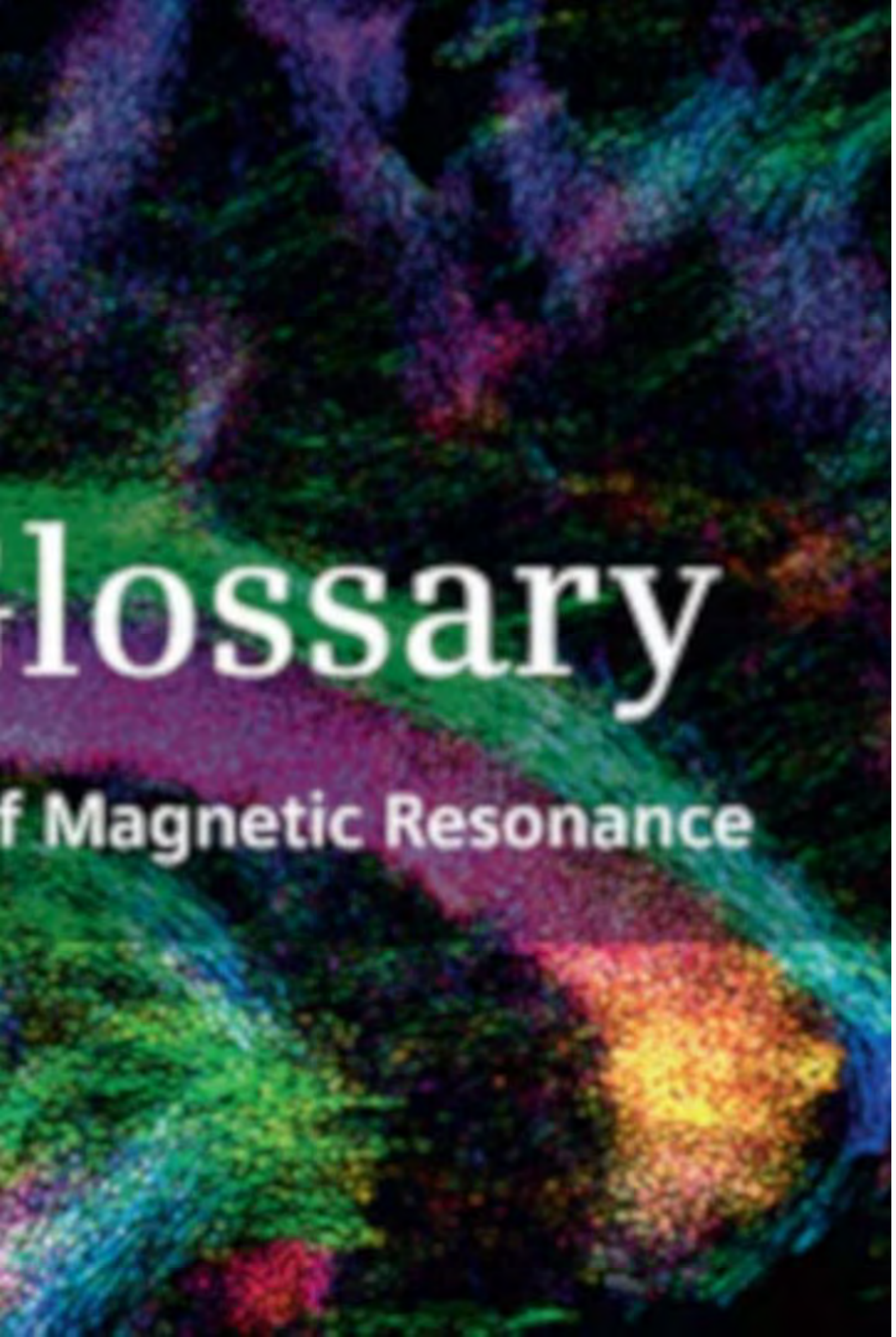
Objectives

Describe the principles of basic magnetism

Understanding magnetic materials, electron behavior, polarity, and magnetic fields

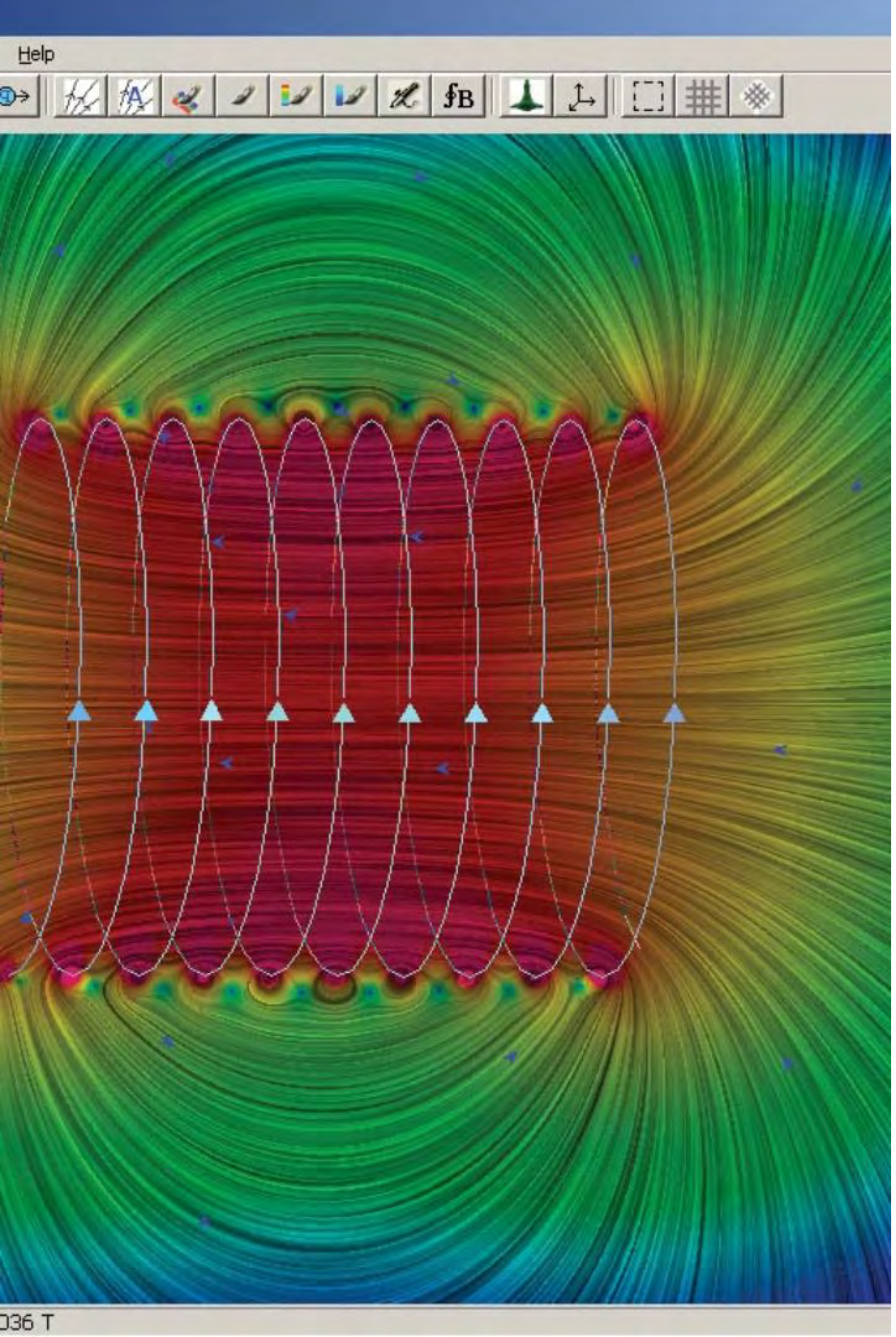
Describe the principles of basic electromagnetism

Understanding how electricity and magnetism interact in conductors, coils, and electromagnetic devices



Key Terminology

Term	Definition
Electromagnet	Magnet that is a product of passing an electric current through a conductor
Electromagnetism	Magnetism that results from the movement of electrons
Ferromagnetic materials	Materials that attract other magnetic materials
Flux density	Magnitude of a magnetic, electric, or other flux passing through a Unit area
Lines of force or flux lines	Imaginary line that represents the strength and direction of a magnetic, gravitational, or electric field at any point



More Key Terminology

Term	Definition
Magnetic field	Region around a magnetic material or a moving electric charge within which the force of magnetism acts
Permanent magnets	Magnets that retain their magnetic effects
Permeability	Ease with which a material accepts magnetic lines of force
Temporary magnets	Magnets that do not retain their magnetic effects

Magnetic Materials

Ferromagnetic Materials

Magnetism is the property certain materials have that allows them to attract other magnetic materials. These are called ferromagnetic materials.

Natural Ferromagnetic Metals

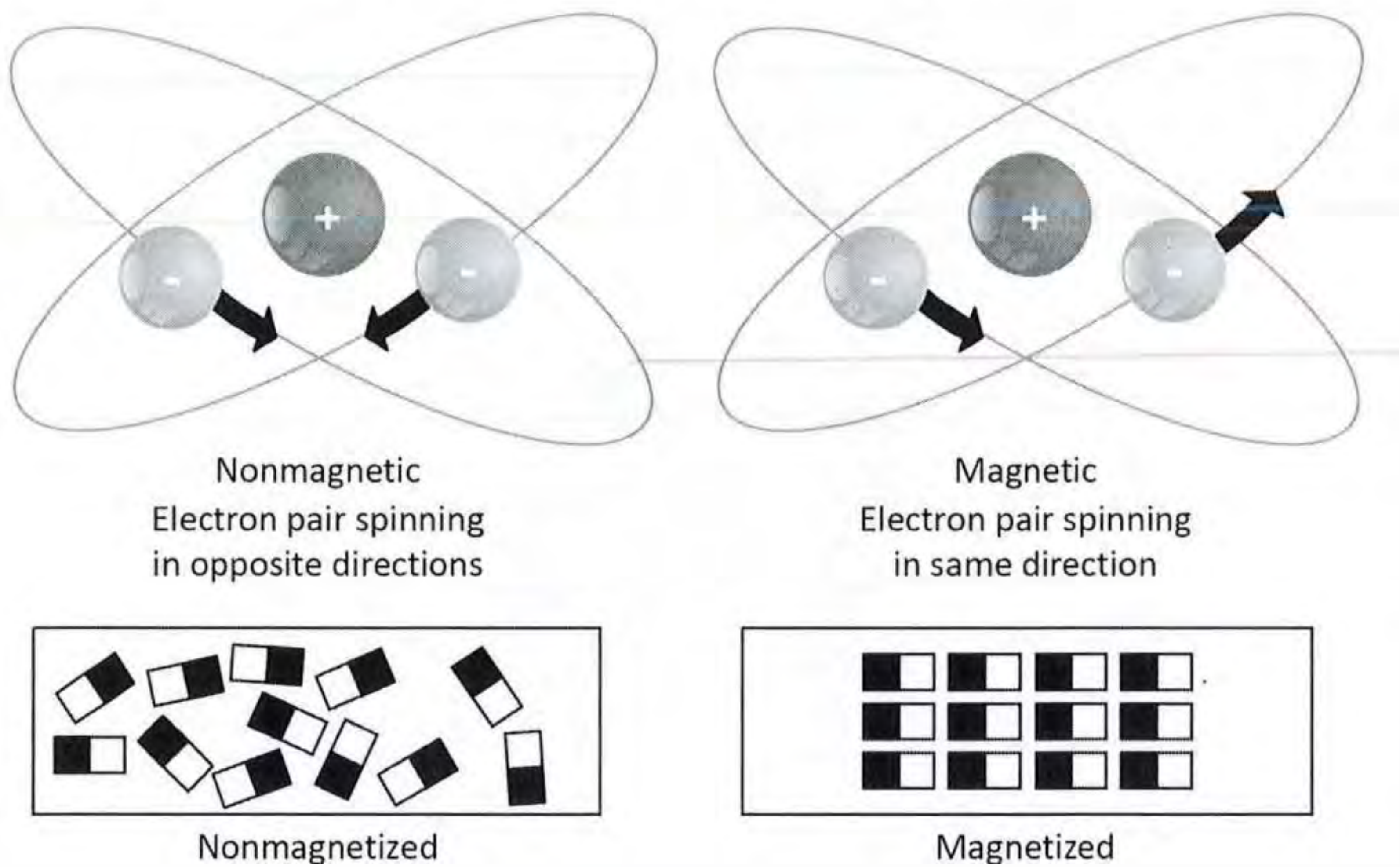
Iron, nickel, and cobalt are the only naturally occurring ferromagnetic metals. (Steel is ferromagnetic but is made from iron.)

Types of Magnets

Magnets that retain their magnetic effects are permanent magnets. Those that do not retain their magnetic effects are temporary magnets.

Electrons, Molecules, and Magnetism

Figure 4-1
Molecular alignment in a magnet



Electron Spin and Magnetism

Any conductor of electric current acts like a magnet. In fact, it is spinning electrons that cause magnetic forces.

In most atoms, electrons tend to pair off in orbits that have spins in opposite directions. Each spin produces a tiny magnetic field and the magnetic fields of these pairs cancel each other.

Magnetic Materials

In a magnetic material, electrons with similar spins can pair off. Their magnetic fields add together and the molecules of the material have a net magnetic field.

When a ferromagnetic material is not magnetized, its molecules are randomly oriented. Their magnetic effects work in different directions and cancel each other.

Magnetized Materials

Unmagnetized State

When a ferromagnetic material is not magnetized, its molecules are randomly oriented. Their magnetic effects work in different directions and cancel each other.

Magnetized State

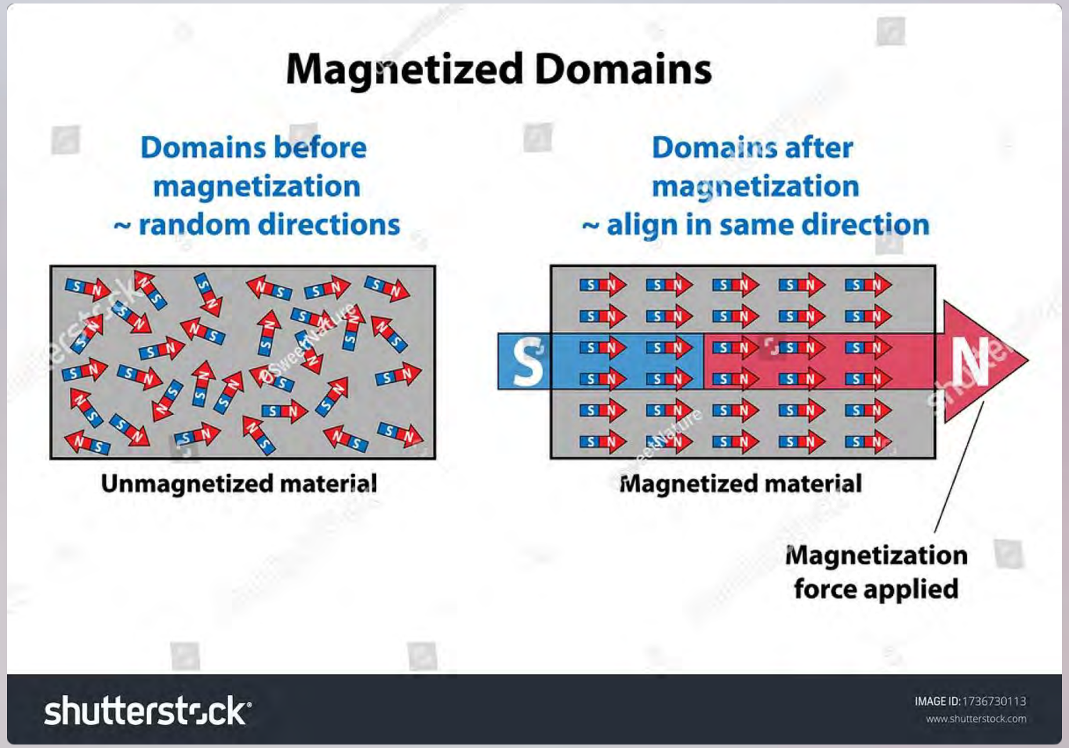
In a magnetized metal, the molecules are aligned with each other so that the magnetic effects of the molecules all work together. This produces a strong magnet.

Partially Magnetized

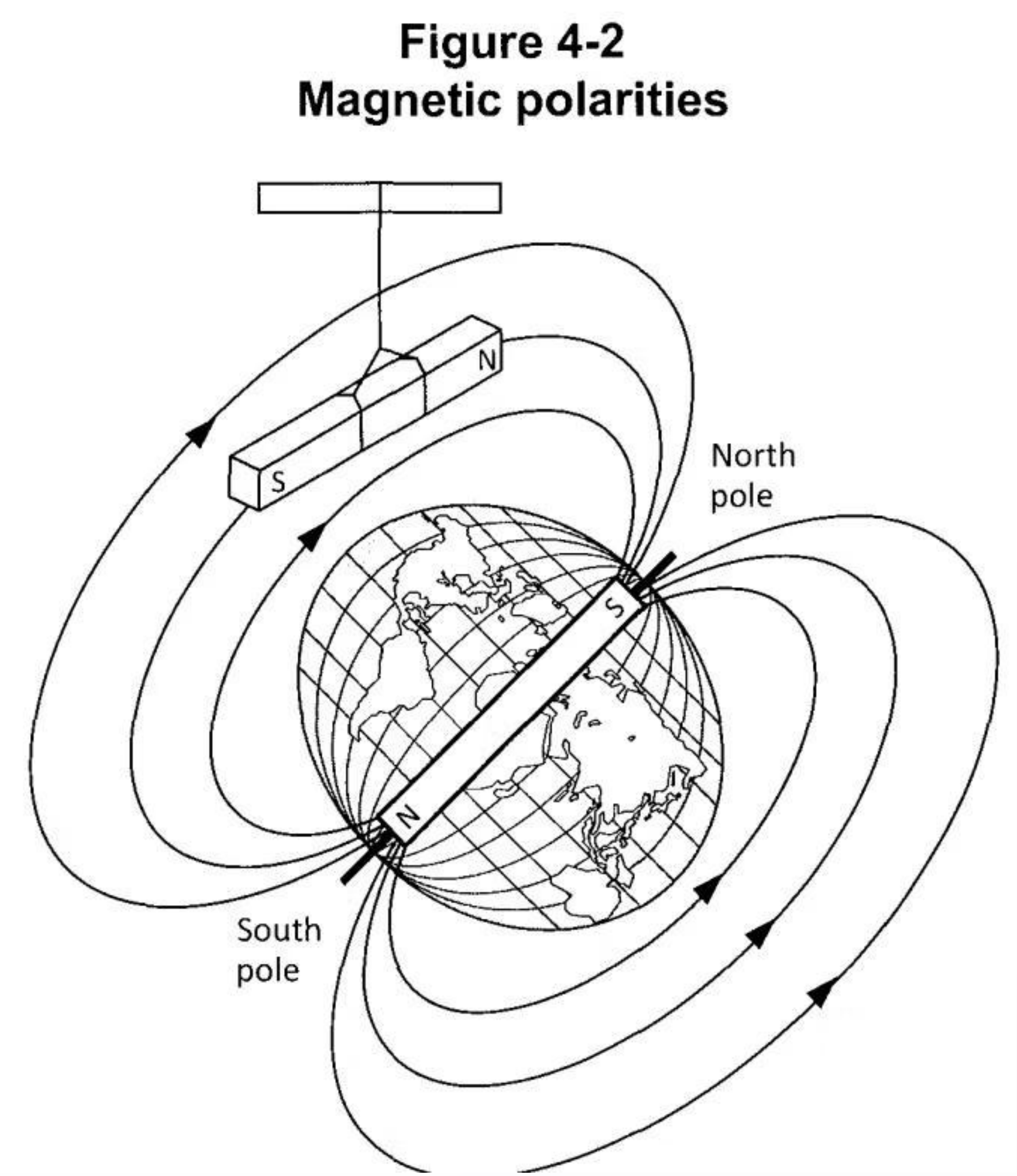
If a magnetic material is partially magnetized, only some of the molecules are aligned. This produces a weak magnet.

Losing Magnetism

If the molecules of a magnet become misaligned again, the material loses its magnetism. This can gradually happen. It can also happen if the magnet becomes very hot or receives a strong physical shock.



Magnetic Polarity

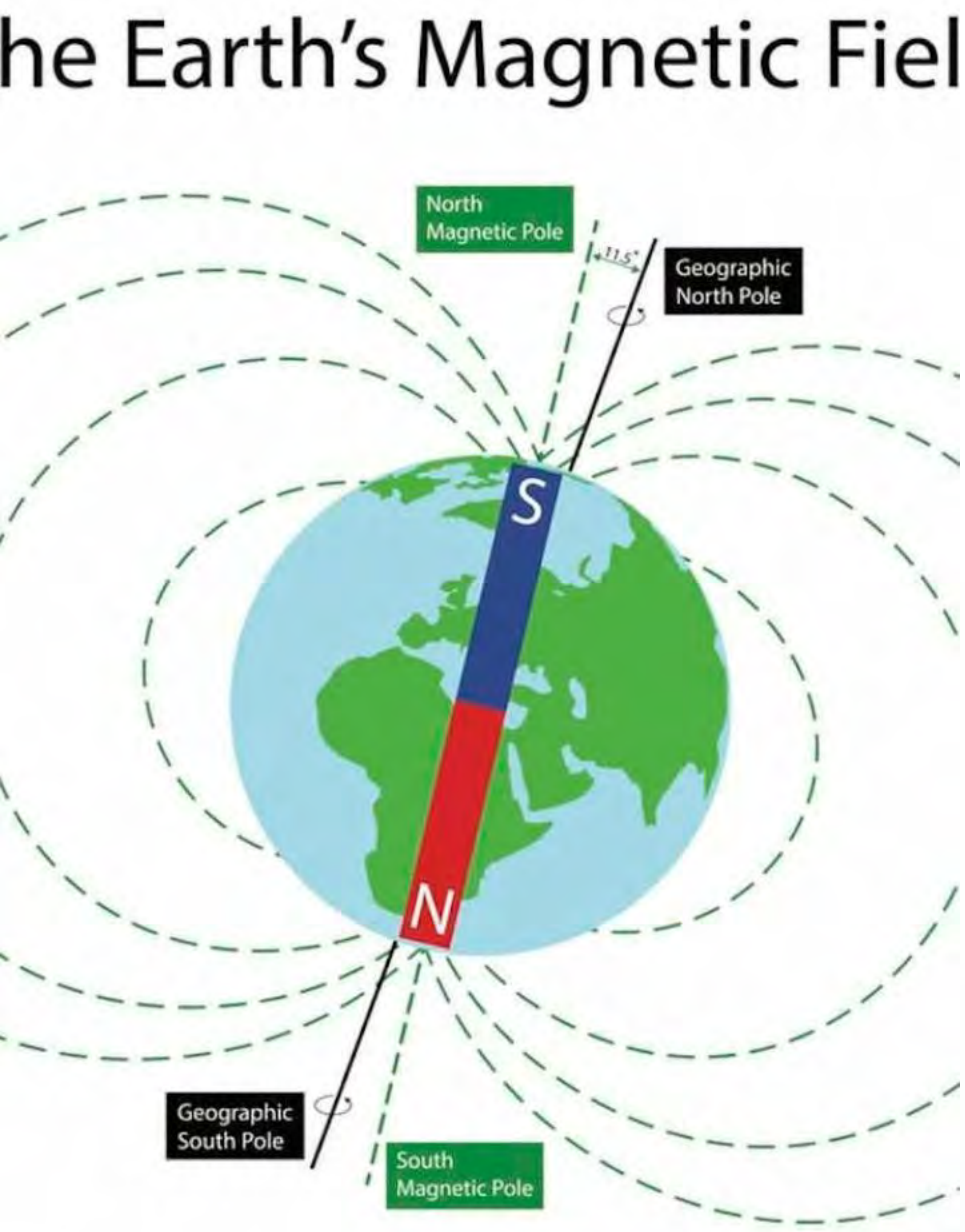


Magnetic Poles

The magnetic field is strongest at each end of a magnet. These ends are what you call the poles of the magnet.

North and South Seeking Poles

When you suspend a magnet so that it is free to move, it will turn so that one pole always points toward the Earth's North Pole.



Compass Operation

Compass Principle

The interaction of a magnet with the earth's magnetic effect is the operating principle of a compass. The needle of a compass is a small permanent magnet that indicates its north-seeking pole.

Compass Direction

Regardless of the direction towards which the compass turns, its needle always swivels to point north.

Law of Attraction and Repulsion

If the north poles of two magnets point toward each other, they repel each other. Two south poles also repel each other. On the other hand, a north and a south pole attract each other.

Like poles repel, unlike poles attract.

Magnetic Fields and Lines of Force

Magnetic Field Definition

A magnetic field consists of lines of force that interact with magnetic substances. The most common magnetic substances are iron and steel.

You can make iron magnetic but it will lose its magnetism quickly. Steel, on the other hand, remains magnetic for a longer period.

Permanent Magnets

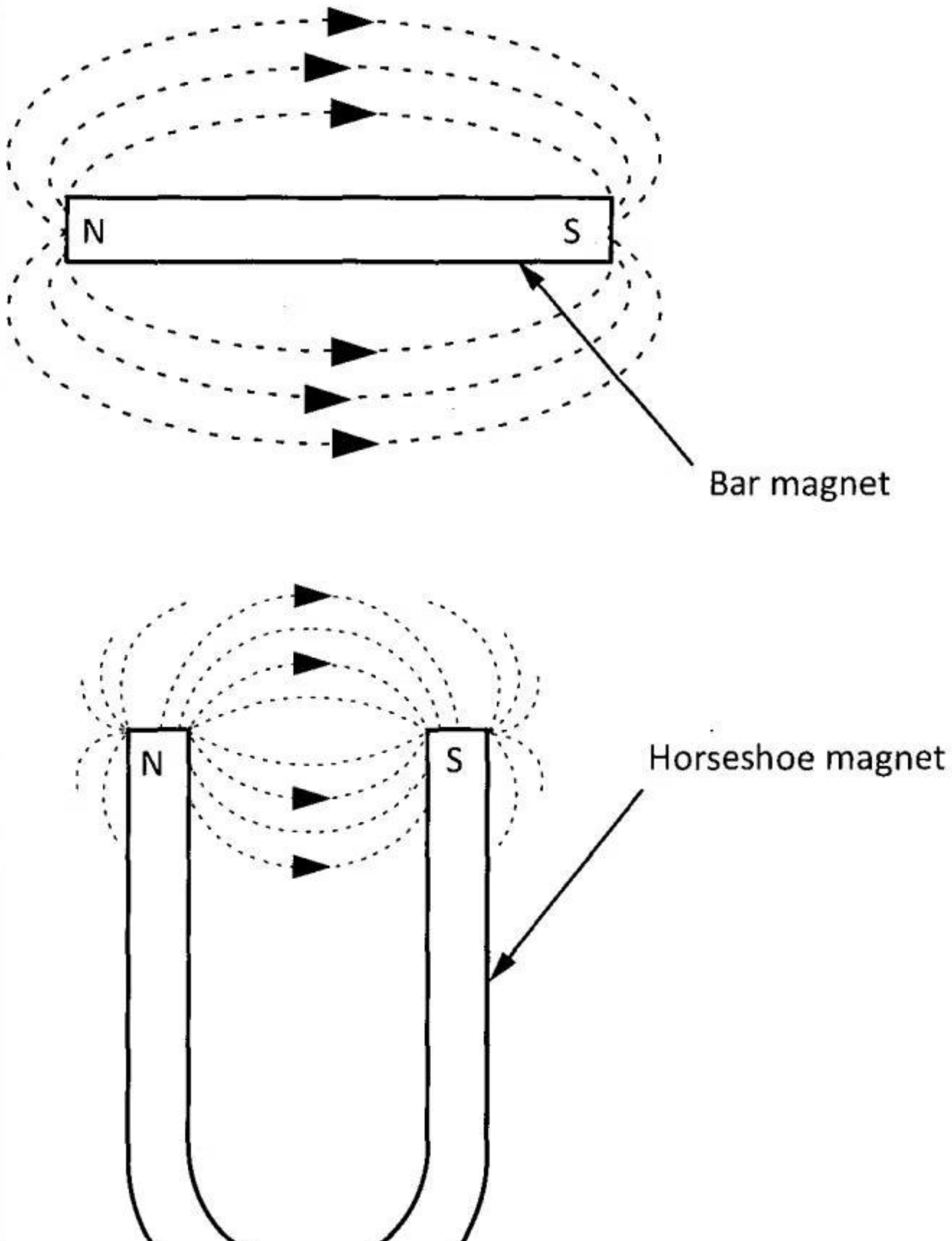
Magnetized metal bars are what you call permanent magnets. There are different types of permanent magnets:

- A bar magnet
- A horseshoe magnet

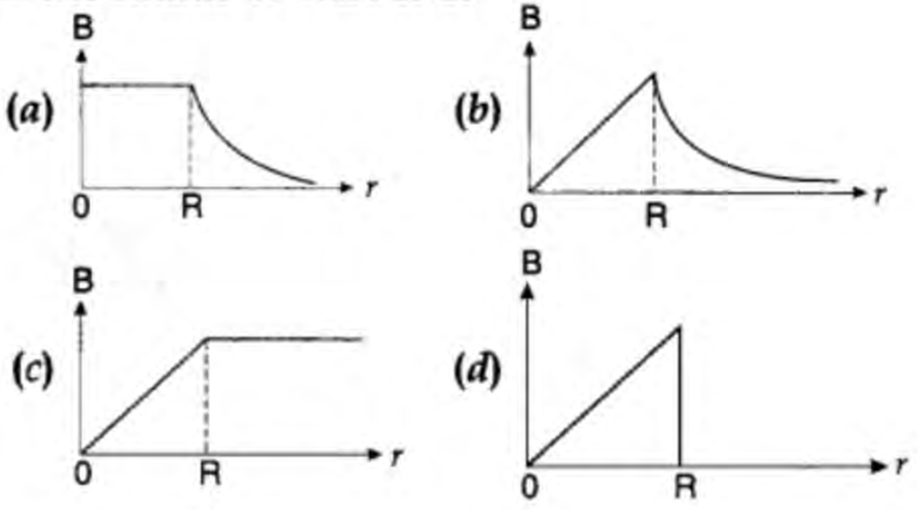
Permanent magnets appear to be ordinary pieces of steel. Even close observation will not reveal any visible signs of magnetism.

Types of Permanent Magnets

Figure 4-3
Magnetic fields



7. The correct plot of the magnitude of magnetic field $\vec{B}$ vs distance r from centre of the wire is, if the radius of wire is R



Magnetic Force and Fields

Action at a Distance

The magnetic force can act at a distance without contact. It can act in the magnetic field, the area that surrounds the magnet.

Lines of Force

In the magnetic field, the force acts in lines of force or flux lines.

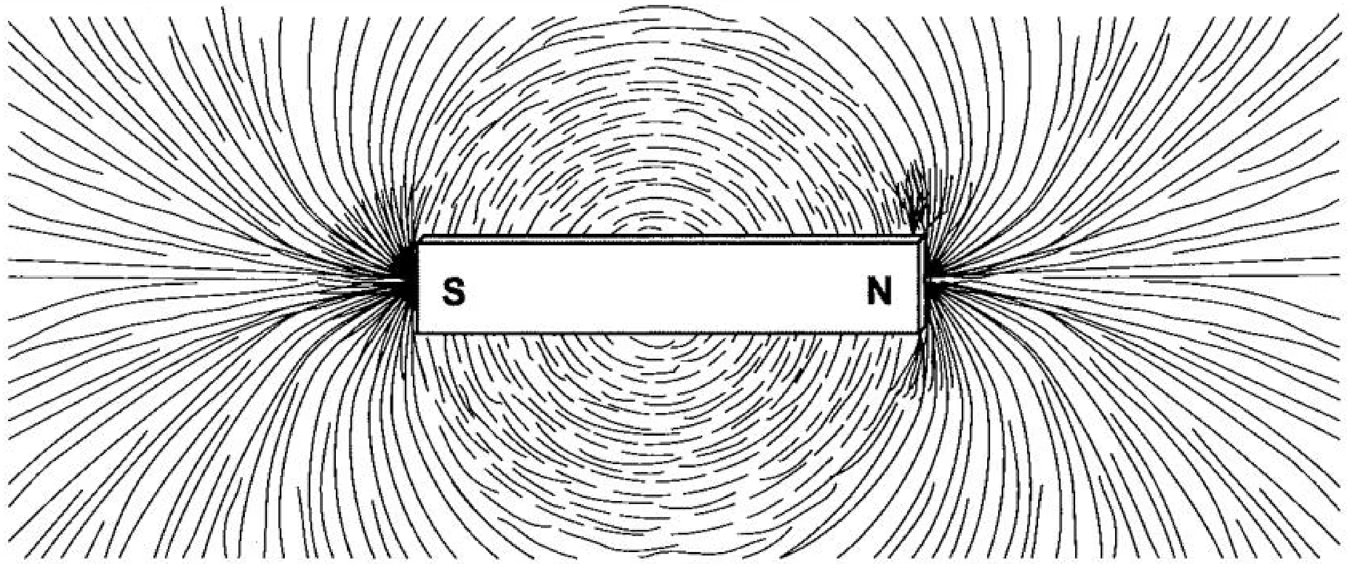
Affected Materials

The magnetic field will only affect magnetic material such as iron, steel, nickel, and cobalt.

Invisible Force

If you bring any iron or steel object close to the magnet, the invisible magnetic field will pull it toward the magnet.

Visualizing Magnetic Fields



Iron Filings Experiment

Although flux lines are not visible, you can see if you place a small magnet under a sheet of paper and sprinkle iron filings over the top of it.

When you tap the paper gently, the iron filings move slightly to align themselves along the flux lines.

Characteristics of Flux Lines

Notice that flux lines are:

- More concentrated at the two poles (the magnetic field and force is stronger here)
- Farther apart at greater distances from the magnet (the magnetic field and force is weaker here)
- Curved and do not cross

Permeability of Materials

Material	Relative Permeability
Copper	0.9999906
Silver	0.9999736
Lead	0.9999831
Air	1.00000037
Oxygen	1.000002
Aluminum	1.000021
Titanium 6-4 (Grade 5)	1.00005
Palladium	1.0008
Platinum	1.0003
Manganese	1.001
Cobalt	250
Nickel	600
Iron	280,000

Definition of Permeability

The ease with which a material accepts magnetic lines of force is what you call its permeability.

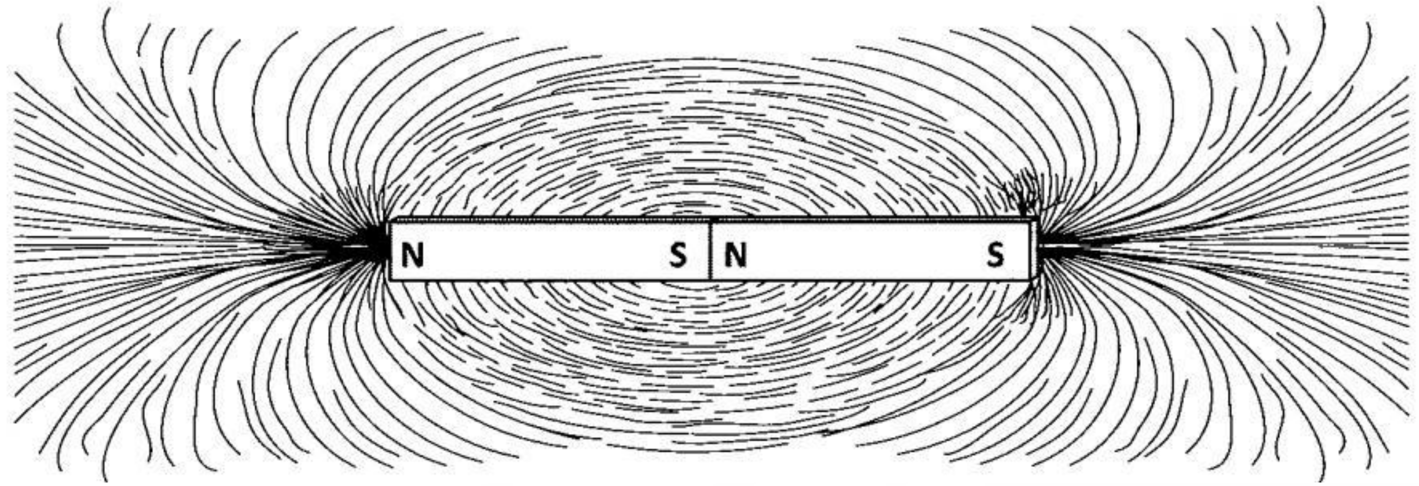
High Permeability Materials

Iron and steel have high permeability, meaning they readily accept magnetic lines of force.

Low Permeability Materials

Air, on the other hand, has low permeability, meaning it does not readily accept magnetic lines of force.

Interaction of Magnetic Fields



Combined Flux Patterns

When you bring together two magnets, their magnetic fields interact. You can clearly see the way the flux lines combine using iron filings.

Magnets always have north and south poles. The magnetic lines of force extend from the north pole of a magnet to the south pole.

Magnetic Attraction and Repulsion

The poles react with each other. If you bring two north or two south poles together, they will repel or push away each other.

If a north pole and a south pole come together, however, they will attract and stick together (like poles repel and unlike poles attract).

You use this magnetic field effect to operate electric motors, generators, and other devices.

Magnetic Strength and Flux Density

Varying Magnetic Strength

Some magnets are stronger than others. A stronger magnet pulls harder and is harder to separate from a magnetic substance.

Lines of Force

If you place a stronger magnet under the iron filings, more lines of force will show. The stronger the magnet, the more lines of magnetic force produced.

Flux and Flux Density

These lines are what you call flux, and their concentration is what you call flux density.

$$\boxed{\text{force} = \text{magnetic flux density} \times \text{current} \times \text{length}}$$

$$\boxed{F = B\,I\,l}$$

Direction of Flux Lines

Flux Direction Convention

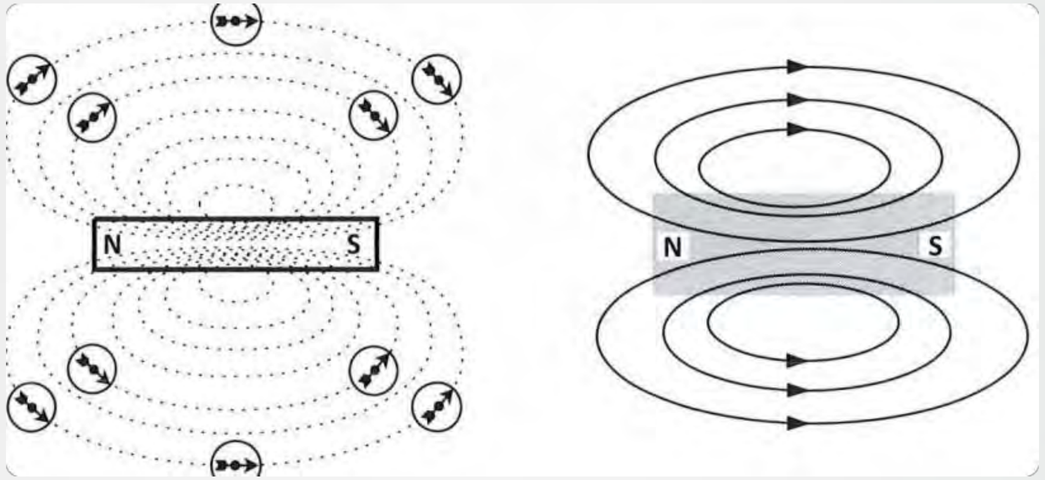
Lines of force are considered to emerge from the magnet's north pole and move toward the south pole. Diagrams show the direction using arrows.

Complete Magnetic Circuit

They travel from south to north within the magnet to form a closed loop.

Compass Indication

The direction of flux lines is the direction in which the north-seeking pole of a compass would point.



Principles of Basic Electromagnetism

Definition of Electromagnetism

Electromagnetism is magnetism that results from the movement of electrons.

Whenever current flows in a conductor, a magnetic field forms around the conductor.

Electromagnetic Induction

If you move a conductor within a magnetic field, the movement will induce a voltage and current will flow in the conductor.

Electric currents and magnetic fields are inseparable. In the area where current flows, there are always magnetic fields.

Characteristics of Electromagnets

Current Dependency

Electromagnets depend upon current flow for their magnetism. If current flow decreases, so does the magnetism.

Polarity Determination

The direction of current flow determines the polarity of the magnet.

On/Off Capability

If the current is turned off, the electromagnet is no longer magnetic.

Electromagnetism in a Straight Wire

Figure 4-7
Using a compass near a conductor to show the presence of a magnetic field and its polarity

Compass Detection

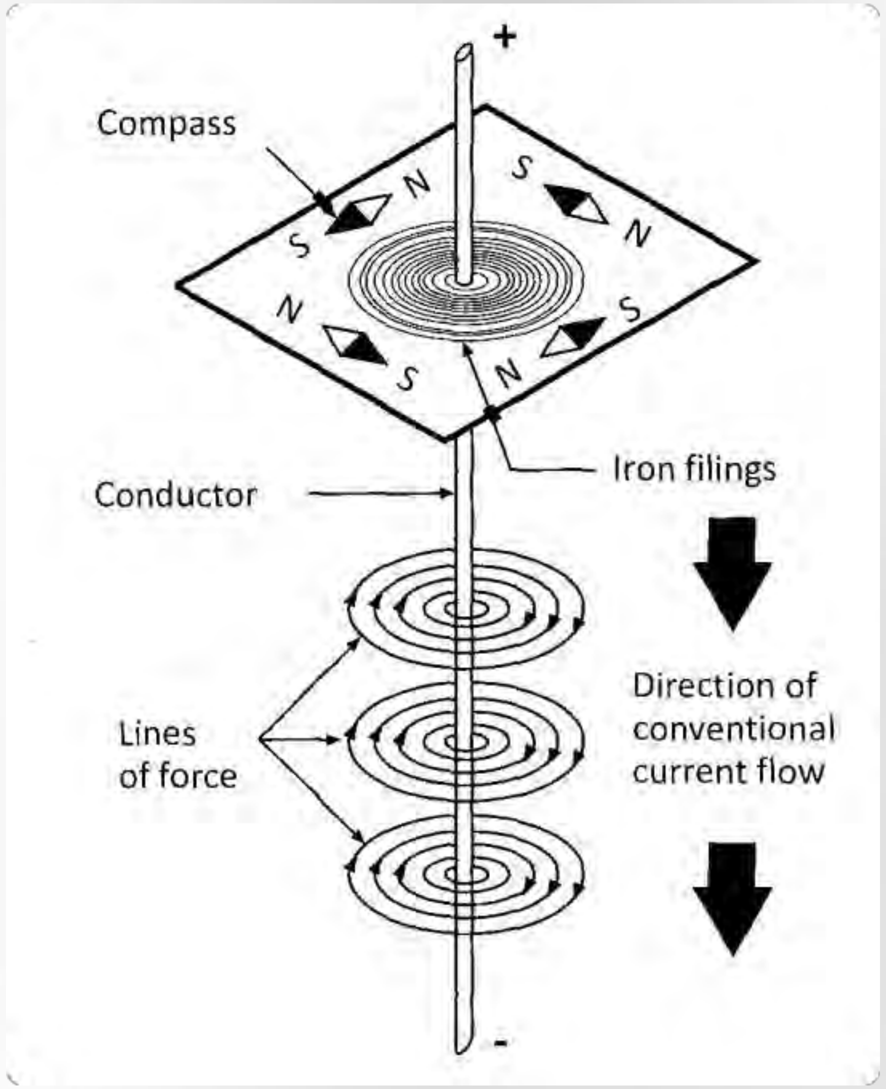
If you move around a compass near a straight wire conductor, it shows the presence and direction of a magnetic field.

The flux lines encircle the wire.

Current Direction Effect

If the direction of current flow changes, the direction of the magnetic field also changes.

You use a simple rule to work out the direction of the magnetic lines of force around a wire.



The Right-Hand Rule

Determining Magnetic Field Direction

Imagine grasping the wire with your right hand. If your thumb points in the direction of conventional current flow, your fingers wrap around the wire in the direction of the magnetic lines of force.

Right-Hand Rule Application

This simple technique allows you to predict the direction of the magnetic field around any current-carrying conductor.

Practical Importance

Understanding the relationship between current direction and magnetic field direction is crucial for designing and troubleshooting electromagnetic devices.

Magnetic Forces Between Conductors

Figure 4-9
Forces of magnetic attraction and repulsion between conductors

Same Direction Current

If the current is flowing in the same direction, the magnetic lines of force around the wires would be in opposition and the two wires would attract each other.

Opposite Direction Current

If the current is flowing in opposite directions, the magnetic lines of force around the wires would be similar and the two wires would oppose each other.

High Current Risks

When very large currents can flow through conductors, the resulting magnetic forces can damage the conductors.

Electromagnetism in a Coil of Wire

Concentrated Magnetic Field

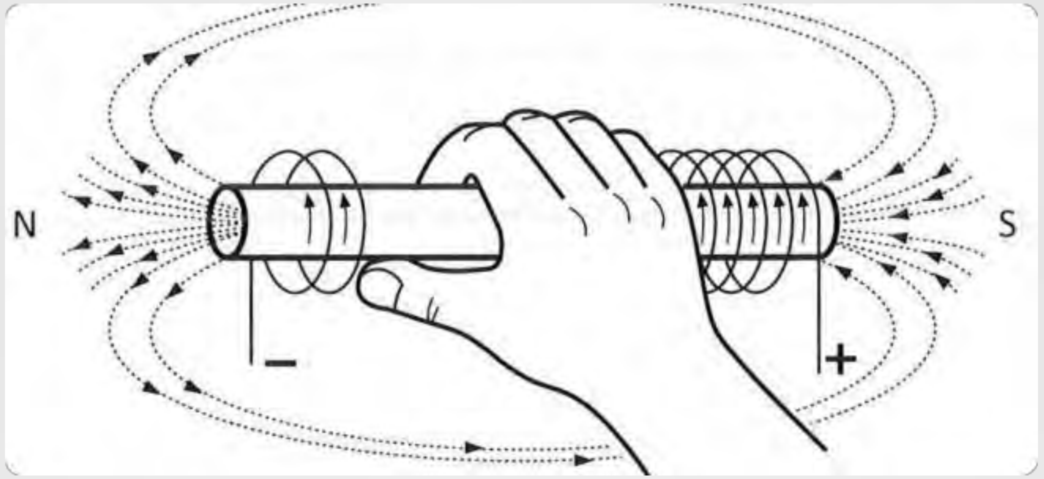
If a wire is coiled in a spiral (helically), the magnetic field is concentrated in the centre of the coil.

Steel Core Enhancement

If you have wound the wire around a steel bar, the resulting magnet can be very strong.

Field Shape

The shape of the magnetic field of a coil is like a large bar magnet. The lines of force leave the north pole at one end of the coil and pass toward the south pole at the other end.



Right-Hand Rule for Coils

Finding Coil Polarity

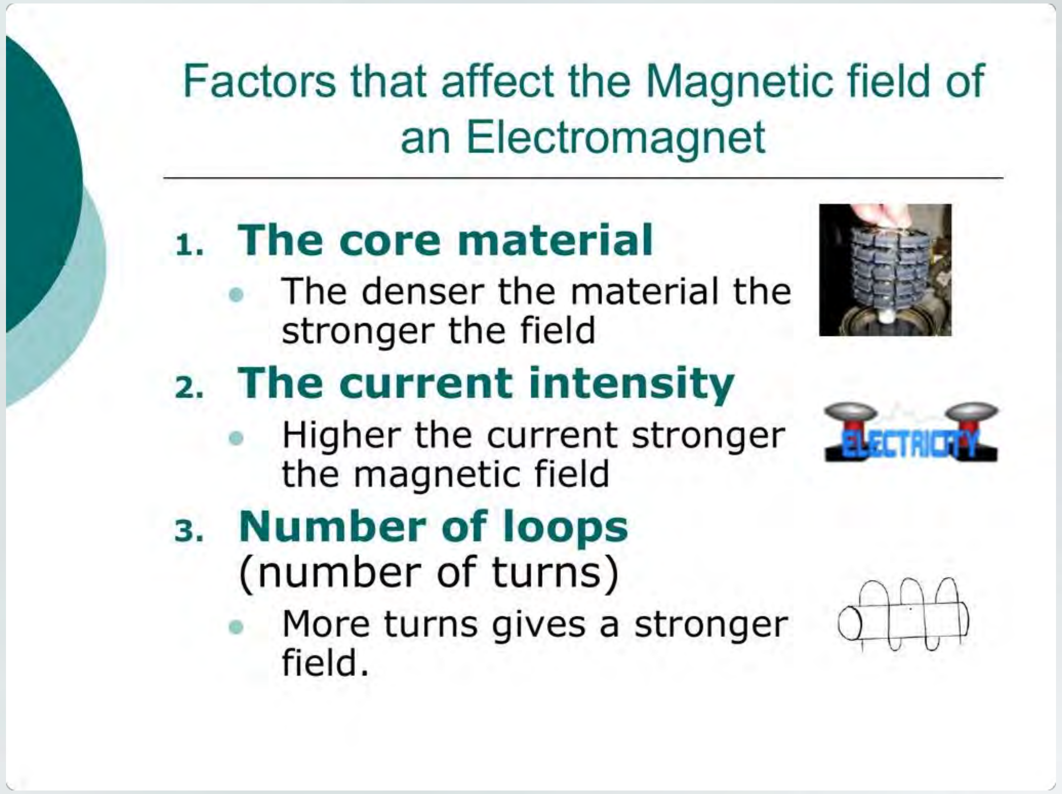
You can use another right-hand rule to find the direction of the magnetic field of a coil.

Application Method

Imagine grasping the coil with your right hand: If the fingers wrap in the direction of conventional current flow around the coil, the thumb then points in the direction of the north pole of the coil.

Practical Use

This rule helps determine which end of an electromagnet will be the north pole and which will be the south pole based on the direction of current flow.



Strength of a Coil's Magnetic Field

Coil Winding Density

A closely wound coil creates a stronger magnetic field.

Core Material

Because the permeability of iron is much higher than air, permanently placing an iron or steel core inside the wire coil makes the magnetic field of a coil even stronger.

Current Magnitude

Increasing the current flowing through the coil increases the strength of the magnetic field.

Number of Turns

More turns in the coil result in a stronger magnetic field for the same current.

Making an Electromagnet

Core Selection

Using an iron core in a coil is the basis for making an electromagnet. A coil is wound around a core of steel with a low carbon content (or iron).

This has high permeability but does not retain much magnetism after the current stops flowing, removing the magnetic field.

Applications of Electromagnets

You use various sizes of electromagnet in many ways in the home and in industry. You use them in:

- Motors
- Generators
- Clocks
- Voltage testers
- Solenoid and relay Units in control circuits
- Cranes for lifting scrap metal, etc.

Electricity and Magnetism

Inseparable Relationship

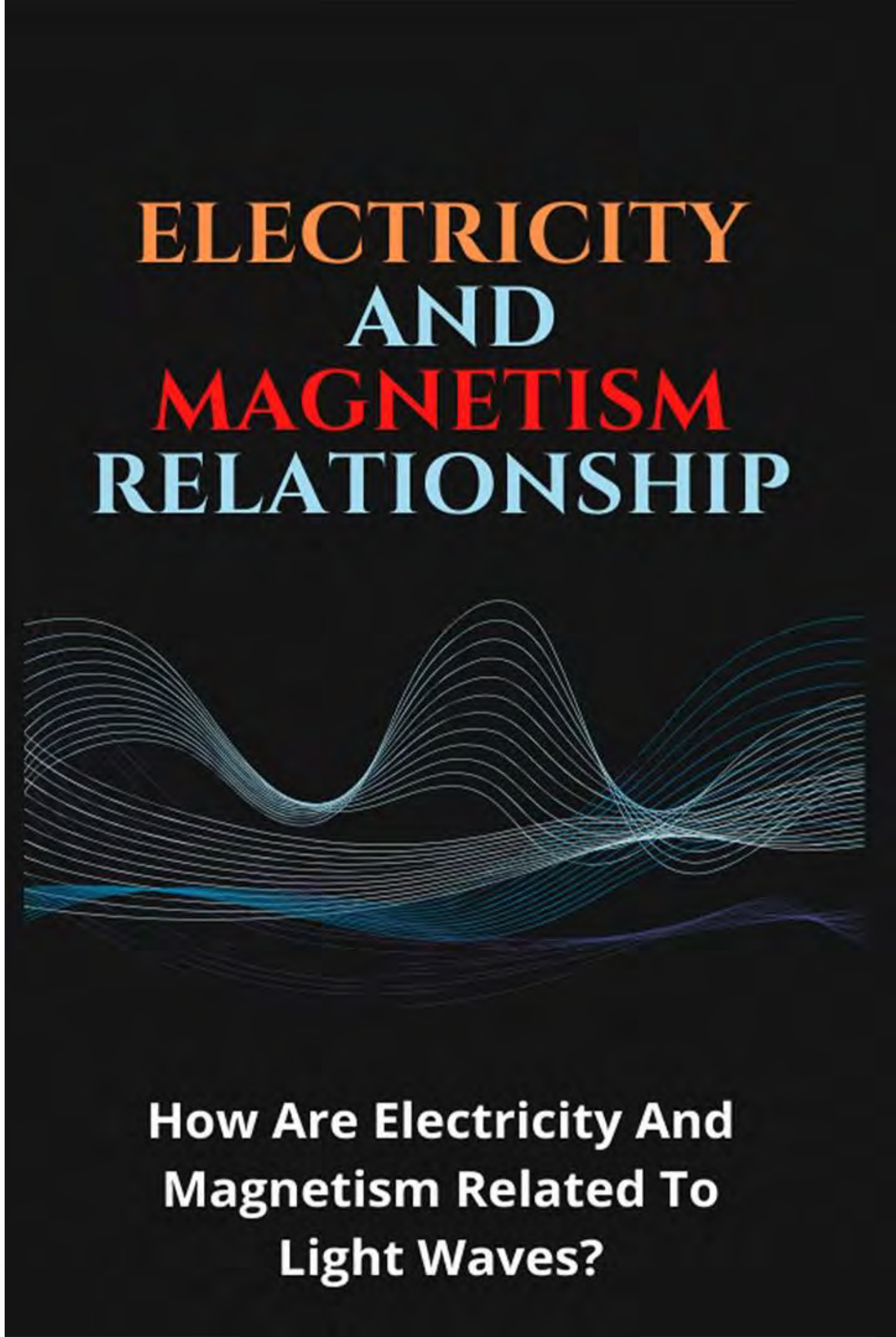
Magnetism and electric current are inseparable. The flow of current through a conductor (wire) produces a magnetic field around that conductor.

Direct Current Effects

If the electric current flow is constant, as with DC current, the magnetic field is constant, and the product is a magnet.

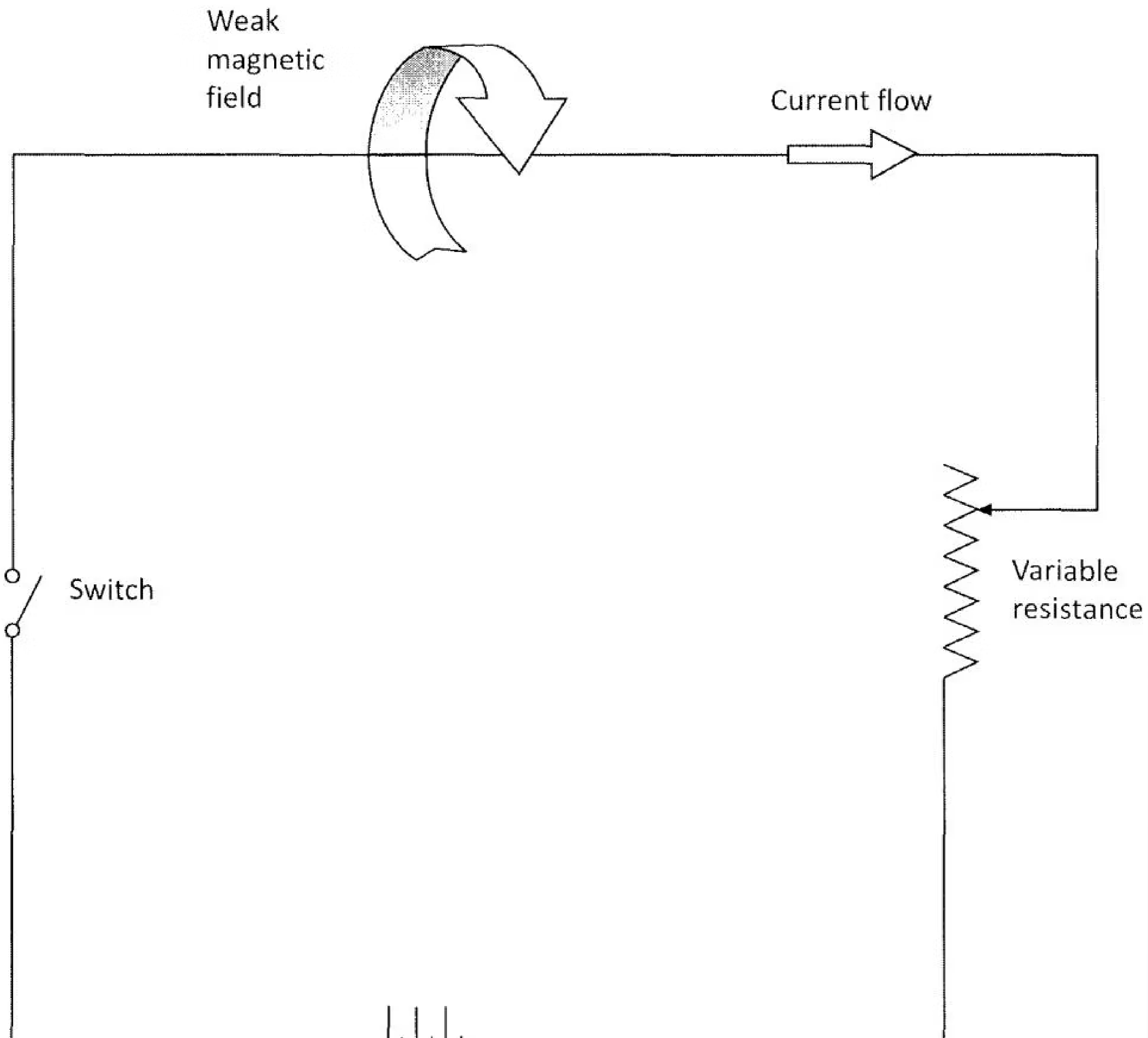
Alternating Current Effects

With alternating current, the magnetic field changes direction every time that the current flow changes direction.



Current Flow and Magnetic Field

Figure 4-11
Induced magnetic fields



Current Magnitude and Magnetic Field Strength

Circuit Activation

When the switch is closed, current begins to flow through the circuit.

Resistance Adjustment

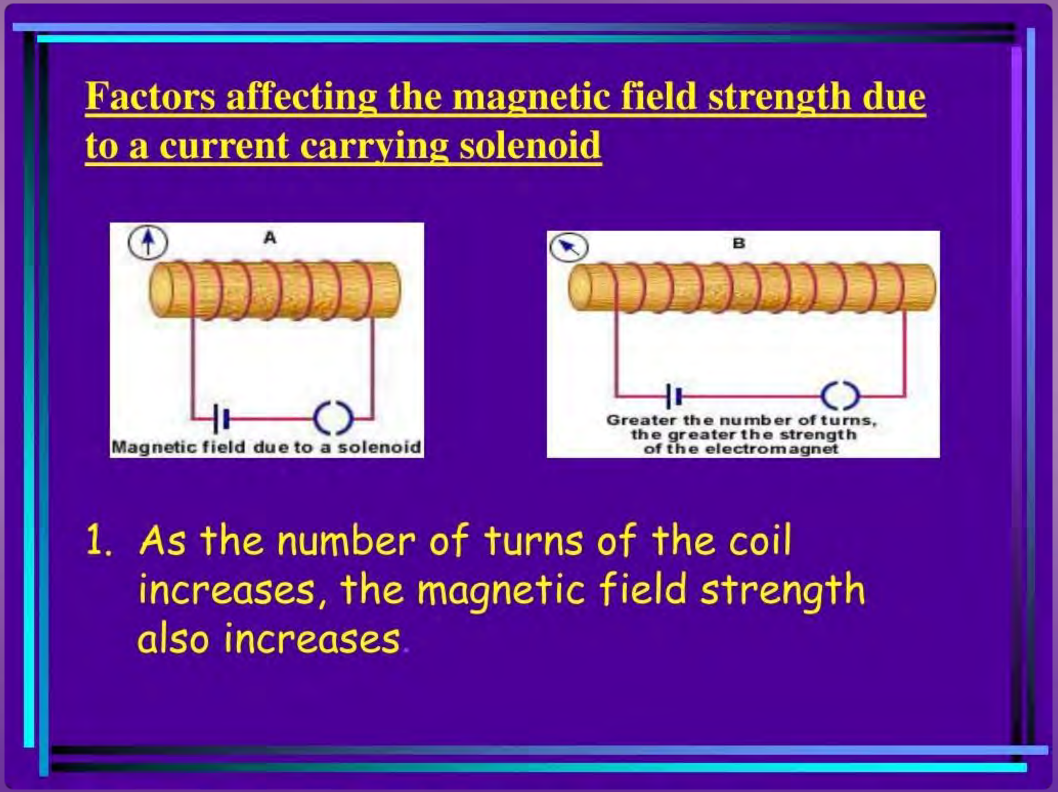
If the switch is closed and the variable resistance adjusted, the current flow will change.

Increasing Current

As the resistance lowers, the current flow increases.

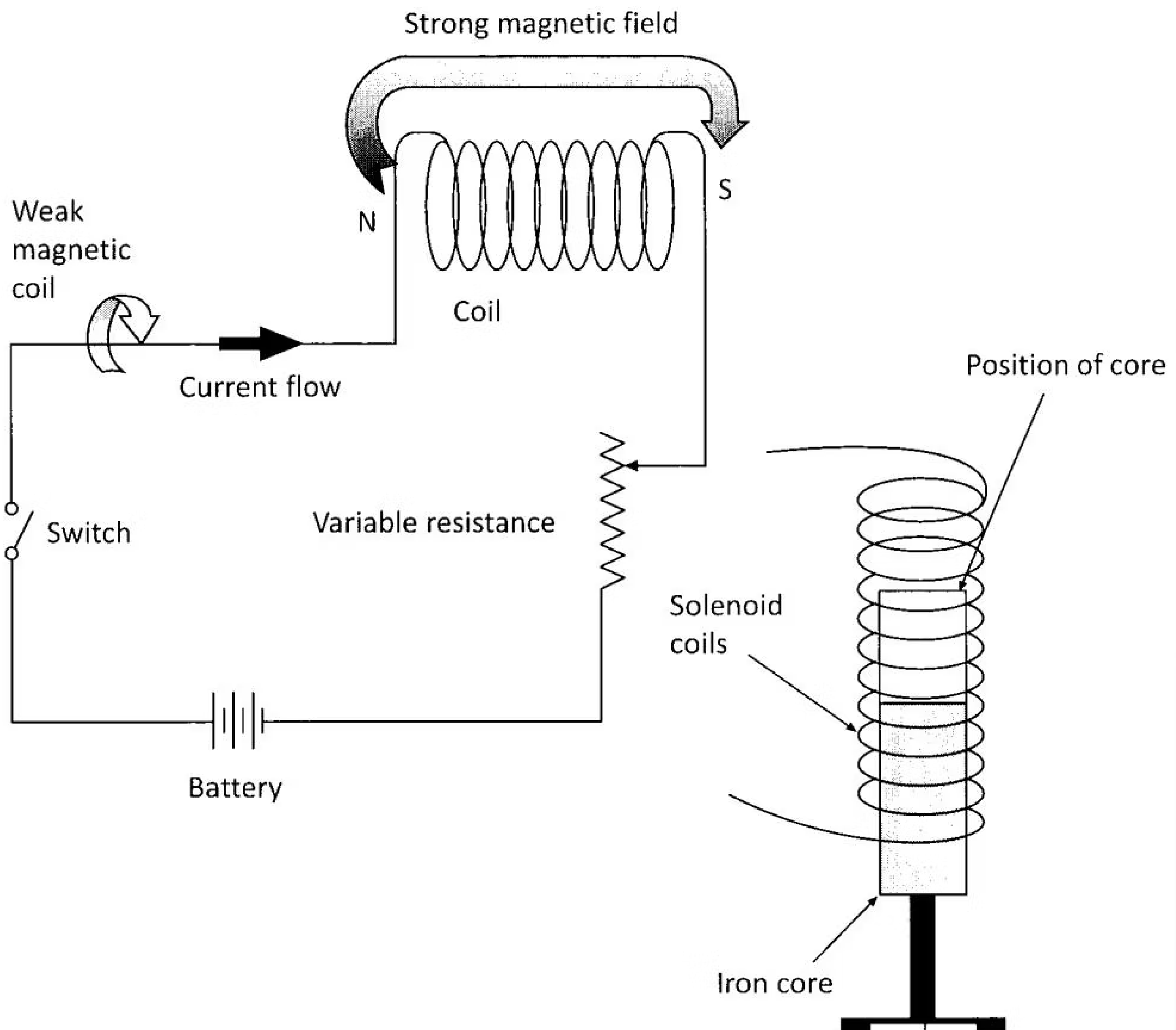
Magnetic Field Strengthening

When the current flow increases, the magnetic field surrounding the wire strengthens.



Coiled Wire and Electromagnets

Figure 4-12
Magnetic coils



Combined Magnetic Fields in Coils

1 Individual Wire Contribution

Each wire in the coil carries the current flow through it. Therefore, each loop of the coil generates a small magnetic field around itself.

2 Field Alignment

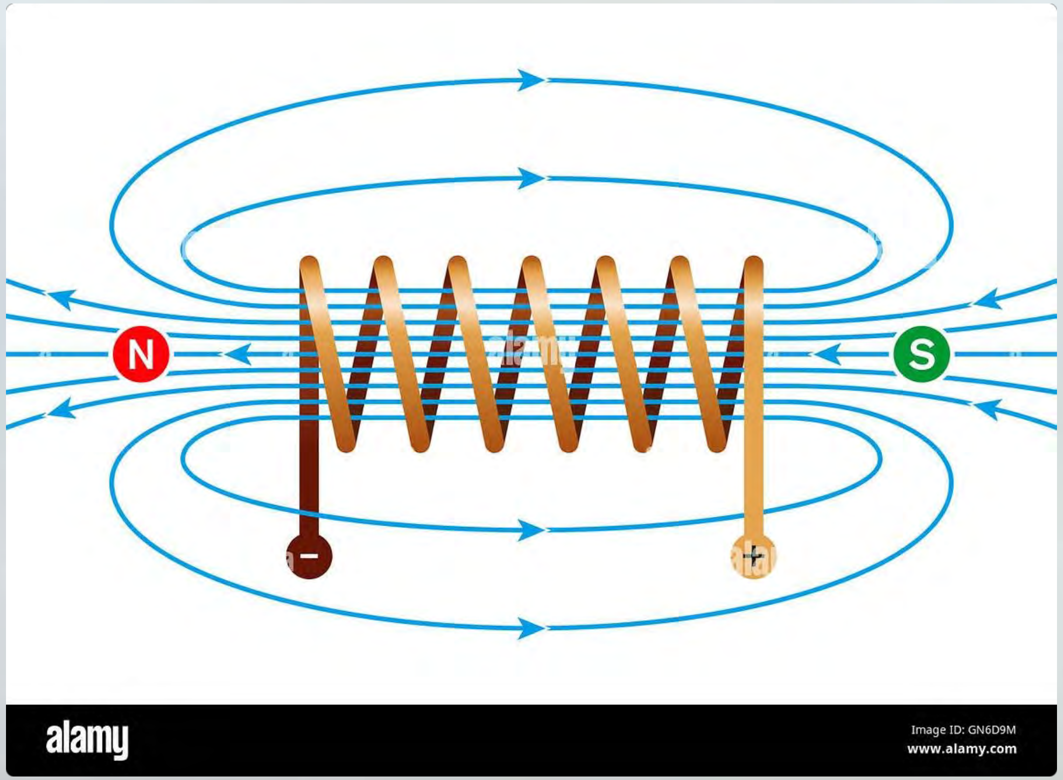
Since the electric current flows in the same direction through each loop, the magnetic field around each wire extends in the same direction.

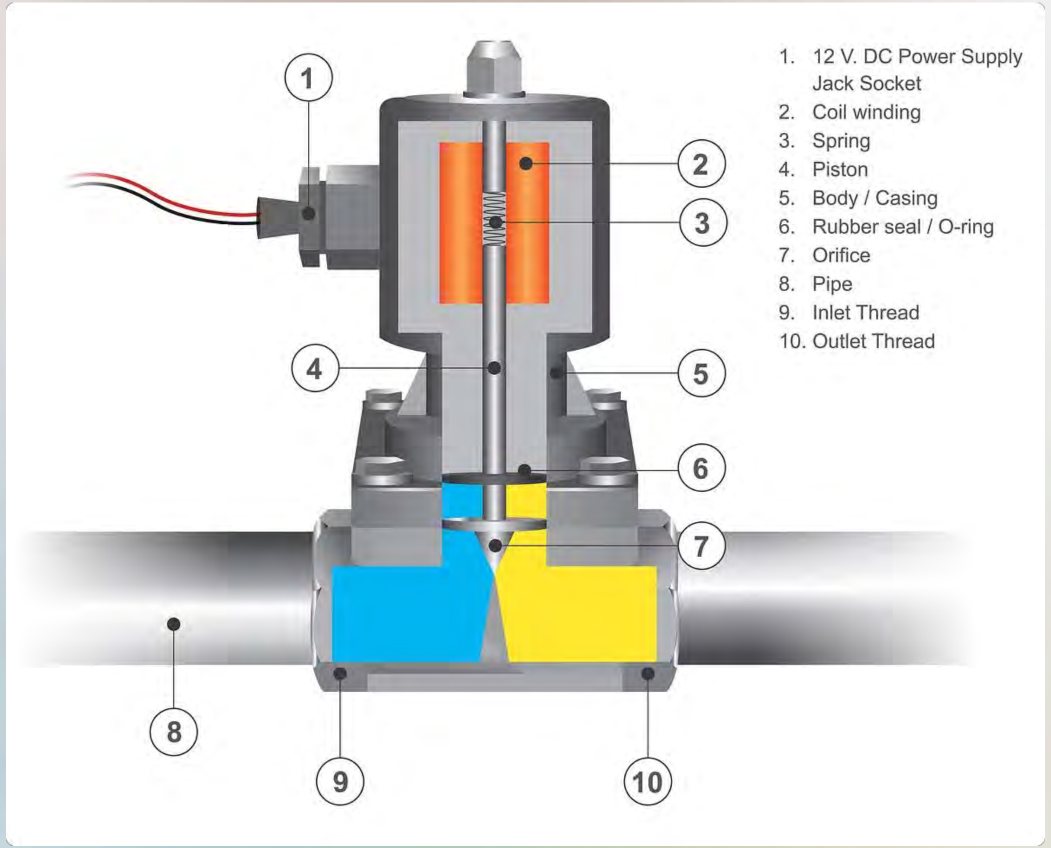
3 Combined Effect

These small magnetic fields combine to produce a single, larger field. The strength of the larger field depends on the number of loops in the coil.

4 Strengthening Methods

You can strengthen a magnetic field by increasing the applied voltage or by increasing the number of loops in the coil.





Solenoid Operation

Coil with Iron Plunger

If you place a magnetic plunger, such as a soft iron bar, inside a coil of wire in a DC circuit.

Circuit Activation

When the switch is closed, current flows through the coil.

Magnetic Field Generation

The current flow produces a magnetic field within and around the coil.

4

Plunger Movement

The magnetic field produced will attract the iron bar, pulling it to the centre of the coil.

Solenoid Applications

Motor Contactors

Solenoids are used in motor contactors to mechanically connect or disconnect electrical circuits, allowing for remote control of motors.

Solenoid Valves

In fluid control systems, solenoid valves use electromagnetic force to control the flow of liquids or gases through pipes and tubes.

Relays

Electromagnetic relays use solenoids to open or close electrical contacts, allowing a low-power circuit to control a high-power circuit.

Magnetic Permeability in Coils

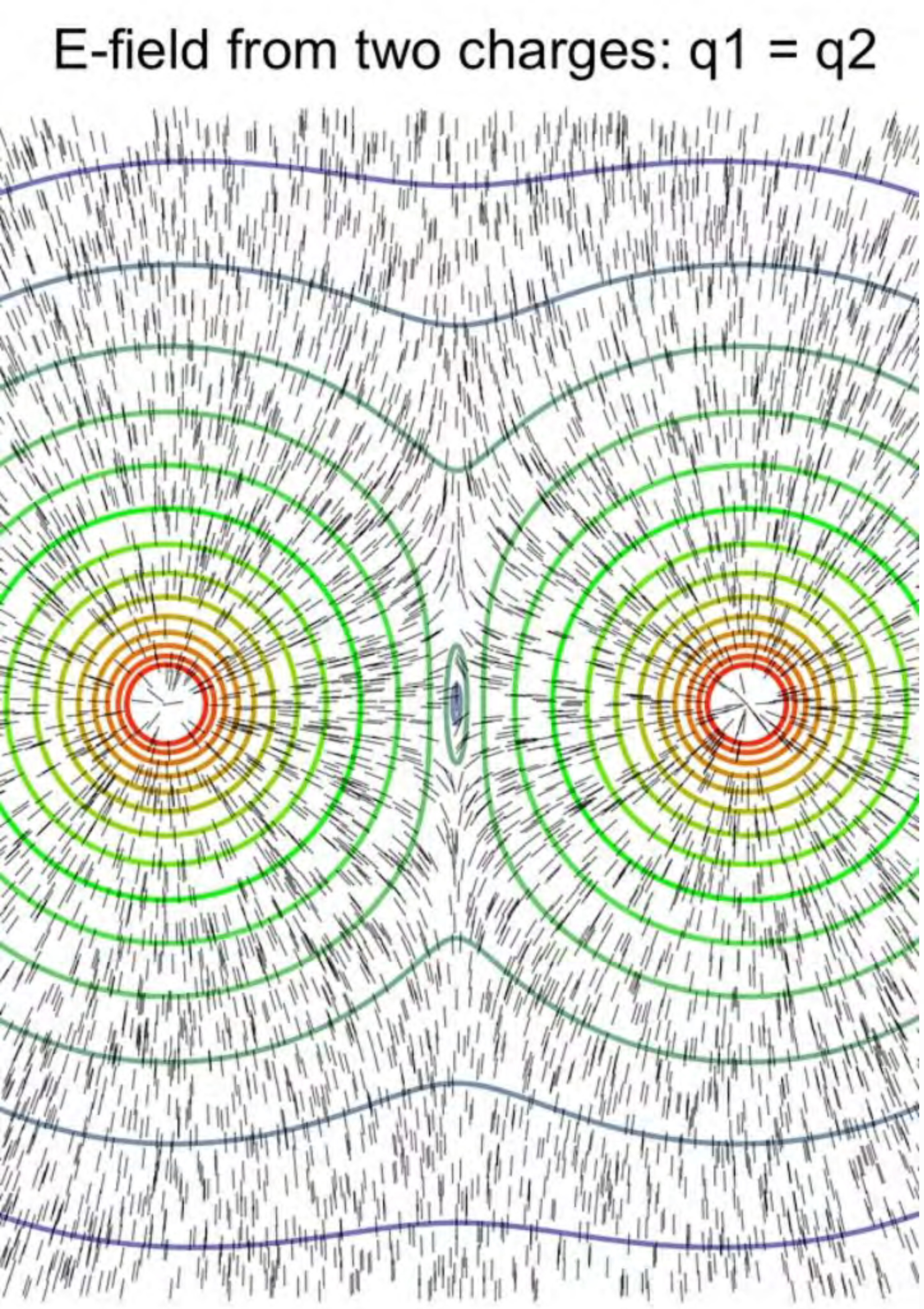
Magnetic Circuit Analogy

A magnetic field is a bit like an electric circuit. Magnetic lines pass through a magnetic conductor better than through a magnetic insulator.

Air vs. Iron Core

Air has a high magnetic resistance. For that reason, an air-filled coil will not produce as strong a magnet as a coil that is wrapped around an iron core.

Iron is a better conductor of magnetism and is said to be more permeable.



AC Current and Magnetic Fields

Universal Magnetic Effect

Electric current flow through any conductor produces a magnetic field around the conductor. This is true for alternating current as well as for direct current.

Alternating Field Direction

With alternating current, however, the magnetic field changes direction every time that the current flow changes direction.

Mechanical Effects

The rapid switching of magnetic fields can cause vibration in AC electric machines. This explains why some machines, such as transformers, sometimes hum as the iron parts vibrate.

Magnetic Relay

Relay Structure

A magnetic relay consists of an electromagnet (coil) and a set of electrical contacts that can be opened or closed by

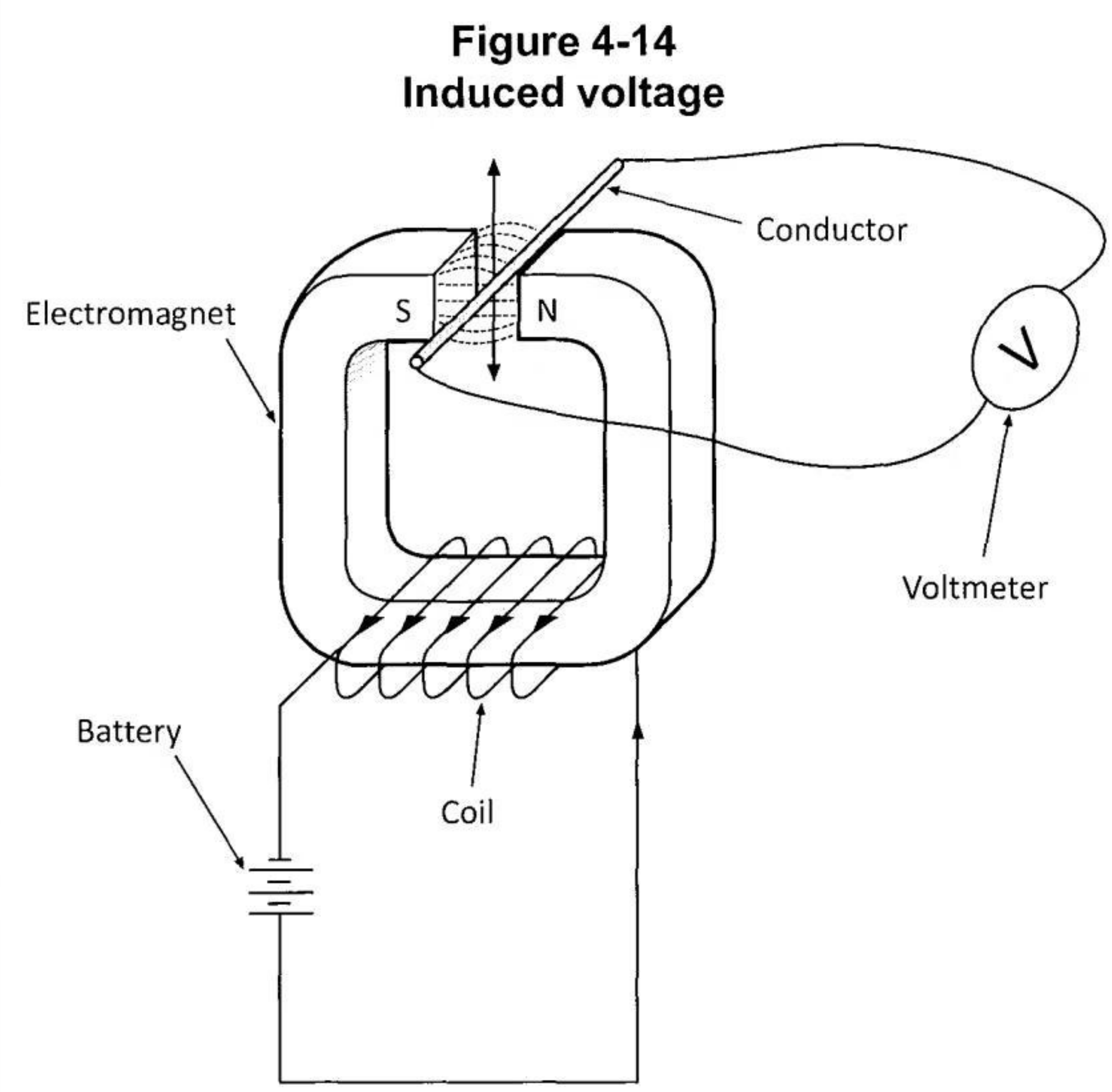
Operation Principle

When current flows through the coil, it creates a magnetic field that attracts a movable armature, which in turn

Applications

Relays are used in control circuits to allow a low-power signal to control a higher-power circuit, providing electrical

Electromagnetic Induction

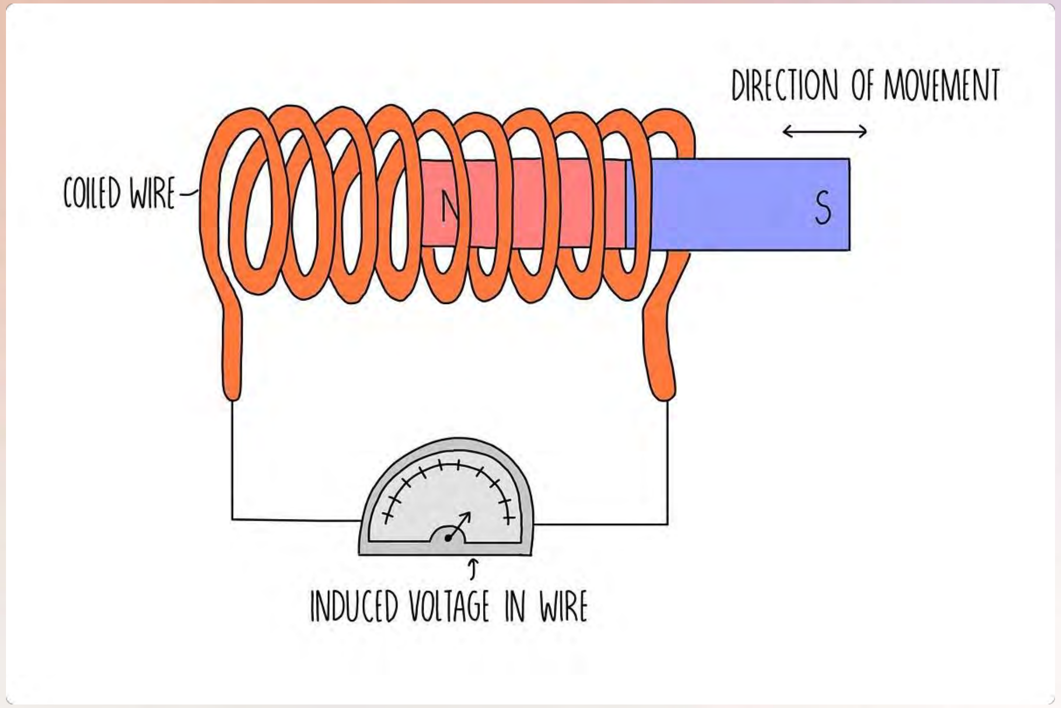


Reciprocal Relationship

As mentioned previously, the flow of an electric current flows through a conductor produces a magnetic field around that conductor.

U-Shaped Electromagnet Example

Figure 4-14 shows a u-shaped electromagnet. The supply of direct current to the coil around the iron core produces an electromagnet.



Factors Affecting Induced Voltage

Voltage Magnitude

The voltage generated is very small, but is measurable with a sensitive meter.

Flux Line Cutting

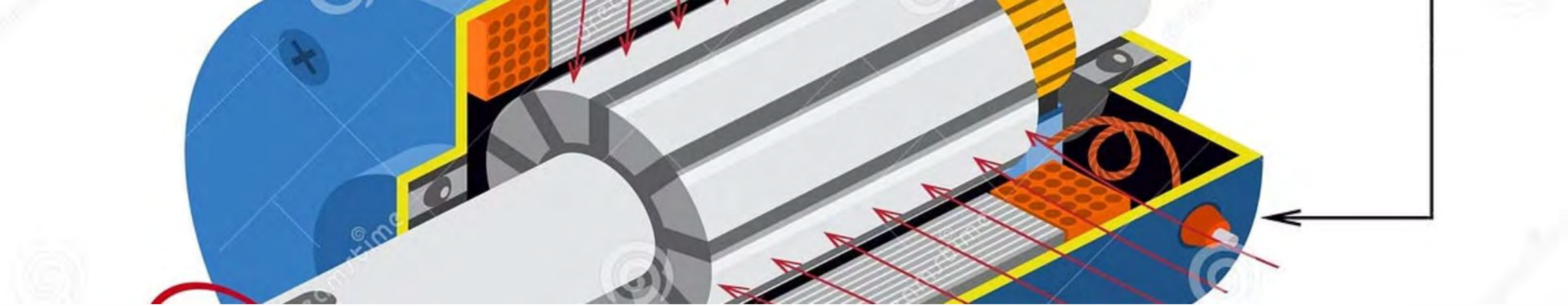
The voltage generated depends on the number of lines of flux that the conductor cuts every second and on the angle at which the conductor cuts the flux.

Speed Effect

The faster the movement of the conductor, the greater the voltage produced.

Flux Density Effect

Increasing the concentration of magnetic flux lines (flux density) increases the induced voltage, with the conductor moving at a constant speed.



Power Generation Application

Industrial Scale Application

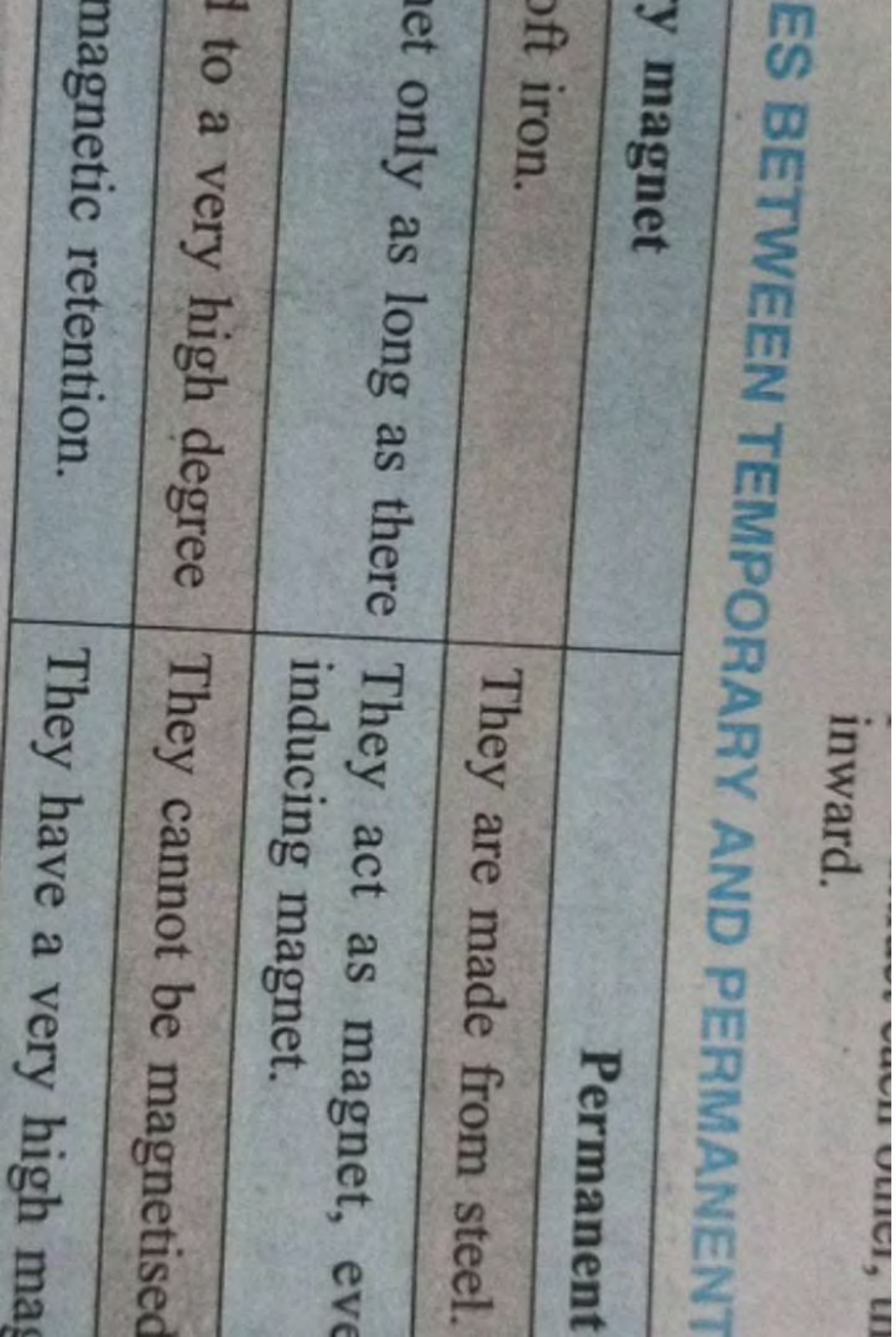
You use the same principle to generate large amounts of electric energy in power stations.

Generator Operation

In power stations, large generators use powerful electromagnets and rapidly rotating conductors to produce electricity on an industrial scale.

Energy Conversion

This process converts mechanical energy (from steam turbines, water turbines, or wind turbines) into electrical energy through electromagnetic induction.



Types of Magnets Comparison

Characteristic	Permanent Magnets	Temporary Magnets	Electromagnets
Retention of magnetism	Retain magnetism indefinitely	Lose magnetism quickly	Only magnetic when current flows
Materials	Special steel alloys, rare earth metals	Soft iron	Wire coil with iron core
Strength control	Fixed strength	Fixed strength	Variable (by changing current)
Polarity	Fixed	Fixed	Reversible (by changing current direction)

Magnetic Field Visualization Methods

Iron Filings

Sprinkle iron filings on paper placed over a magnet to see the pattern of magnetic field lines.

Compass Needle

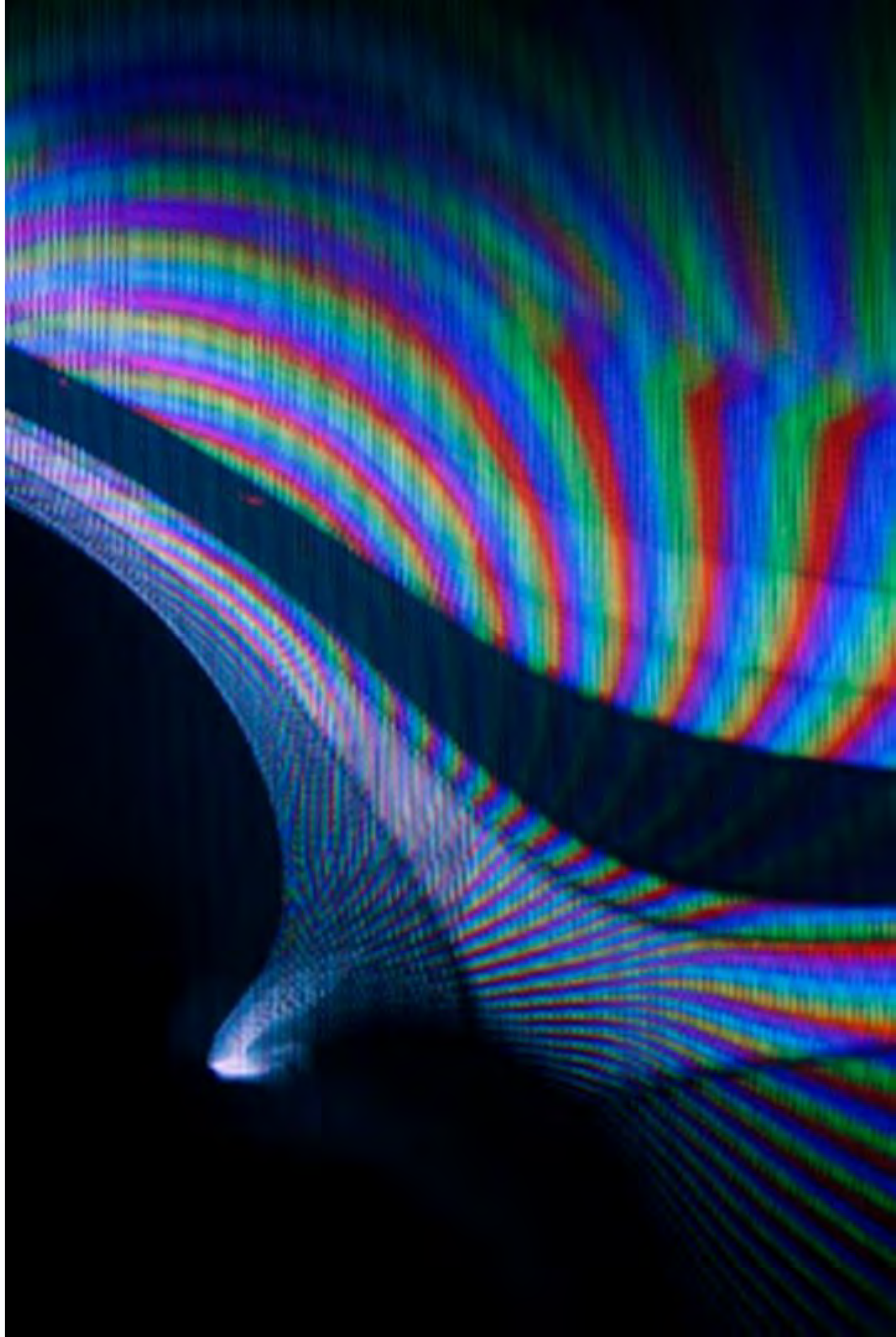
Use a small compass to trace the direction of magnetic field lines around a magnet or current-carrying conductor.

Magnetic Field Sensors

Electronic devices that can measure the strength and direction of magnetic fields at various points.

Ferrofluid

A liquid containing suspended magnetic particles that forms spikes along magnetic field lines.



Applications of Electromagnets

Electric Motors

Electric motors use electromagnets to convert electrical energy into mechanical motion. The interaction between the magnetic fields of stationary electromagnets and rotating components creates rotational force.

Lifting Cranes

Industrial cranes use powerful electromagnets to lift and move ferromagnetic materials like scrap metal. The magnetism can be turned on and off as needed, making loading and unloading efficient.

Medical Equipment

MRI machines use superconducting electromagnets to generate powerful magnetic fields that allow detailed imaging of the human body's internal structures.

Solenoid Valve Applications

Gas Control Systems

Solenoid valves are critical components in gas control systems, where they regulate the flow of gas based on electrical signals.

When current flows through the solenoid coil, it creates a magnetic field that moves a plunger, which opens or closes the valve.

Advantages for Gas Technicians

For gas technicians and fitters, understanding solenoid valves is essential because:

- They provide remote control of gas flow
- They can be integrated with safety systems
- They allow for automated operation
- They can quickly shut off gas flow in emergency situations

Relay Operation in Control Circuits

Signal Reception

A small control current is applied to the relay coil from a low-voltage control circuit.

Electromagnetic Activation

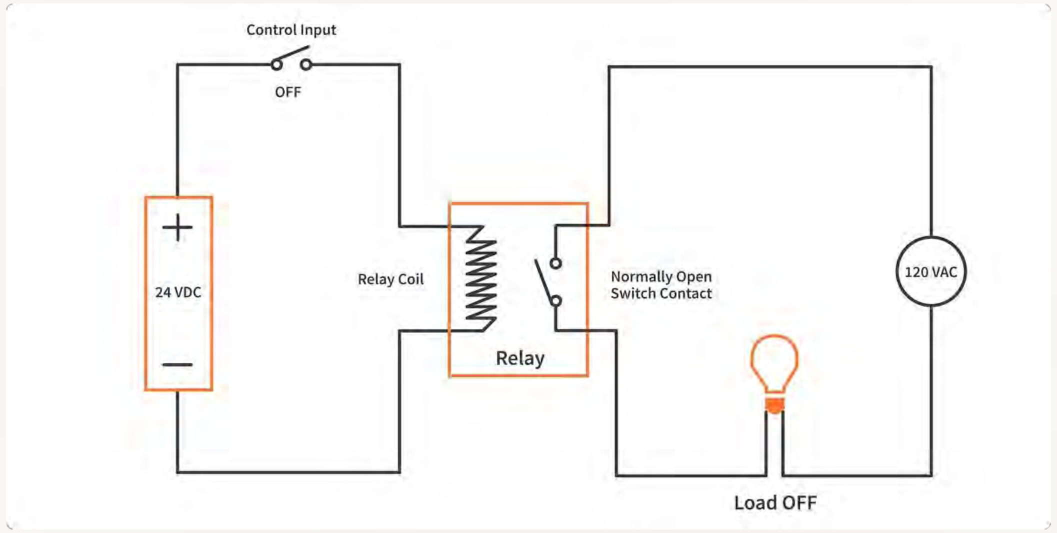
The current in the coil creates a magnetic field that attracts the armature.

Contact Operation

The moving armature mechanically operates the electrical contacts, either opening or closing them.

Power Circuit Control

The contacts control a separate high-power circuit, allowing the low-power control signal to safely manage high-power devices.



Factors Affecting Electromagnet Strength

1000+

Turns of Wire

More turns create stronger magnetic fields

5000

Iron Permeability

Relative to air (which is 1)

100%

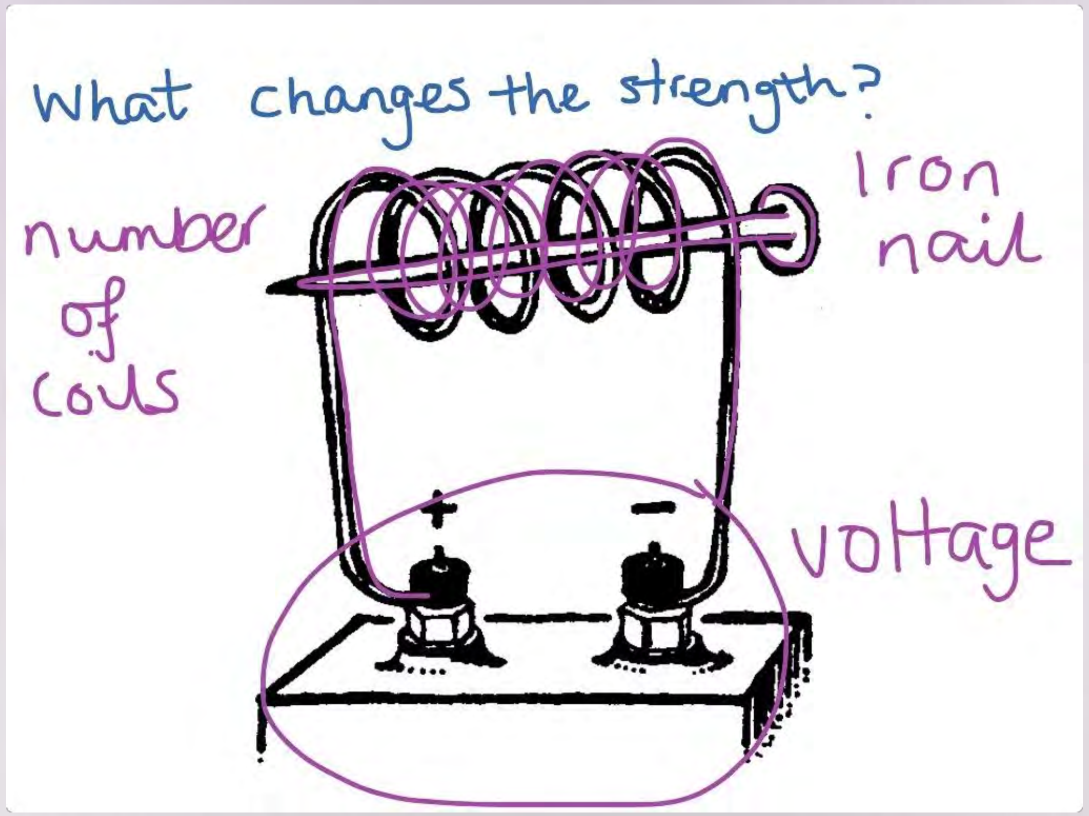
Strength Increase

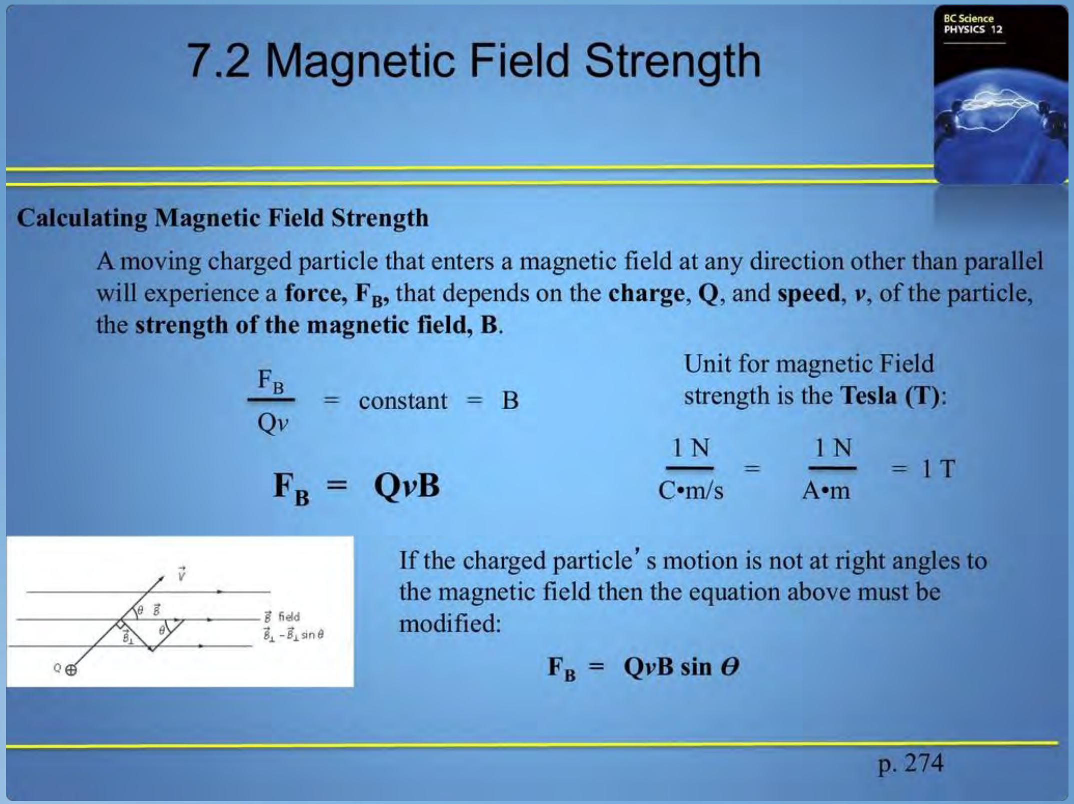
When doubling the current

0

Residual Magnetism

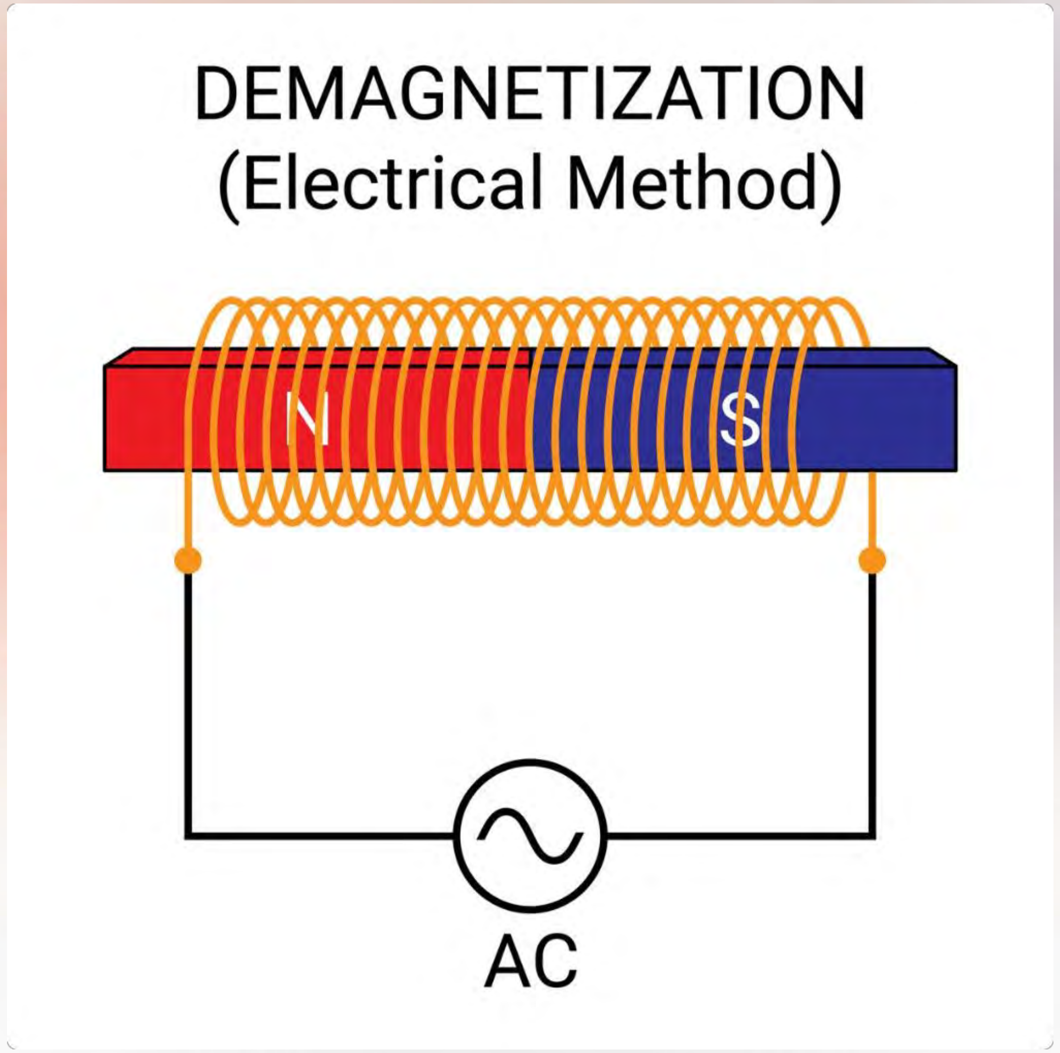
In soft iron when current stops





Magnetic Field Strength Units

Quantity	Symbol	SI Unit	Description
Magnetic field strength	H	Ampere per meter (A/m)	Measure of the magnetizing field produced by current
Magnetic flux density	B	Tesla (T)	Measure of the resulting field in a material
Magnetic flux	Φ	Weber (Wb)	Total magnetic field passing through an area
Permeability	μ	Henry per meter (H/m)	Measure of a material's ability to support magnetic field formation



Demagnetization Methods

Heating

When a magnetic material is heated above its Curie temperature, the thermal energy disrupts the alignment of magnetic domains, causing it to lose its magnetism.

Physical Shock

Strong physical impacts can disrupt the alignment of magnetic domains in a material, reducing or eliminating its magnetism.

Alternating Current

Exposing a magnet to a decreasing alternating magnetic field gradually randomizes the orientation of magnetic domains.

Natural Decay

Over time, some magnetic materials gradually lose their magnetism due to thermal effects and external magnetic influences.

Magnetic Shielding

Principle of Operation

Magnetic shielding works by redirecting magnetic field lines around the area to be protected, rather than blocking them.

Materials with high permeability provide a path of least resistance for magnetic flux, drawing the field lines through the shielding material instead of the protected space.

Applications

Magnetic shielding is used in various applications:

- Protecting sensitive electronic equipment
- Shielding medical devices from external magnetic interference
- Containing magnetic fields in transformers and motors
- Preventing electromagnetic interference between components

Magnetic Hysteresis

Definition

Magnetic hysteresis is the tendency of a magnetic material to retain its magnetization after the magnetizing force is removed.

Hysteresis Loop

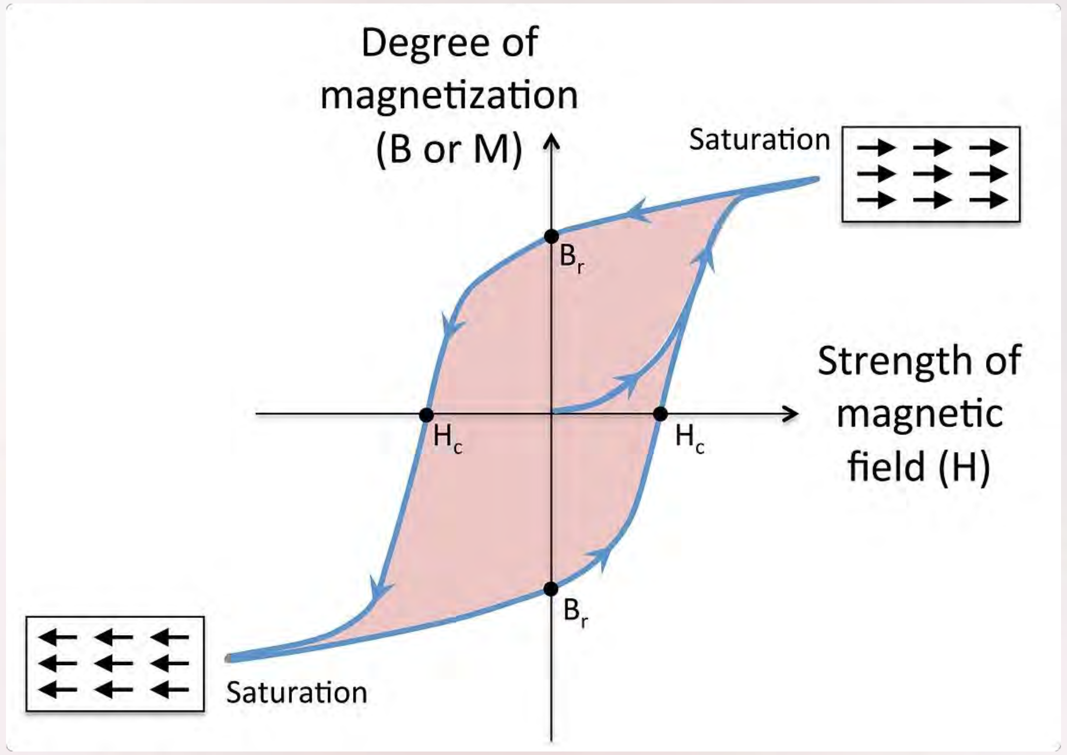
The hysteresis loop is a graph showing how the magnetic flux density (B) in a material changes as the magnetizing force (H) is varied.

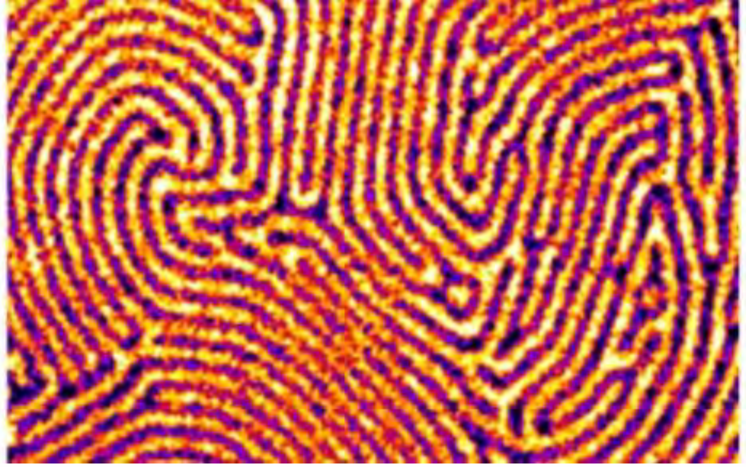
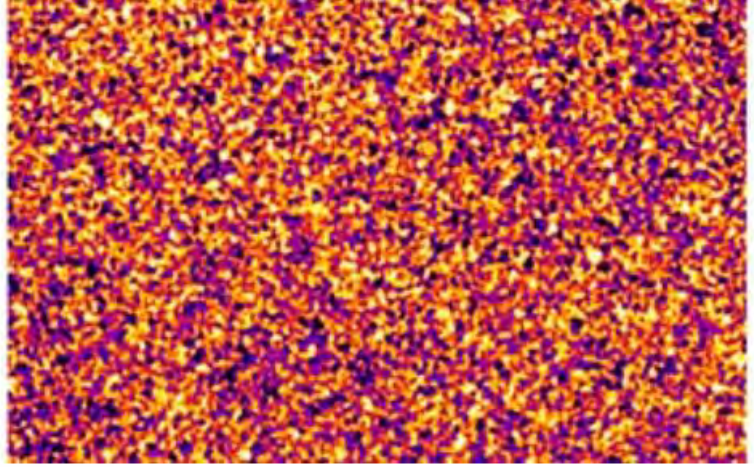
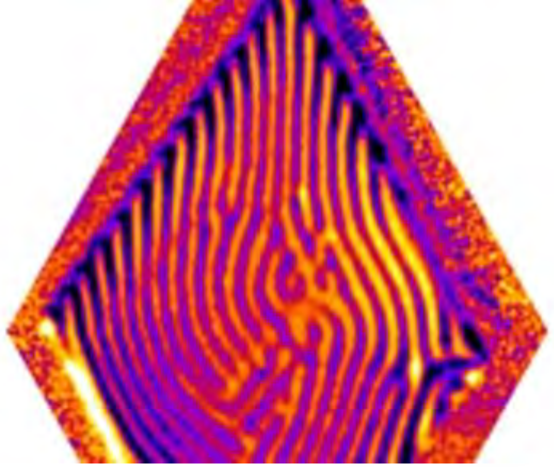
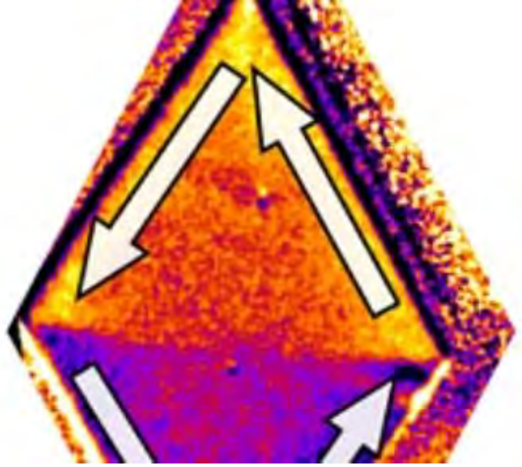
Energy Loss

The area inside the hysteresis loop represents energy lost as heat during each magnetization cycle, which is important in transformer and motor design.

Material Selection

Materials with narrow hysteresis loops (soft magnetic materials) are used in transformers to minimize energy losses, while materials with wide loops (hard magnetic materials) are used for permanent magnets.



Magnetic Domain Theory

Atomic Level Magnetism

In ferromagnetic materials, atoms have unpaired electrons that create tiny magnetic moments.

Domain Formation

These atoms naturally group into regions called domains, where all atomic magnetic moments are aligned in the same direction.

Unmagnetized State

In an unmagnetized material, domains are randomly oriented, and their magnetic effects cancel out.

Magnetization Process

When exposed to an external magnetic field, domains aligned with the field grow at the expense of others, resulting in net magnetization.

Lenz's Law

Definition

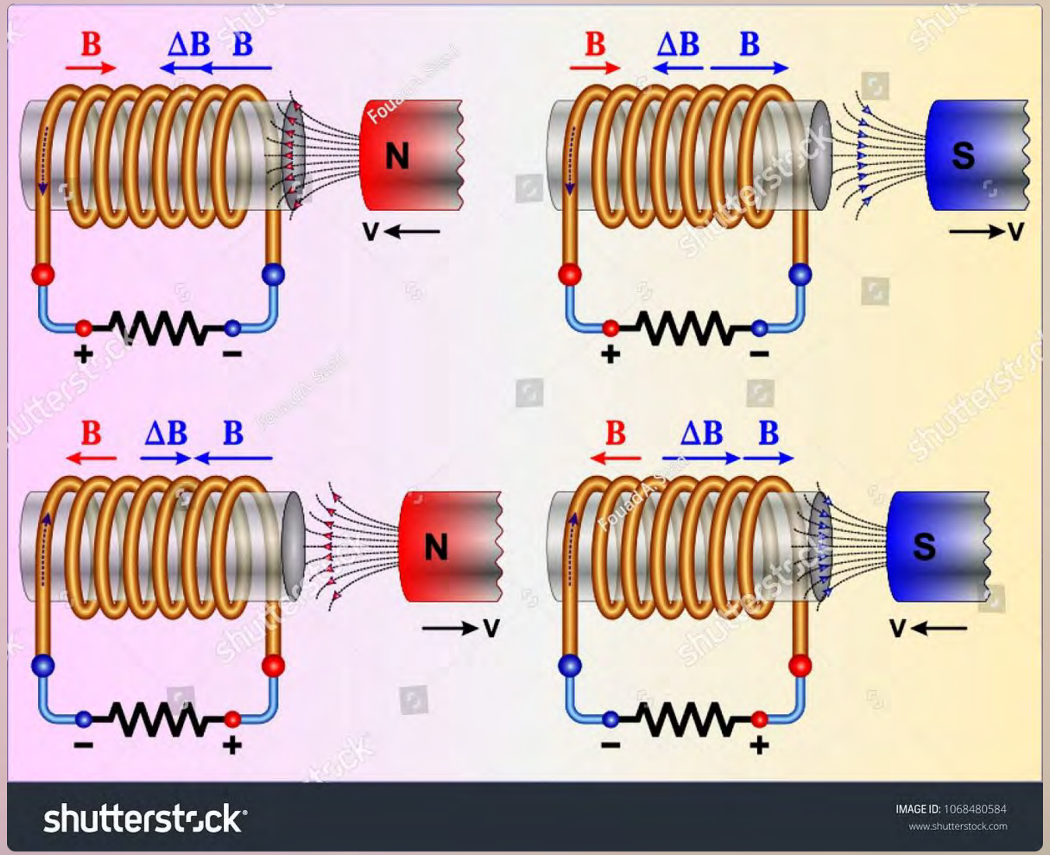
Lenz's Law states that the direction of an induced current is always such that it creates a magnetic field that opposes the change that produced it.

Conservation of Energy

This law is a consequence of the conservation of energy. If the induced current created a field that enhanced the original change, it would create a self-reinforcing system that generated energy from nothing.

Practical Applications

Lenz's Law explains the operation of generators, transformers, and eddy current brakes, and helps predict the behavior of electromagnetic systems.



Eddy Currents

Formation Mechanism

When a changing magnetic field passes through a conductive material, it induces circulating currents called eddy currents within the material.

These currents flow in closed loops perpendicular to the magnetic field, following Lenz's Law to oppose the change that created them.

Effects and Applications

Eddy currents have several important effects:

- They cause heating in the conductor (used in induction heating)
- They create opposing magnetic fields (used in electromagnetic braking)
- They result in energy losses in transformers and motors
- They're used in non-destructive testing to detect flaws in materials

Transformer Principle

Primary Current

Alternating current in the primary coil creates a changing magnetic field

Core Magnetization

The iron core concentrates and directs the magnetic flux

Secondary Induction

The changing magnetic field induces voltage in the secondary coil

Voltage Transformation

The voltage ratio depends on the turns ratio between coils

Electric Motor Operation

Current Supply

Electric current flows through the motor's coil windings, creating electromagnetic fields.

Magnetic Interaction

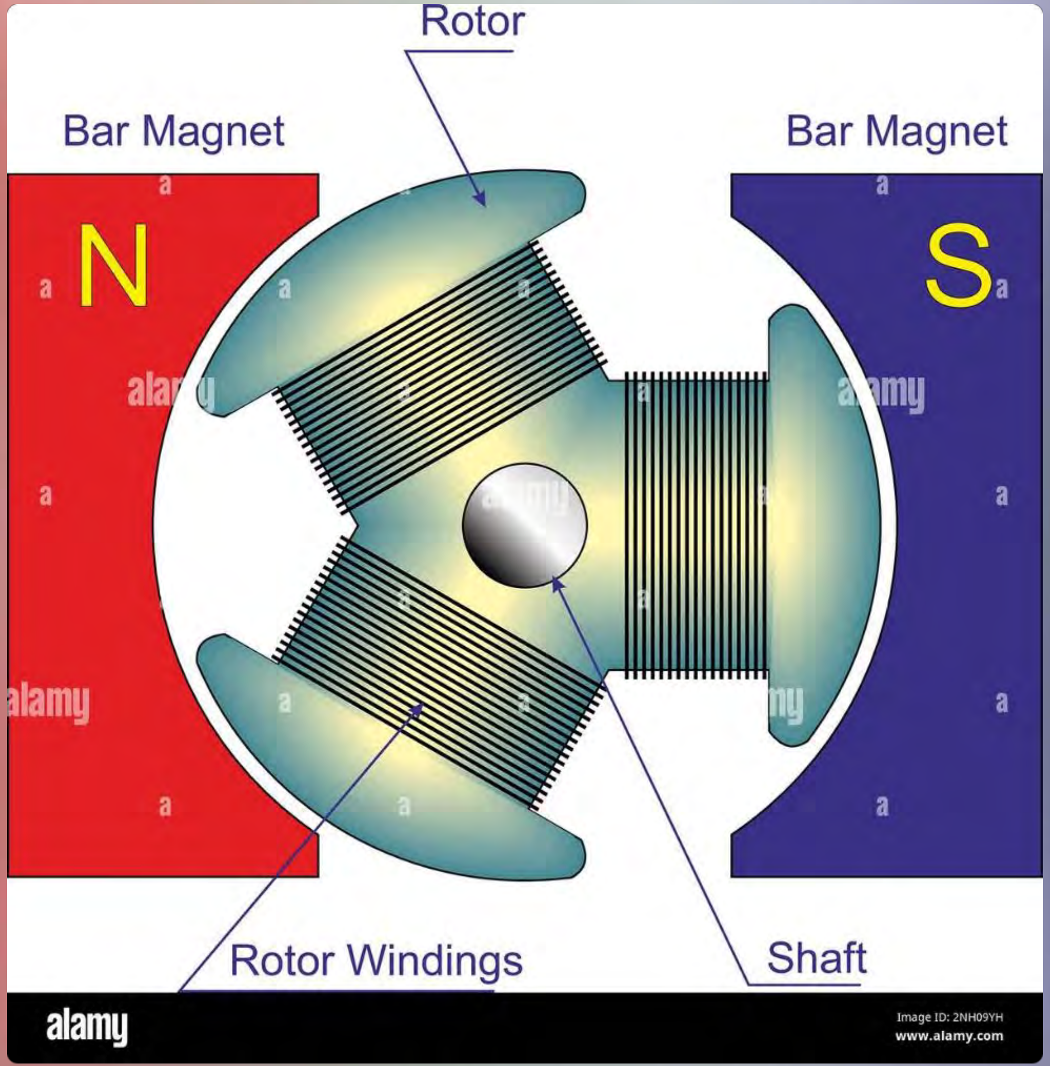
These electromagnetic fields interact with permanent magnets or other electromagnets in the motor.

Force Generation

The interaction between magnetic fields creates forces that cause rotation of the motor's rotor.

Continuous Rotation

Commutation systems or electronic controls continuously change the direction of current flow to maintain rotation.



Magnetic Field Safety Considerations

Medical Devices

Strong magnetic fields can interfere with pacemakers, implantable defibrillators, and other medical implants.

Electronic Media

Magnetic fields can erase or damage information stored on magnetic media like credit cards, hard drives, and magnetic identification cards.

Ferromagnetic Tools

Tools made of ferromagnetic materials can become projectiles in strong magnetic fields, posing serious safety hazards.

Electronic Equipment

Sensitive electronic equipment can malfunction when exposed to magnetic fields, potentially causing control system failures.

Electromagnetic Spectrum

Radio Waves

Lowest frequency electromagnetic waves

Microwaves

Used in communications and cooking

Visible Light

The portion we can see with our eyes

X-rays and Gamma Rays

Highest frequency, most energetic waves

All electromagnetic waves are created by oscillating electric and magnetic fields that are perpendicular to each other and to the direction of wave propagation. They differ only in frequency and wavelength, which determines their properties and applications.

Electromagnetic Compatibility

Definition

Electromagnetic Compatibility (EMC) refers to the ability of electronic equipment to function correctly in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment.

This is particularly important in gas control systems where electromagnetic interference could affect safety-critical components.

Key Considerations

For gas technicians working with control systems, EMC involves:

- Ensuring proper shielding of sensitive components
- Using appropriate grounding techniques
- Separating power and signal cables
- Installing filters to reduce electromagnetic noise
- Following manufacturer guidelines for installation

Troubleshooting Electromagnetic Devices

Visual Inspection

Check for physical damage or loose connections

2 Electrical Testing

Measure resistance, voltage, and current values

Magnetic Field Testing

Verify proper magnetic field generation

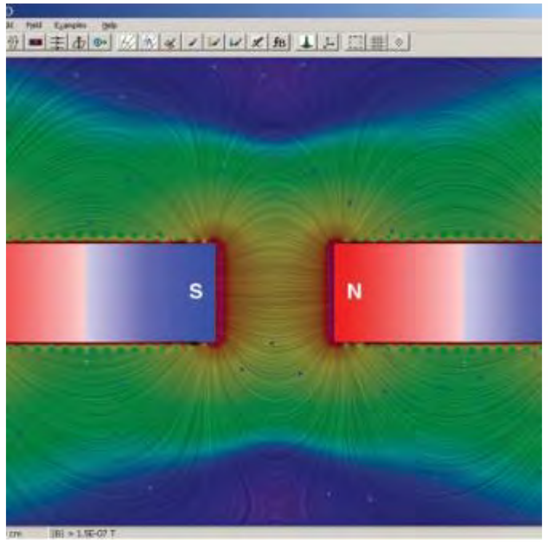
Component Replacement

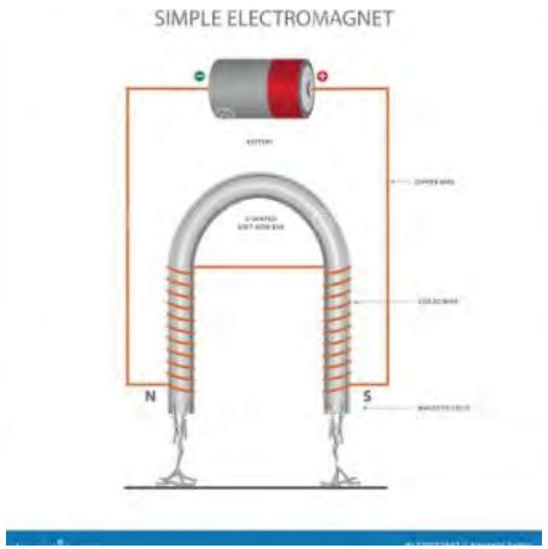
Replace faulty components as needed

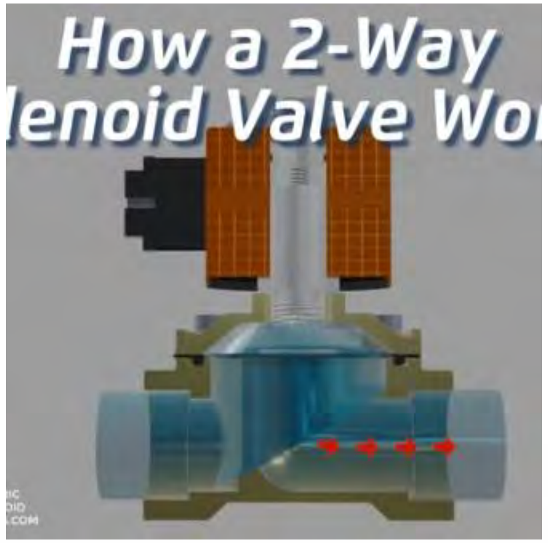
Documentation

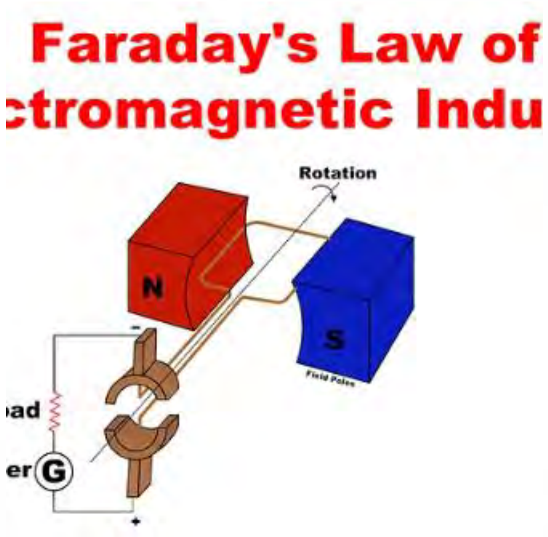
Record all findings and repairs

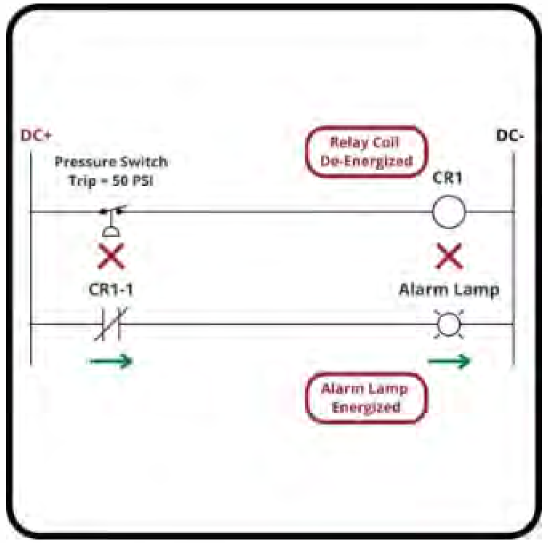
Summary of Magnetism and Electromagnetism

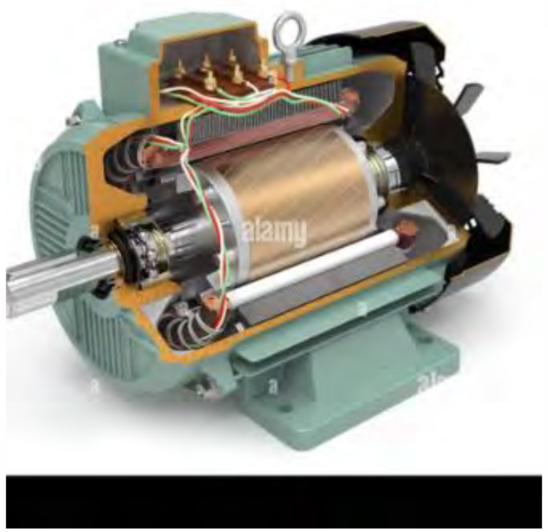




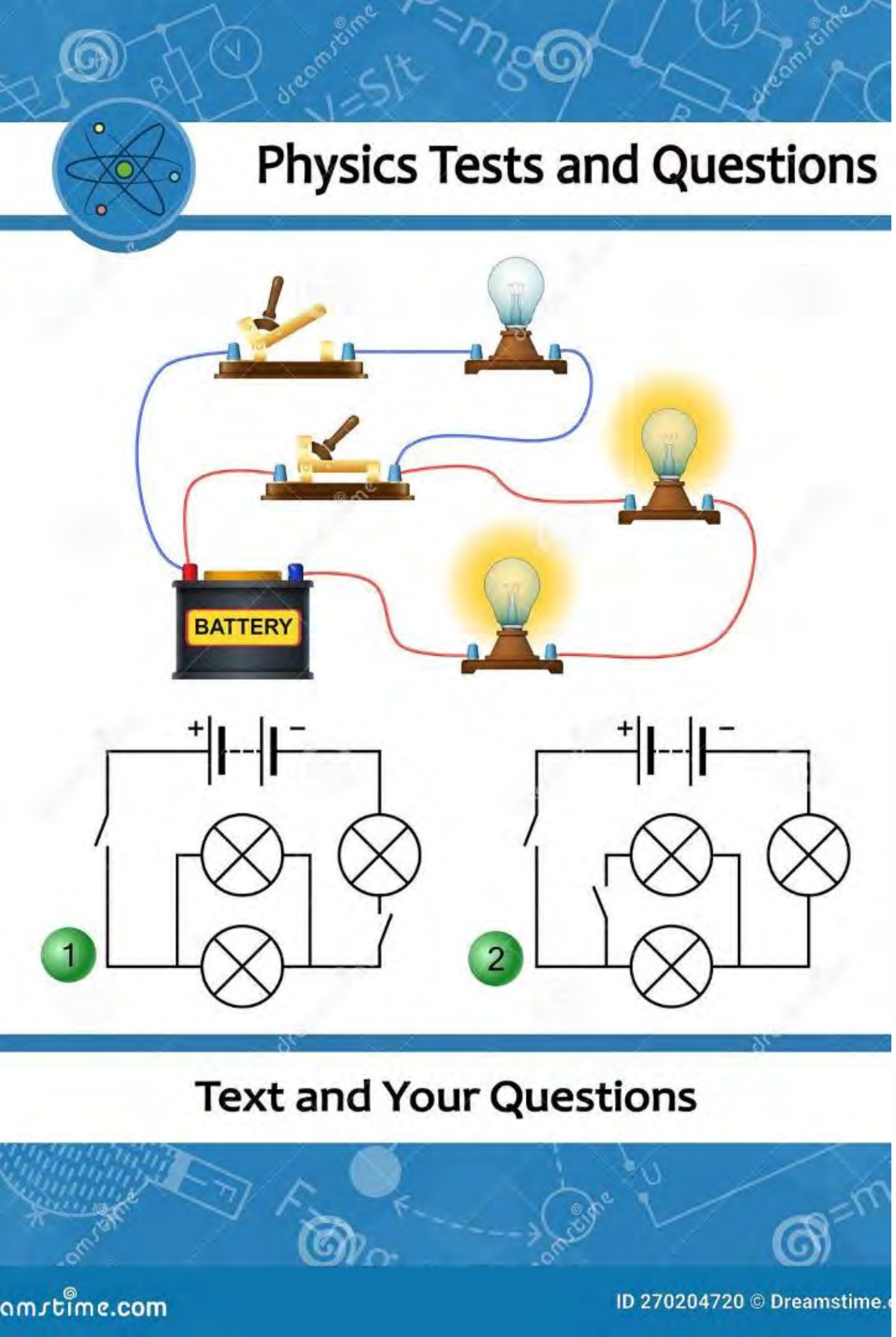








Understanding the principles of magnetism and electromagnetism is essential for gas technicians and fitters. These principles underpin the operation of many devices used in gas systems, including electric motors, solenoid valves, and relay units in control circuits. By mastering these concepts, technicians can effectively install, maintain, and troubleshoot these critical components, ensuring safe and efficient operation of gas systems.



CSA Unit 5

Chapter 5
Theory of Direct and Alternating Current

The gas technician/fitter requires knowledge of direct and alternating current theory in order to properly size, connect, and troubleshoot the type of electrical equipment encountered in the gas industry. This presentation covers the fundamentals of direct and alternating current, leading and lagging in AC circuits, and capacitance in AC circuits.

Learning Objectives

Describe Direct and Alternating Current

Understand the fundamental differences between DC and AC electricity

Describe Leading and Lagging in AC Circuits

Comprehend phase relationships in various types of AC circuits

Describe Capacitance in AC Circuits

Learn about capacitors and their behavior in AC electrical systems

Key Terminology

Term	Abbreviation (symbol)	Definition
AC energy		Energy consumed in an AC circuit
Alternating current	AC or ac	Electric current that reverses its direction many times a second at regular intervals, typically used in power supplies
Direct current	DC or dc	Electric current flowing in one direction only
Waveform		Describes complete cycle of alternating current goes from zero to a maximum positive value, back through zero to a maximum negative value, and back again to zero

Direct Current (DC)

What is Direct Current?

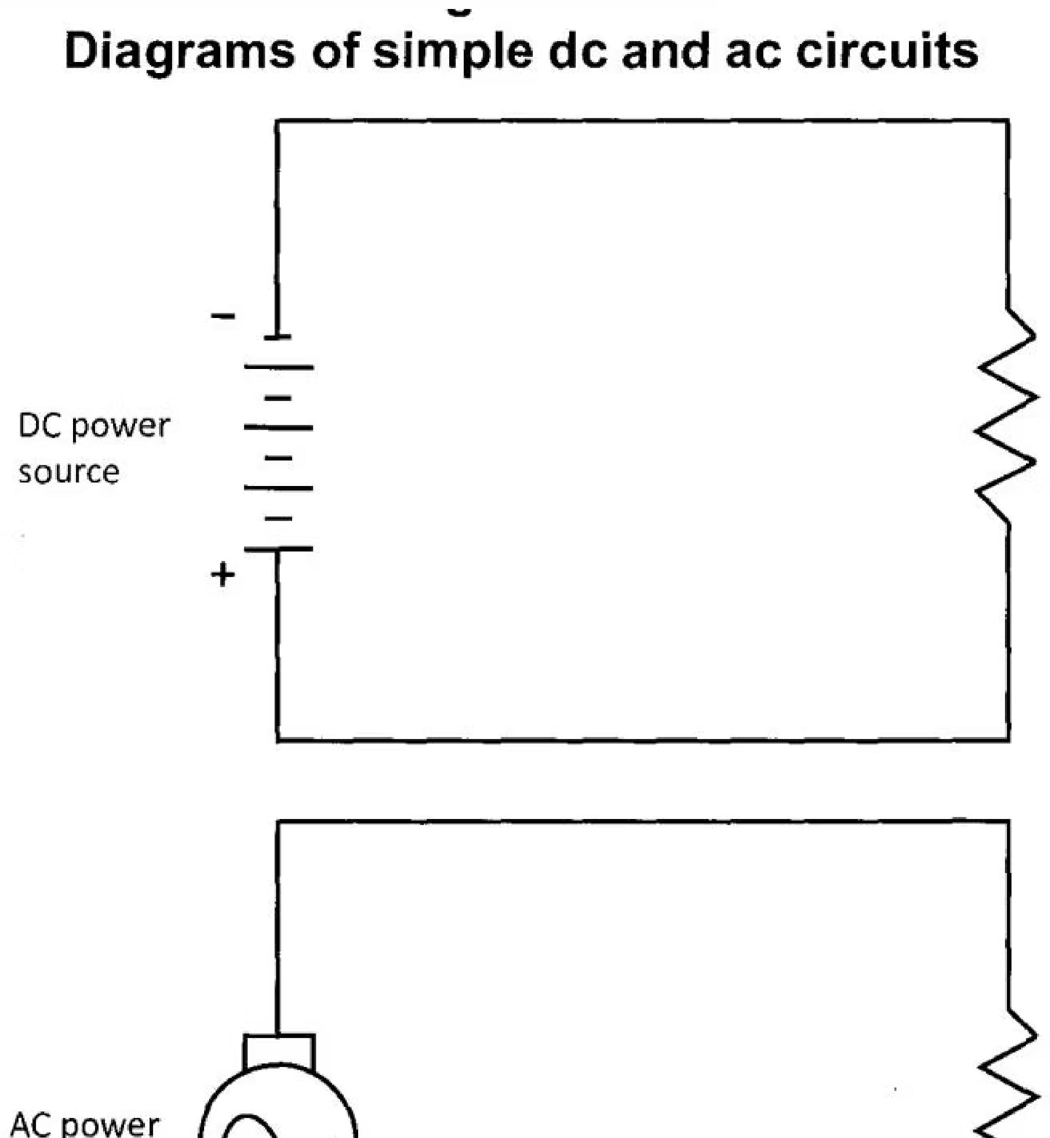
Direct current (DC) is electric current that flows in one direction only. When a circuit is connected to a DC source like a battery, the current flows from one terminal to the other in the same direction.

Batteries have a positive and a negative terminal. The battery shown in the example has a voltage of 12 V.

Common DC Applications

- Electronic devices
- Small appliances
- Automobile electrical systems

DC is often supplied by batteries, which have a limited supply of electrical power and must be replaced or recharged regularly.

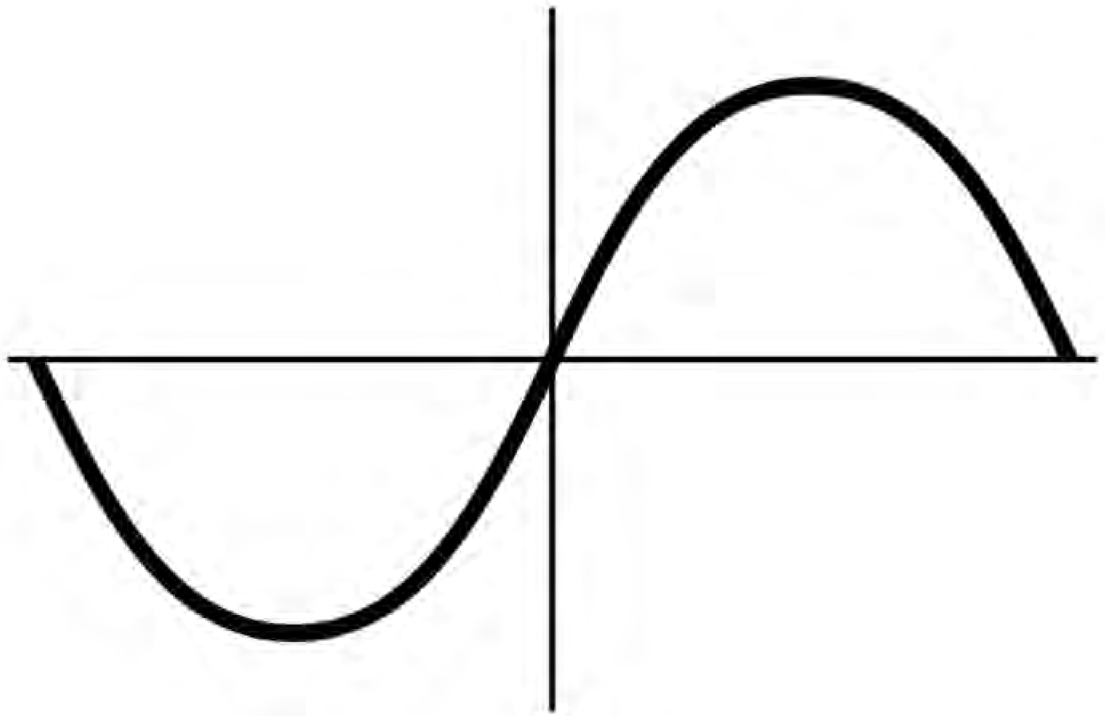


Alternating Current (AC)

What is Alternating Current?

Alternating current (AC) is electric current that flows alternately in both directions. The flow changes or alternates direction rapidly and constantly.

In North America, generators produce and transmit electrical energy as alternating current with a frequency of 60 hertz (cycles per second). This means that the current flows in one direction for 1/120th of a second and then in the other direction for 1/120th of a second.



Unlike DC where one terminal is always negative and the other positive, AC constantly changes direction. Most motors and other devices in homes and industry operate using alternating current.

Why AC is Widely Used

Versatility

AC is more versatile than DC and is usable in a wide variety of ways.

Cost-Effective

It is cheaper to produce than DC.

Long-Distance Transmission

It allows transmission of electricity over long distances more economically.

Voltage Transformation

It easily transforms into lower or higher voltages for use in various equipment.

Energy Efficiency

Transmission of AC energy at high voltage and low current keeps energy losses to a minimum.

Flexibility

Many combinations of voltage and current can produce the same energy level.

AC Generator Principles

Magnetic Field Interaction

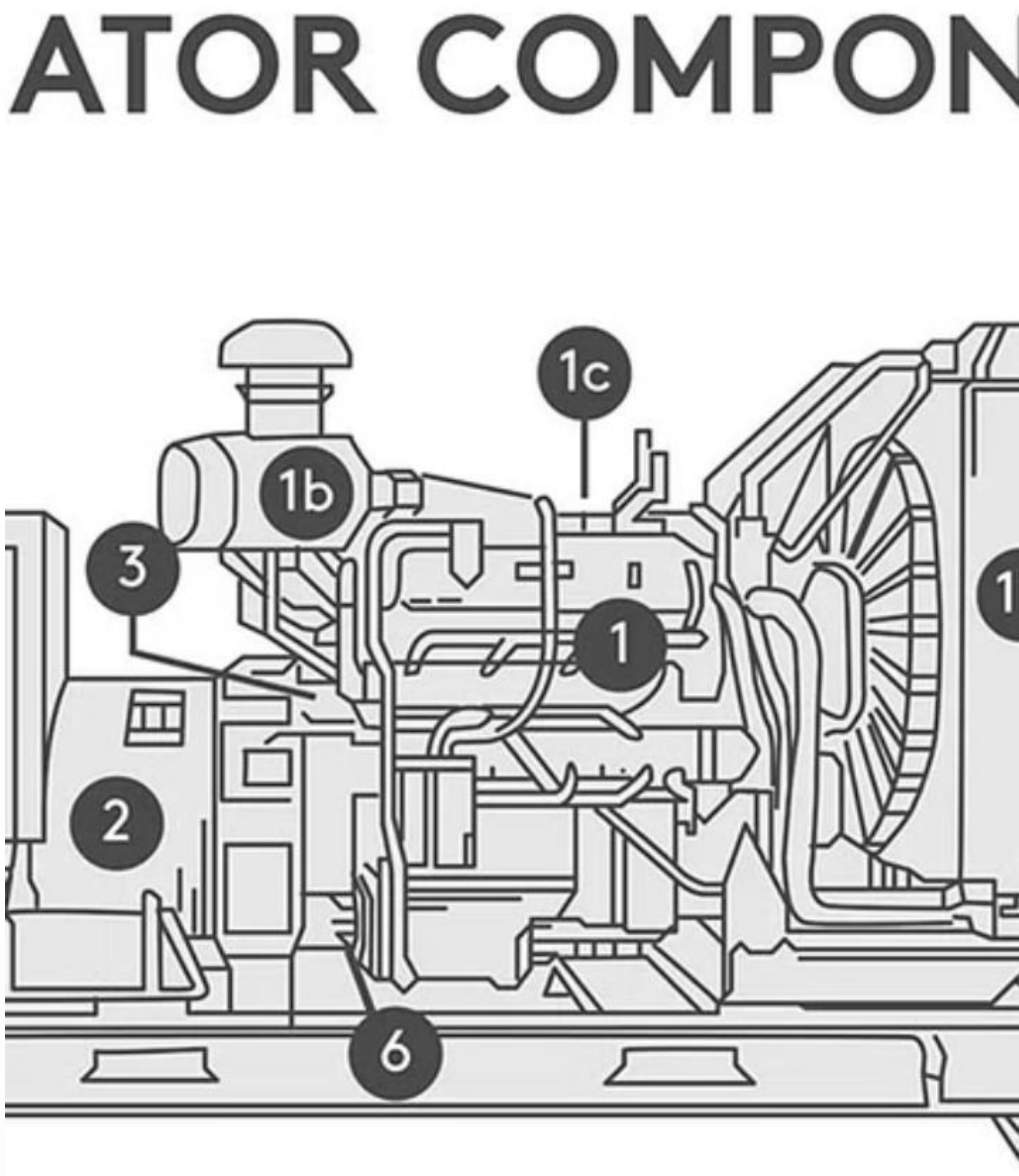
A conductor moved in a magnetic field, or vice versa, crosses the flux lines.

Electron Movement

The field applies a force to the free electrons in the conductor, moving them.

Voltage Generation

The moving electrons result in a potential difference across the ends of the conductor.



Factors Affecting Generated Voltage

Magnetic Field Strength

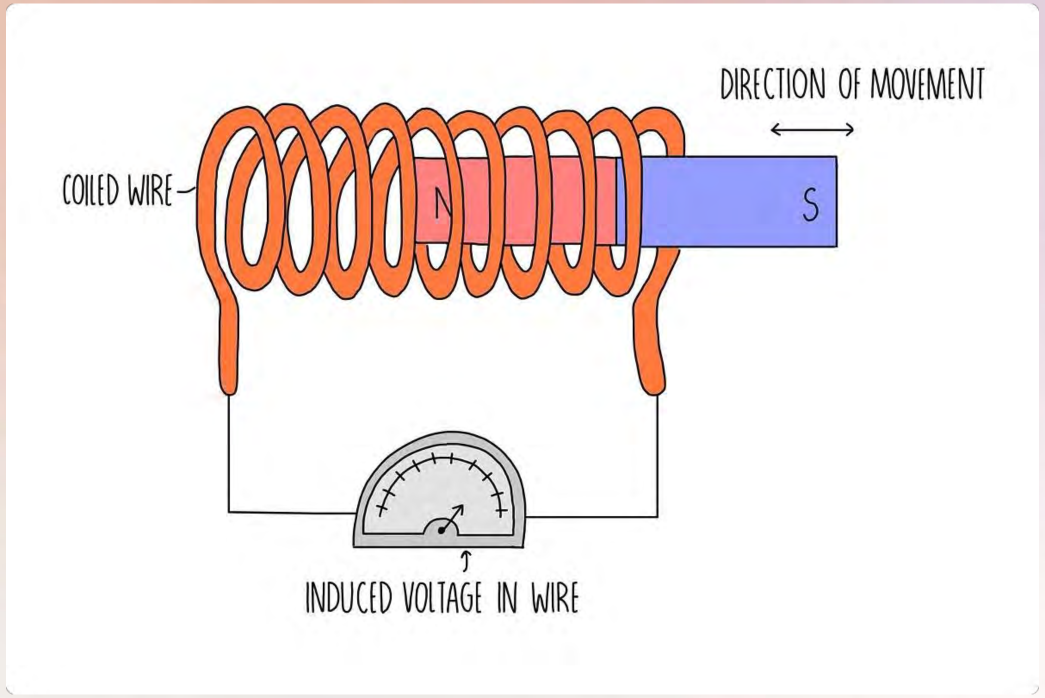
Stronger magnetic fields produce higher voltages

Conductor Speed

Faster movement through flux lines increases voltage

Cutting Angle

The angle at which the conductor cuts the flux lines affects voltage



Simple Generator Operation

Power Source

An outside power source such as flowing water, an internal combustion engine, or steam turns the coil.

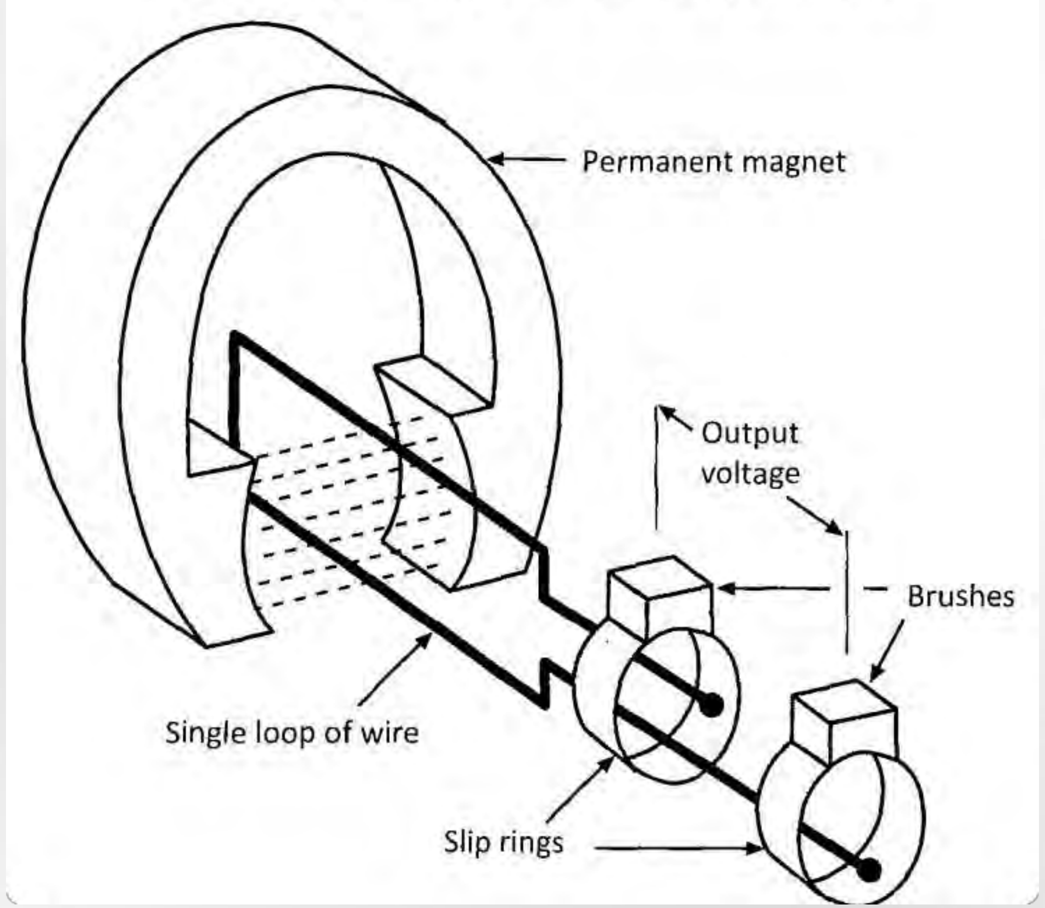
Magnetic Flux Cutting

As the loop rotates, the wire cuts the magnetic flux lines, generating a voltage at the ends of the loop.

Voltage Transfer

The generator transfers the voltage to an external circuit via slip rings and brushes. These maintain proper electrical contact while allowing free rotation of the loop.

Figure 5-2
The basic principle of an ac generator

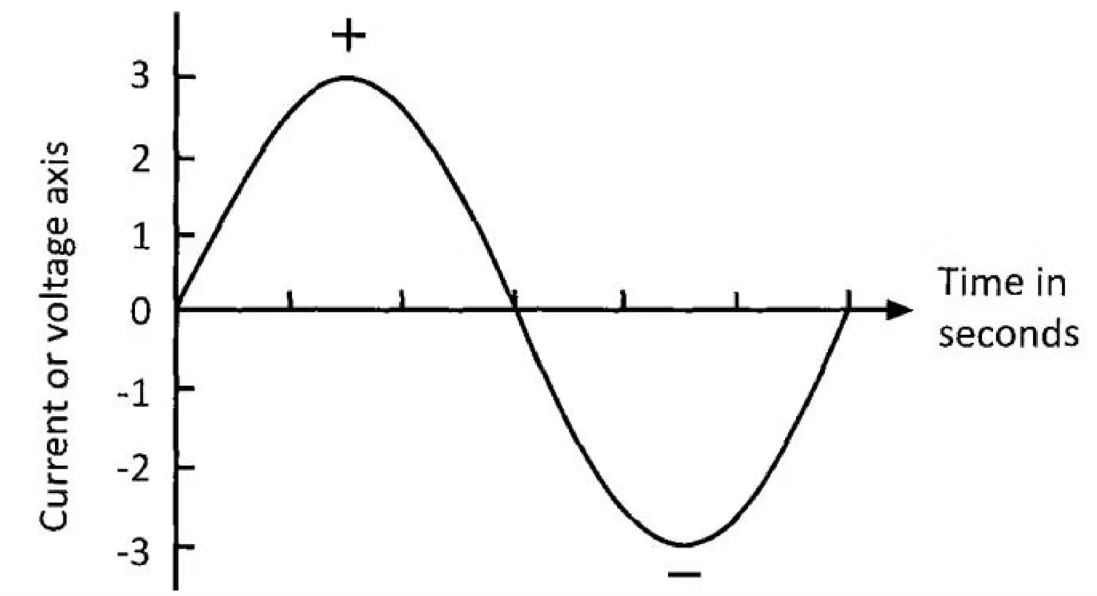


The AC Waveform

Sinusoidal Wave

A complete cycle of alternating current goes from zero to a maximum positive value, back through zero to a maximum negative value, and back again to zero. The voltage makes a similar pattern, rather like a wave.

The correct name for the shape of this waveform is sinusoidal or a sine wave.



At any point on this sine wave, the magnitude of the voltage (or current) is the distance to the time axis. When the waveform is below the zero line, the current has reversed direction.

Waveform Characteristics

Symmetrical Pattern

Note that the waveform is the same shape above and below the horizontal axis (symmetrical)—the positive and negative parts vary in the same way.

The horizontal axis can be divided into degrees of rotation rather than units of time. One complete rotation or cycle equals 360°.

Figure 5-4
The waveform of ac voltage (or current) showing degrees of rotation of the rotor

This graph shows how the output voltage (or current) of the generator varies with the position of the rotor.

AC Frequency

60

Hertz

Standard AC frequency in Canada

1/120

Seconds

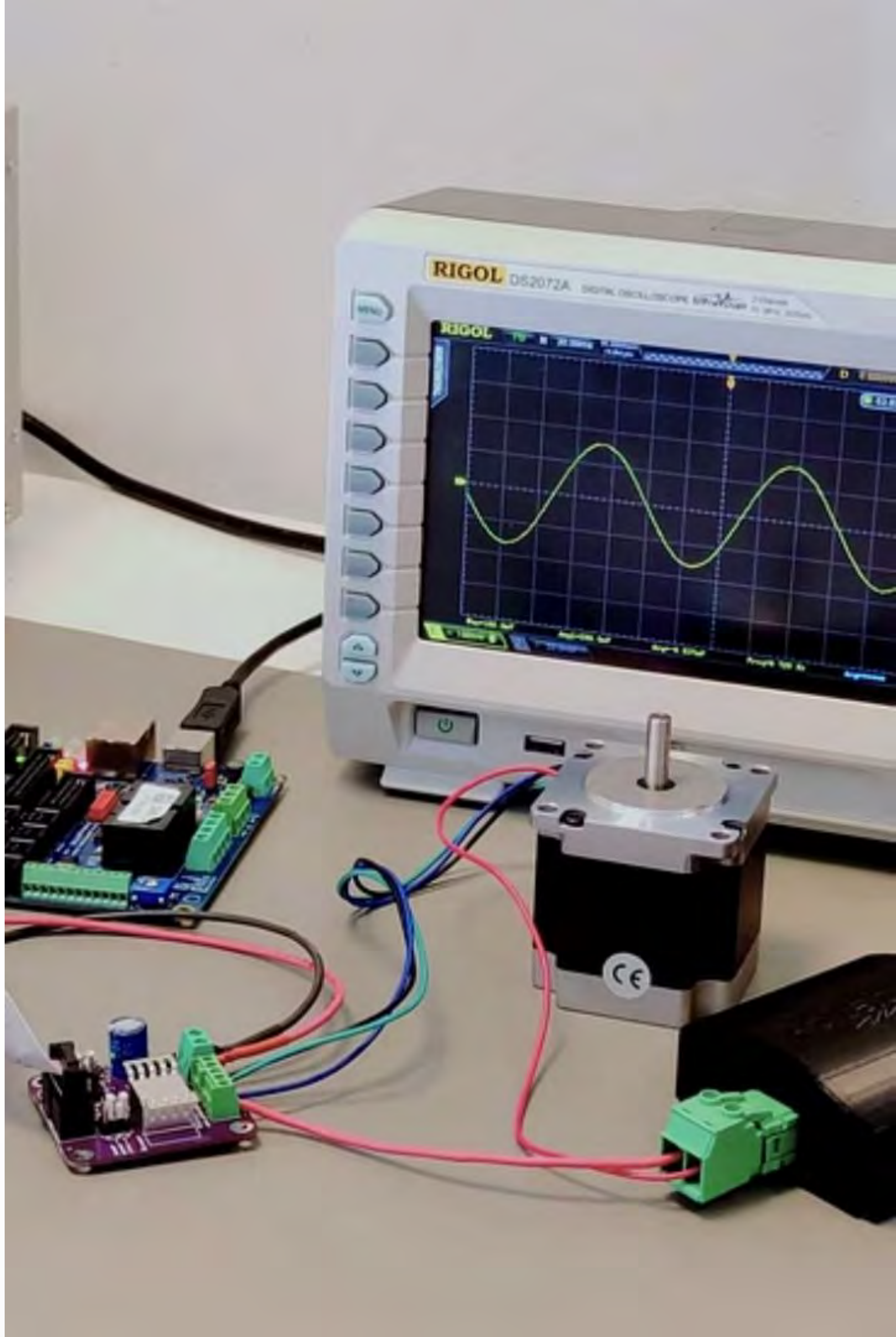
Time current flows in one direction

360°

Degrees

One complete cycle

In Canada, standard AC electrical power goes through 60 complete cycles each second. That is, its frequency is 60 cycles per second or 60 hertz (60 Hz). A simple generator would turn 60 times each second to produce power at 60 hertz.



Phase in AC Circuits

What is Phase?

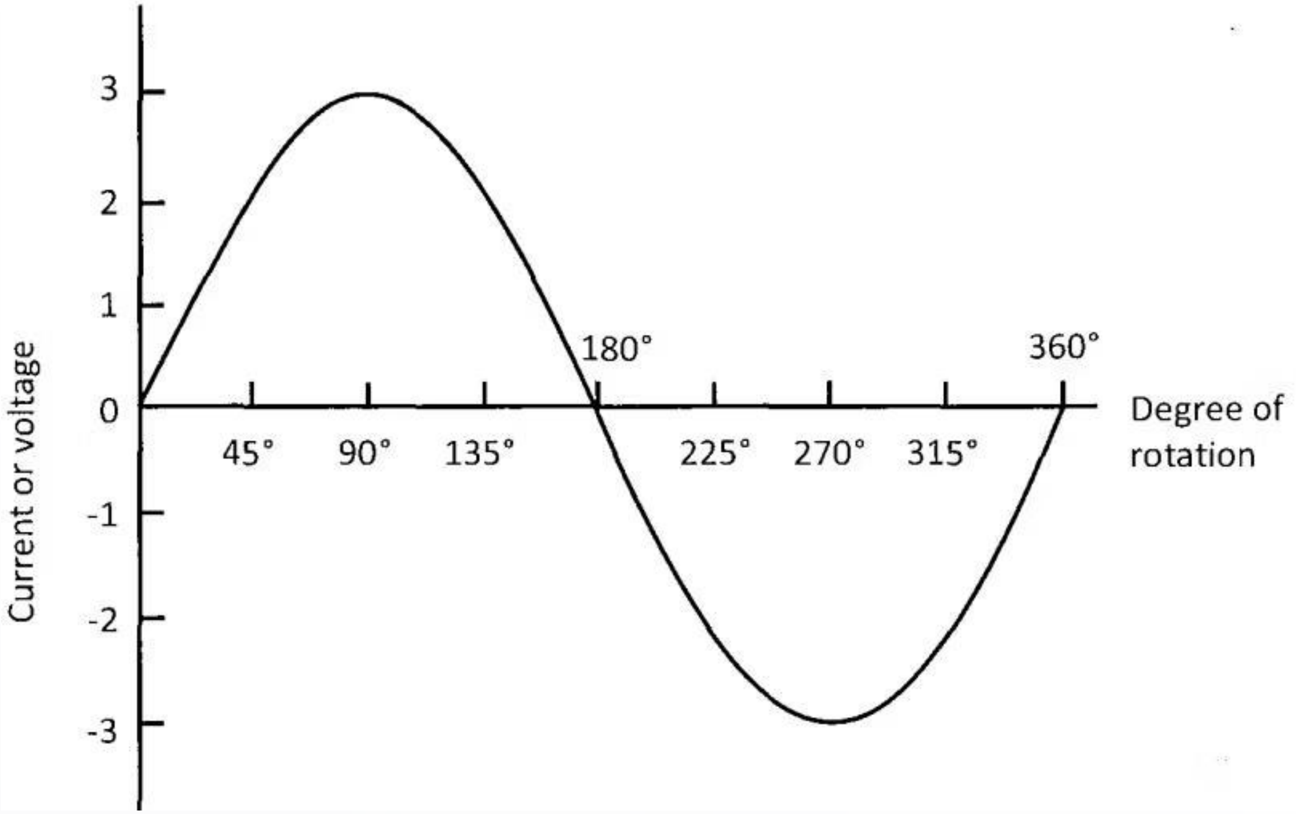
Phase can be described as the difference in electrical degrees between two waveforms.

Single-Phase Generator

A single-phase generator produces one alternating (sinusoidal) voltage waveform.

Three-Phase Generator

Three-phase generators are connected to provide three separate circuits. Each of these circuits carries a sinusoidal voltage waveform. The three waveforms are displaced by 120° from each other.

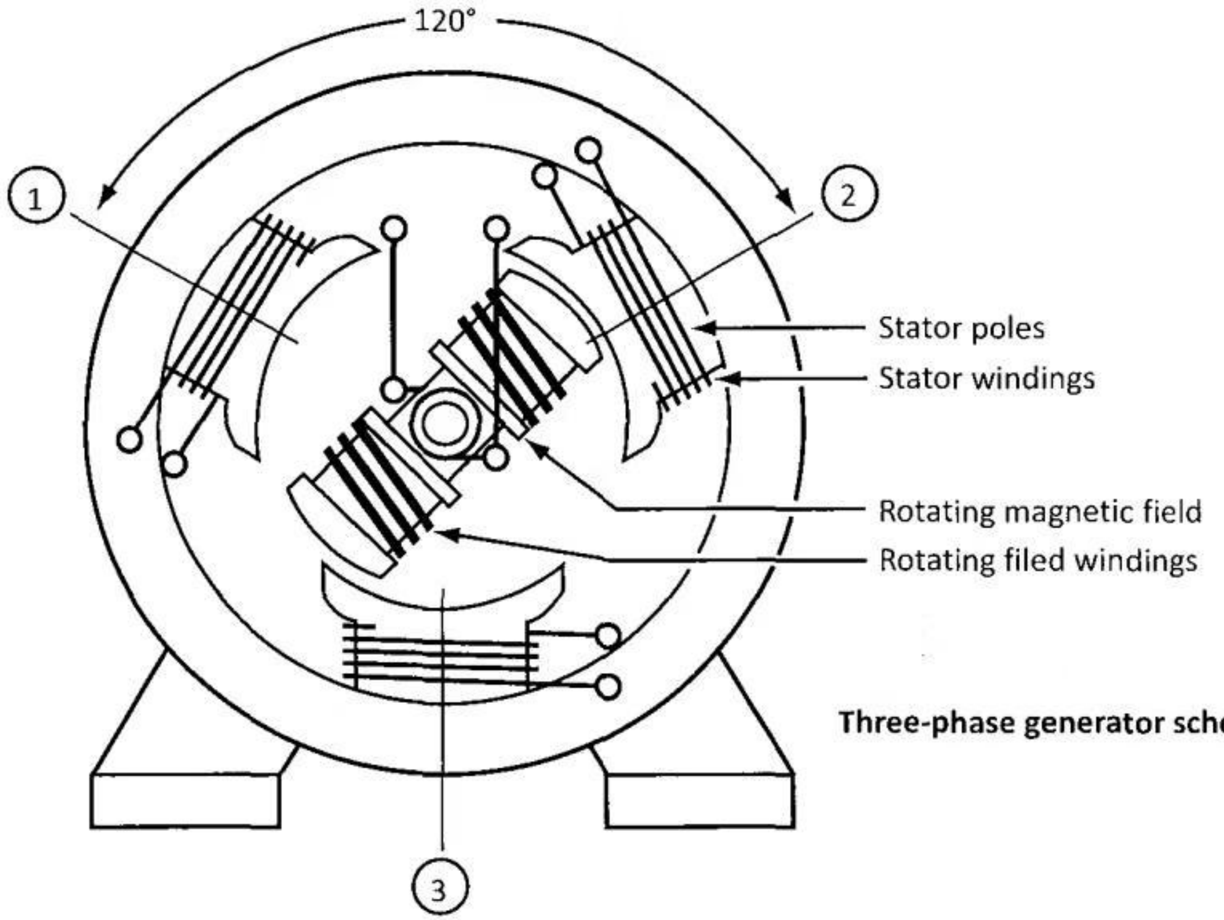


Three-Phase Generator Windings

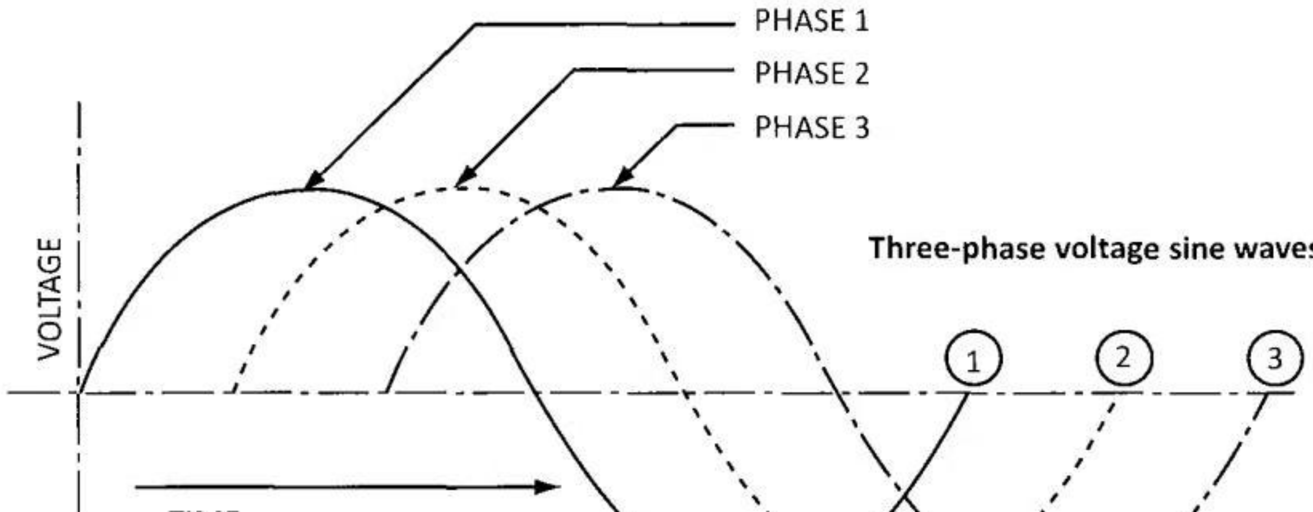
Three-Phase Configuration

Three-phase generators have three separate windings that produce three voltage waveforms displaced by 120° from each other.

This configuration provides more efficient power generation and transmission compared to single-phase systems.



Three-phase generator schematic



Three-phase voltage sine waves

Calculating Alternating Current

Root-Mean-Square (RMS) Values

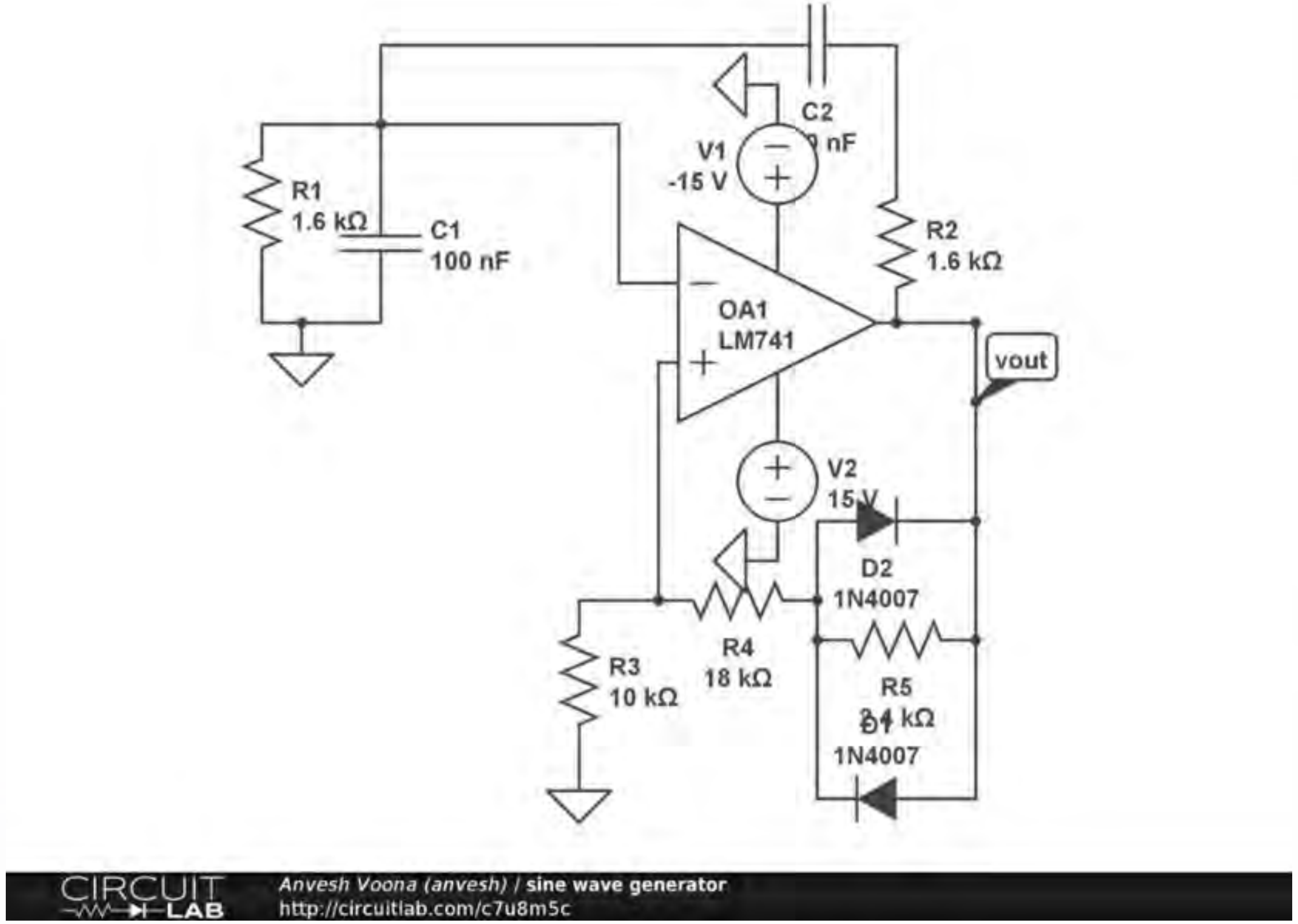
Alternating current is calculated by determining the effective work that the electric current performs or heat it generates. This is referred to as root-mean-square or RMS current.

RMS current is the peak current (Imax or Im) divided by square root of 2 (0.707):

$I_{rms} = 0.707 \times I_{max}$

Similarly for voltage:

$V_{rms} = 0.707 \times V_{max}$



Residential voltages in North America are 120 V, which is the RMS voltage. The actual supplied voltage is alternating according to a sine curve with a peak of approximately 170 V.

Circuit Characteristics

Inductance

Predominates in motor circuits

Resistance

Predominates in heating circuits

Capacitance

Predominates in long supply lines

Every real electrical circuit exhibits a combination of resistance, inductance, and capacitance. The nature of the circuit determines which of these quantities predominates. Whichever quantity predominates, the other two are always present to some extent or other—although, from a practical point of view, at least one of the others is so insignificant that you may ignore it.

Key Electrical Quantities

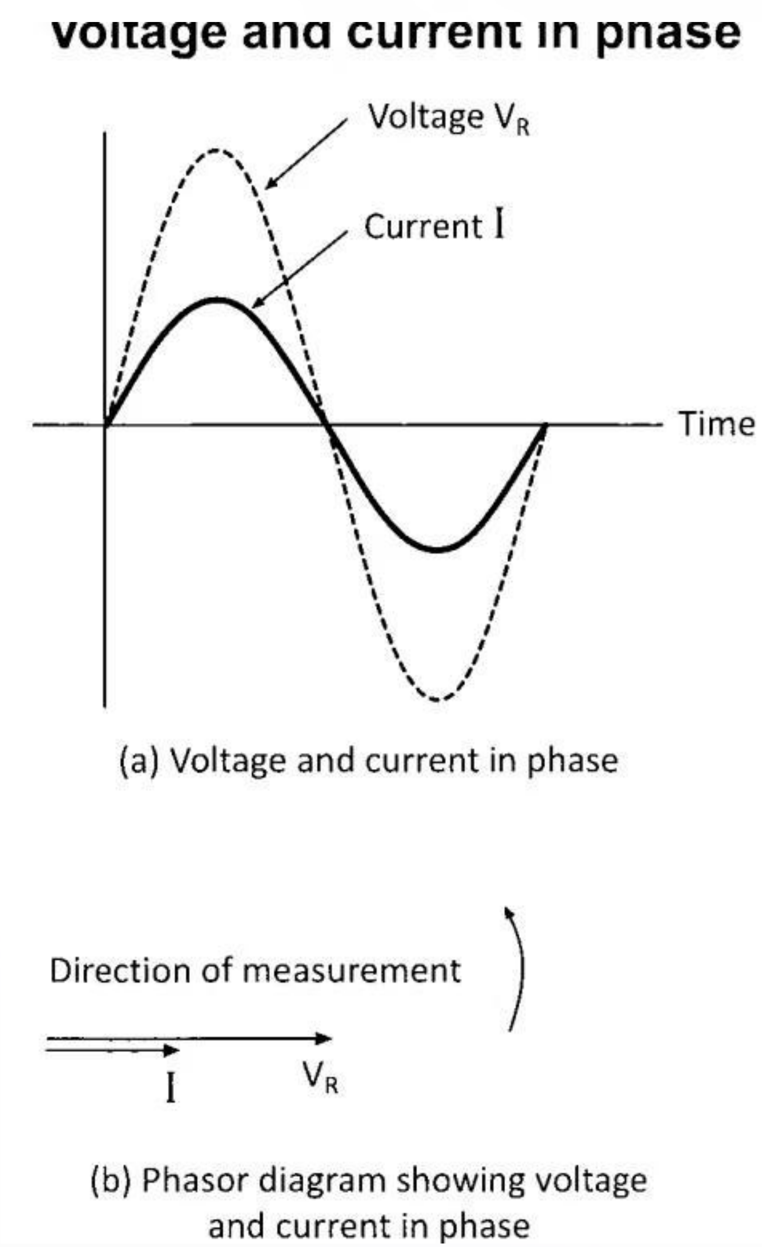
Quality	Symbols	Definition	Measured in
Resistance	R	Ratio of applied emf to the resulting current in a circuit and the real component of impedance in an ac circuit	Ohm (Ω)
Reactance	X	Depends upon a circuit's inductance or capacitance and the frequency of the supply voltage	Ohm (Ω)
Impedance	Z	Total opposition to the flow of current in a circuit and consists of a circuit's resistance and reactance	Ohm (Ω)
Inductance	L	Property of an electric circuit by virtue of which a varying current induces an emf in that circuit or an adjacent circuit	Henry (H)
Capacitance	C	Ratio of a quantity of electricity to a potential difference and ability of conductors separated by dielectric material to store energy	Farad (F)

Purely Resistive Circuit

Current and Voltage Relationship

When an AC current flows through pure resistance, a voltage-drop (VR) occurs across that resistance. You use Ohm's law to calculate the value of that voltage-drop: VR = IR.

When the current is maximum, the corresponding voltage-drop is also maximum; as the current falls to zero and reverses direction, the resulting voltage-drop also falls to zero and changes direction.



In a purely resistive circuit, the current and voltage are in phase with each other. The phasor diagram shows the current and voltage phasors lie along the same direction because they are in phase.

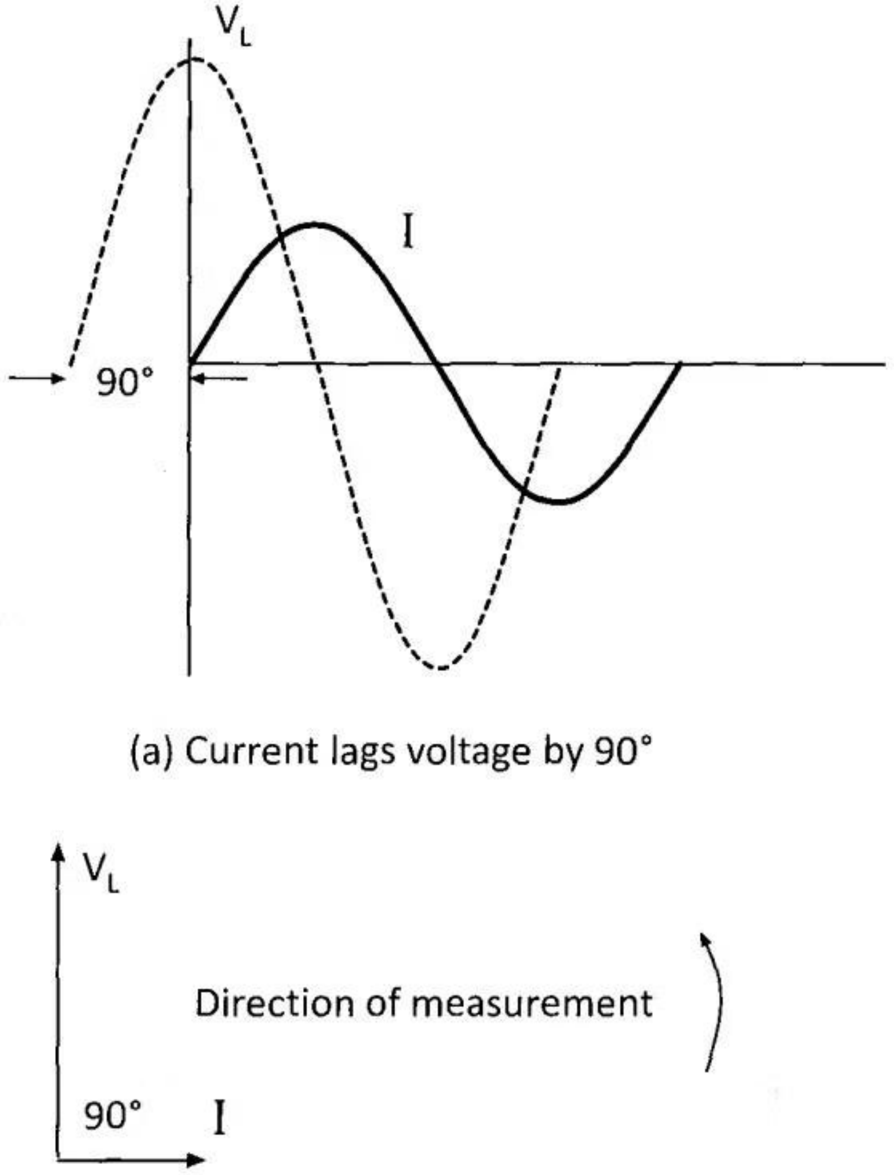
Purely Inductive Circuit

Current and Voltage Relationship

When an AC current flows through pure inductance, a voltage (VL) appears across that inductance. The opposition to current is inductive-reactance (XL), so VL = I × XL.

The changing current induces the voltage (VL) into the inductance. The greater the rate of change of current, the greater this voltage. The greatest rate of change occurs as the current passes through zero, so this is where the maximum voltage occurs.

Figure 5-7
Current lags voltage by 90°



(a) Current lags voltage by 90°

(b) Phasor diagram showing current lagging voltage

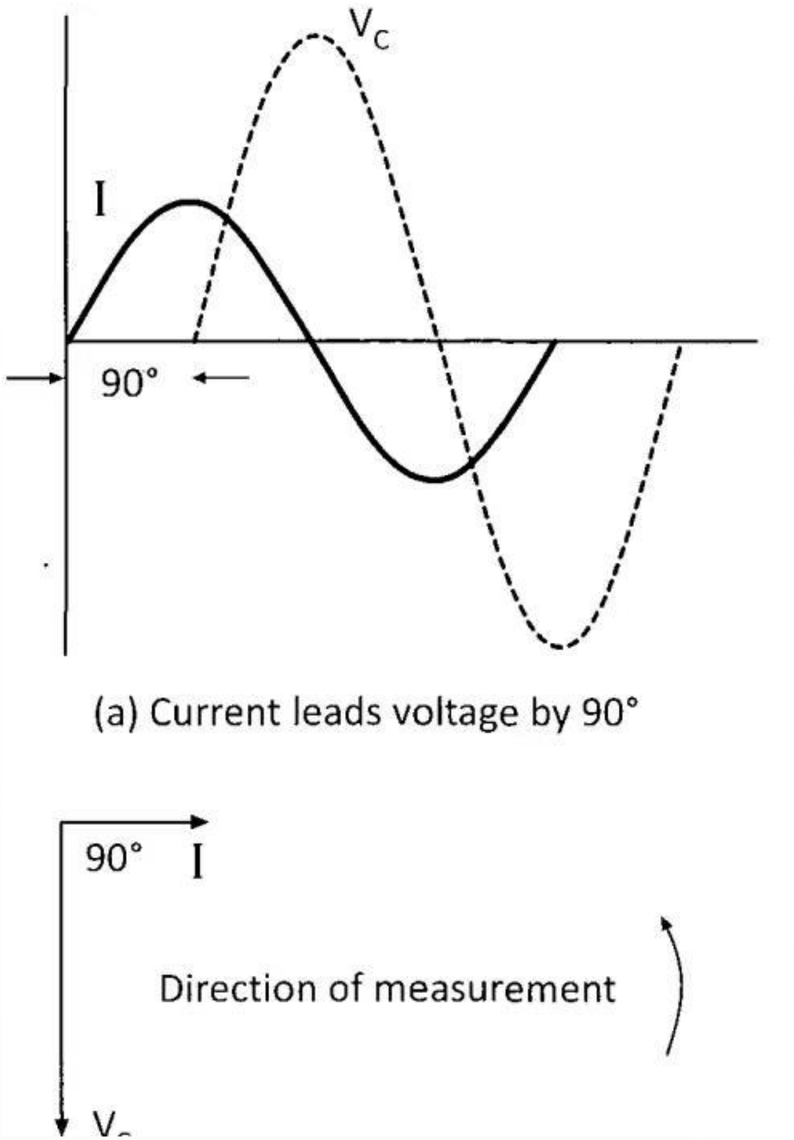
Purely Capacitive Circuit

Current and Voltage Relationship

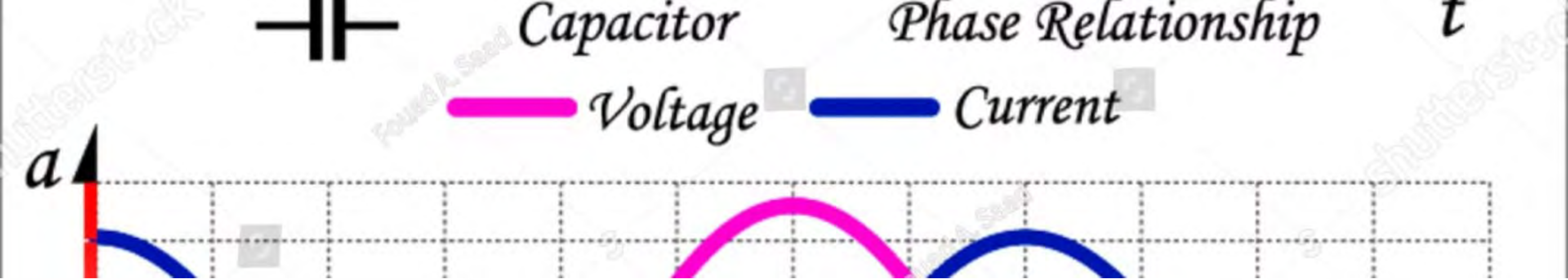
When an AC current flows through pure capacitance, a voltage (VC) appears across that capacitance. The opposition to current is capacitive-reactance (XC), so VC = I × XC.

The voltage (VC) builds up across the plates of the capacitor as the current flows onto those plates. This voltage increases as the current decreases and reaches its maximum value as the current falls to zero.

Figure 5-8
Current leads voltage by 90°



In a purely capacitive circuit, the current peaks ahead of the voltage by 90°. It is said to lead the voltage by 90°. The phasor diagram shows a 90° angle between the



Phase Relationships Summary

Resistive Circuit

Current and voltage are in phase (0° phase difference)

Inductive Circuit

Current lags voltage by 90°

Capacitive Circuit

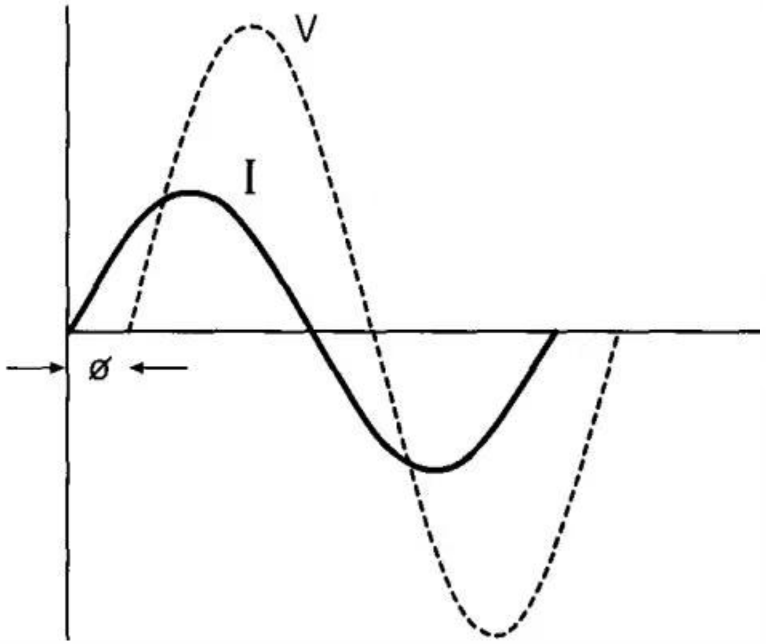
Current leads voltage by 90°

Resistive-Inductive (R-L) Circuit

Combined Effect

Many real circuits are resistive-inductive (R-L) circuits. An R-L circuit is one that has both resistance and inductance.

If the current in a purely resistive circuit is in phase with the voltage-drop, and the current in a purely inductive circuit lags the voltage-drop by 90°, then it follows that, in an R-L circuit, the current will lag the voltage by some angle between 0° and 90°.



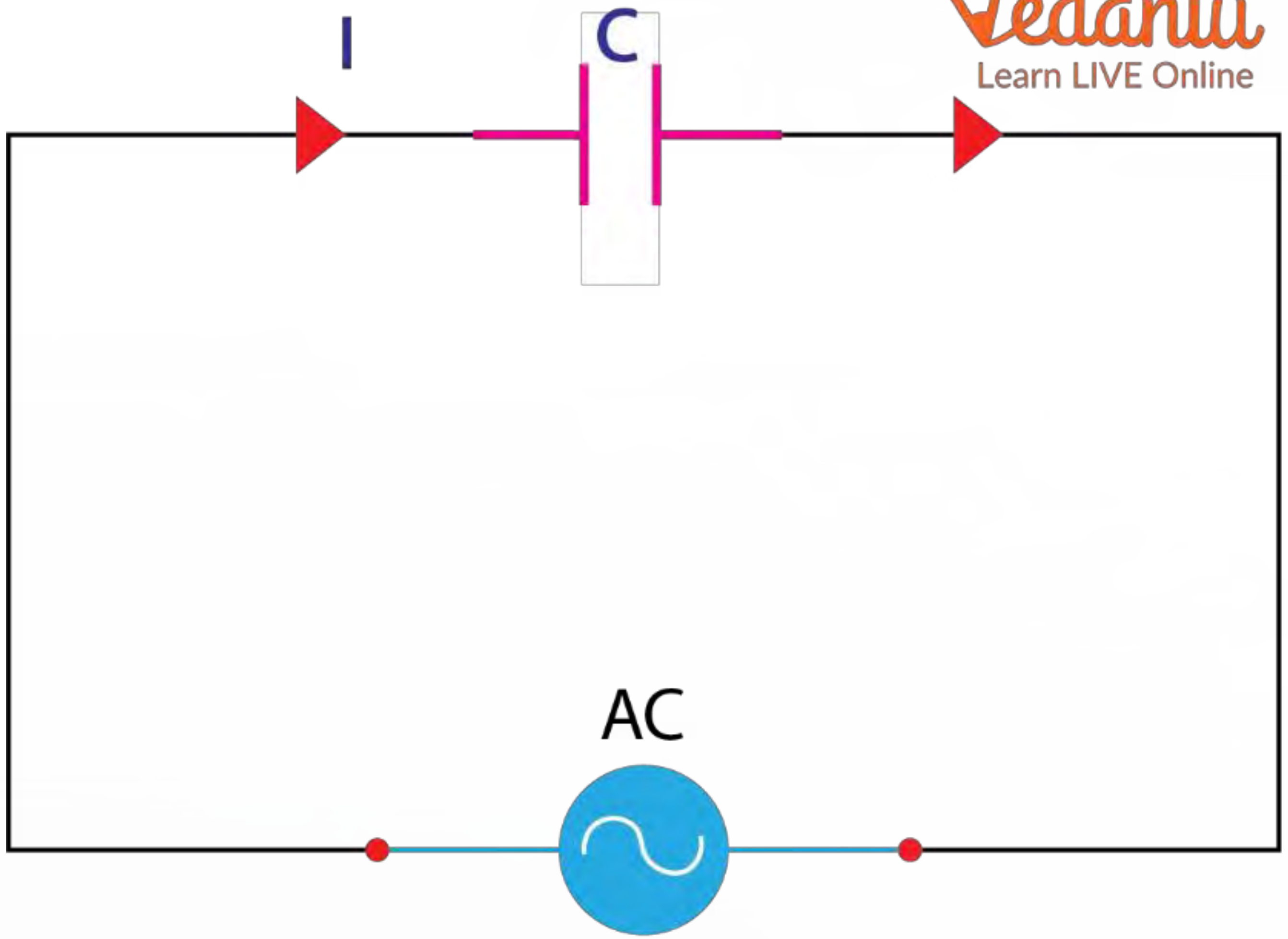
This angle is called the phase angle (φ, Greek letter phi). Exactly what this angle will be depends on the values of the circuit's resistance and inductive-reactance.

Resistive-Capacitive (R-C) Circuit

Combined Effect

Less common than R-L circuits, R-C circuits are those that have both resistance and capacitance.

Current in an R-C circuit leads the voltage by some angle (the phase-angle, φ) between 0° and 90°.



The exact phase angle depends on the relative values of resistance and capacitive reactance in the circuit.

Resistance in Electrical Circuits

Definition

In purely resistive circuits, the opposition to current is resistance. Resistance (R) depends upon the length, cross-sectional area, and material of a conductor.

Measurement

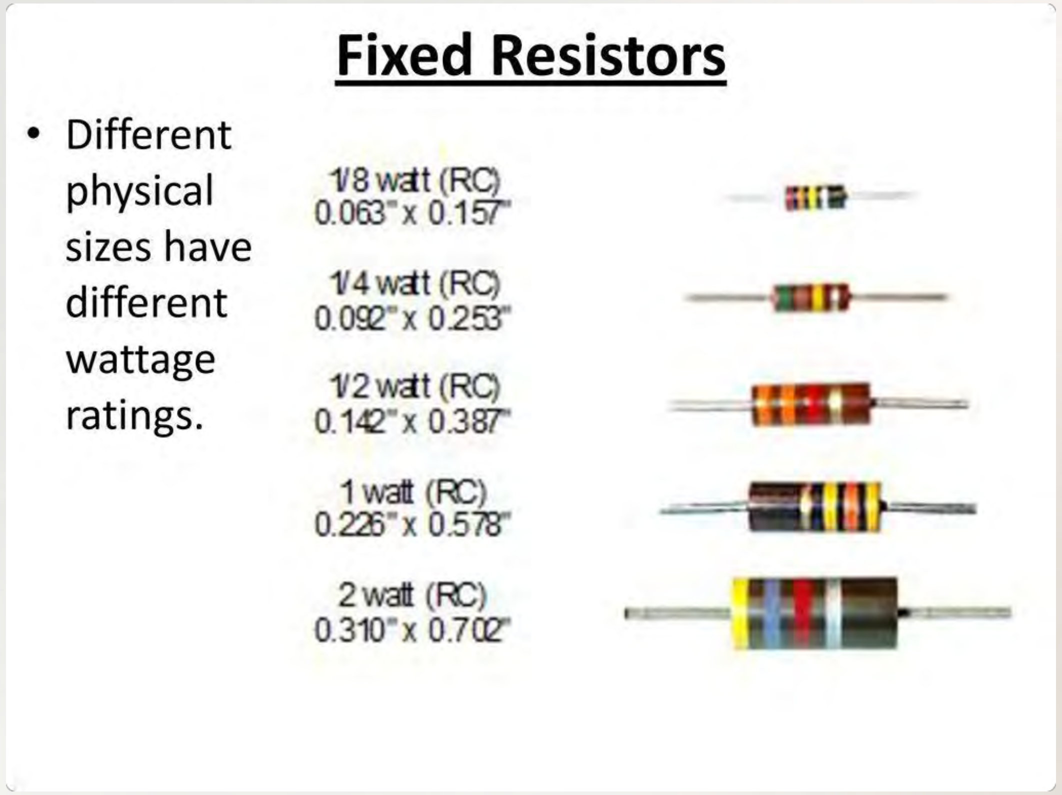
Resistance is measured in ohms (Ω).

Ohm's Law

The relationship between voltage, current, and resistance is defined by Ohm's Law: $V = I \times R$

Applications

Resistance predominates in heating circuits and other applications where electrical energy is converted to heat.



Reactance in Electrical Circuits

Definition

In purely inductive or capacitive circuits, the opposition to current is called reactance. There are two types:

- Inductive reactance (XL)
- Capacitive reactance (XC)

Calculation

Reactance depends upon a circuit's inductance (L) or capacitance (C) and the frequency (f) of the supply voltage. It is calculated as follows:

(Inductive reactance) $XL = 2\pi fL$

(Capacitive reactance) $XC = 1/(2\pi fC)$

Reactance is measured in ohms (Ω).

Impedance in Electrical Circuits

Definition

Impedance (Z) is the total opposition to the flow of current and consists of a circuit's resistance and reactance.

Calculation

For circuits with resistance and inductive reactance:

$Z = \sqrt{(R^2 + XL^2)}$

For circuits with resistance and capacitive reactance:

$Z = \sqrt{(R^2 + XC^2)}$

For circuits with resistance, inductive reactance, and capacitive reactance:

$Z = \sqrt{(R^2 + (XL - XC)^2)}$

Impedance is measured in ohms (Ω).

Power in AC Circuits

Phase Angle and Power Factor

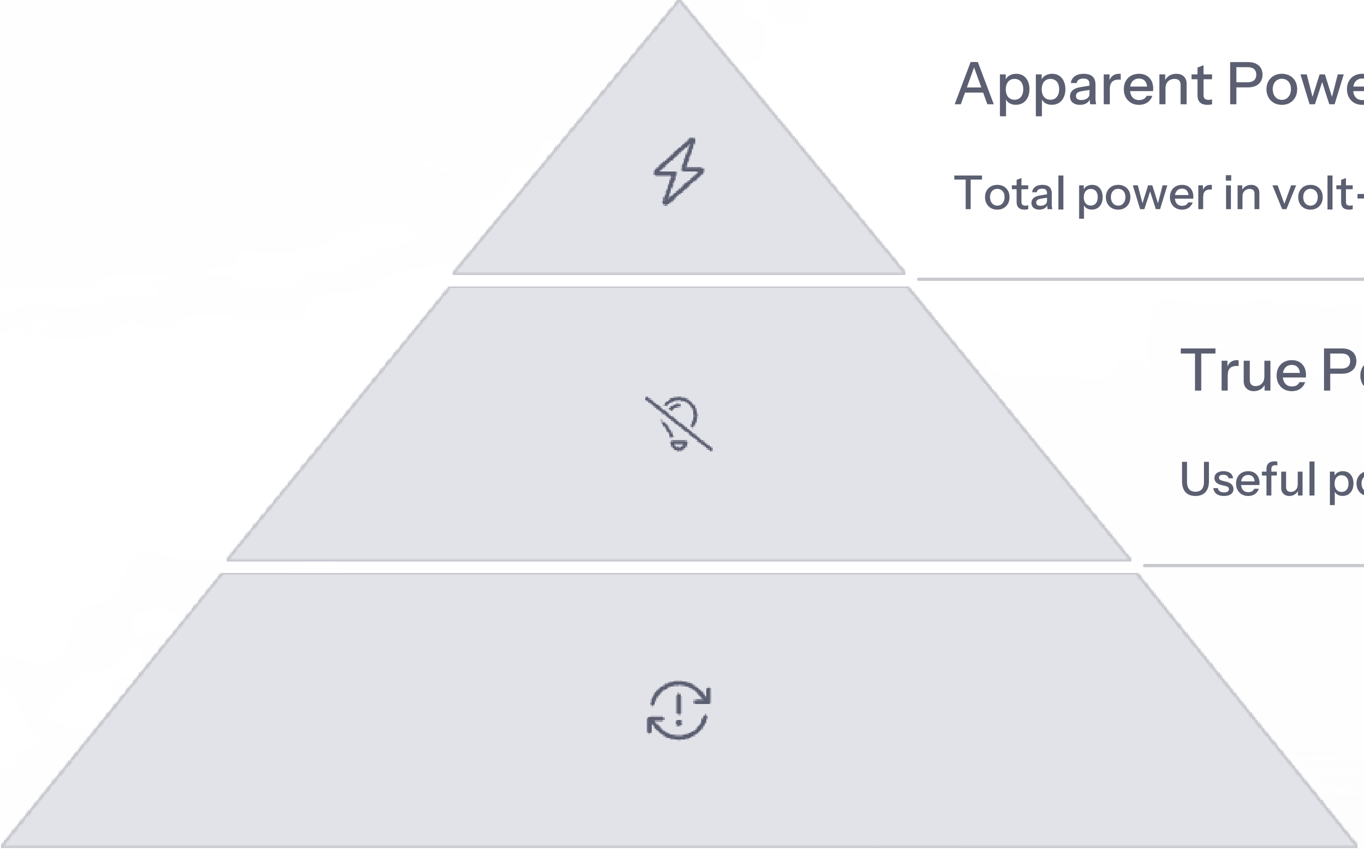
The angle between the voltage and current sine curves is measurable. This angle is called the phase angle (φ, Greek letter phi).

The cosine of this angle is the power factor of the circuit. A circuit's power factor varies between 0 (corresponding to a phase angle of 90°) and 1 (corresponding to 0°).

Types of Power

- True power (or useful power, or active power) - measured in watts (W)
- Reactive power - measured in reactive volt amperes (var)
- Apparent power - measured in volt amperes (V·A)

Power Relationships in AC Circuits



Apparent Power

Total power in volt-amperes (VA)

True Power

Useful power in watts (W)

Reactive Power

Power for magnetic/electric fields in var

The relationship between the three forms of power is based on the Pythagorean Theorem: $(\text{Apparent power})^2 = (\text{True power})^2 + (\text{Reactive power})^2$ or $\text{Apparent power} = \sqrt{((\text{True power})^2 + (\text{Reactive power})^2)}$

Power Calculations in AC Circuits

Apparent Power Calculation

Apparent power = Voltage × Current

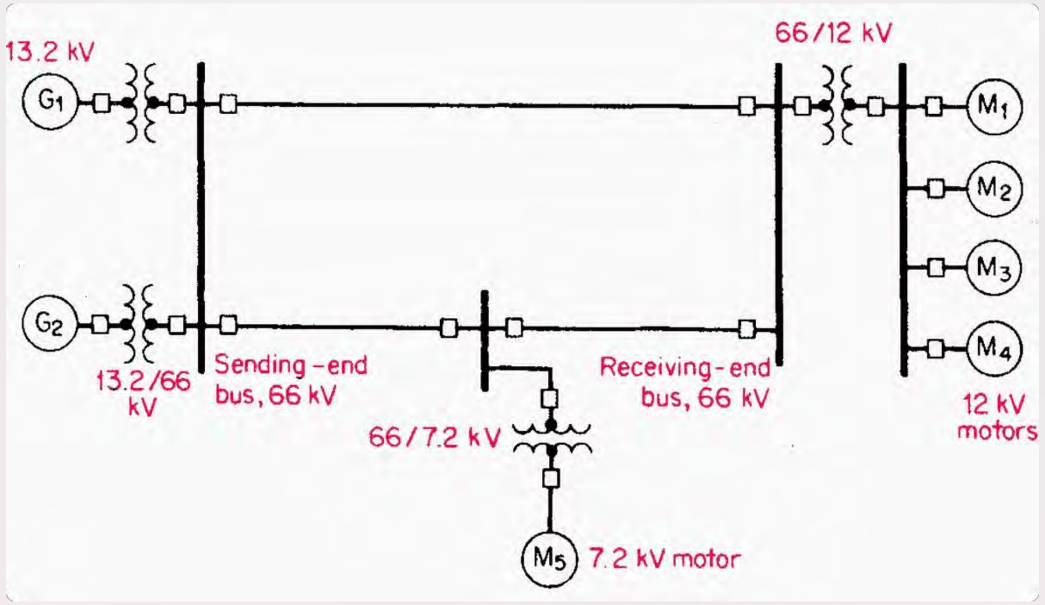
Power Factor Consideration

Power factor = cos(φ)

True Power Calculation

True power = Apparent power × Power factor

True power = Voltage × Current × Power factor



Power Factor Importance

Efficiency Considerations

For a given value of true power, the apparent power increases as the power factor falls. For low values of power factor, a generator must produce a large amount of apparent power in order to supply a relatively small amount of true power.

Optimization Goal

As the apparent power determines the amount of current that a generator supplies, it is desirable to make the value of the apparent power as close as possible to the true power.

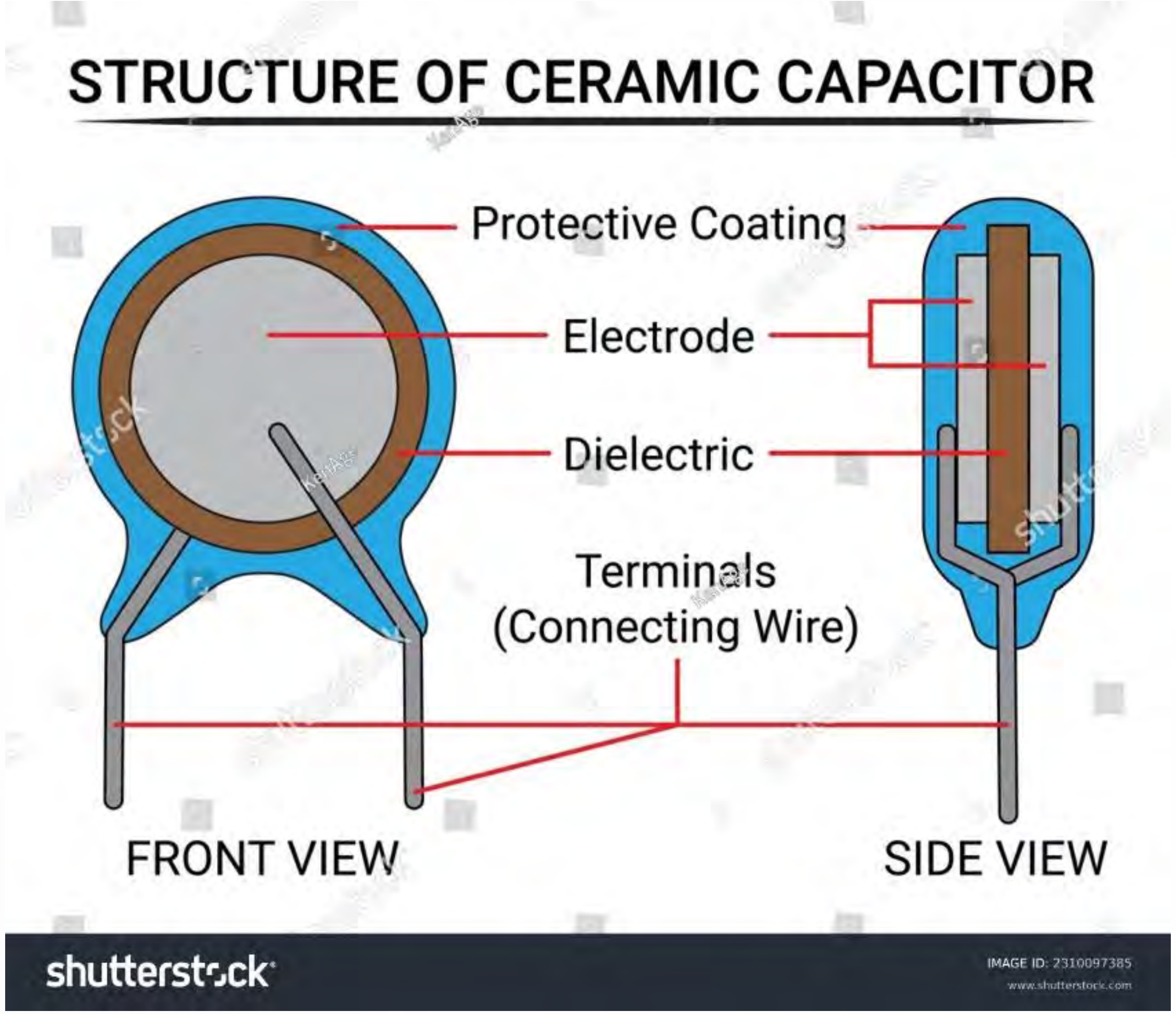
This can be achieved by ensuring that the circuit's power factor is as high (as close to 1) as possible.

Capacitance in AC Circuits

What is a Capacitor?

The capacitor consists of two aluminum electrodes (plates) with dielectric material between them. The non-conducting dielectric prevents electron flow between the plates but allows storage of an electrical charge.

The DC resistance of a capacitor is infinite (∞).



Capacitors store electrical energy in an electric field between their plates. They are essential components in many AC circuits, particularly in motor applications.

Types of Capacitors for Gas Technicians

Starting Capacitors

The starting capacitor consists of two aluminum plates separated by a dielectric of chemically treated paper, impregnated with non-conducting electrolyte. Starting capacitors are available with capacitance ratings from 75 to 600 microfarads (μF) and with voltage ratings of 110 V to 330 V.

Running Capacitors

Running capacitors stay in the motor circuit for the entire cycle of operation. For this reason, they must have some means of dissipating the resulting heat. They do this by means of an oil-filled case. The oil-filled running capacitor is larger than the starting capacitor, but its capacity is smaller.

Starting Capacitors

Physical Characteristics

Starting capacitors have relatively small cases. They are only used for a short period on each cycle of the motor they serve. Therefore, they have no need to dissipate heat, although their capacity is larger than that of running capacitors.

Technical Specifications

- Capacitance: 75 to 600 microfarads (μF)
- Voltage ratings: 110 V to 330 V
- Construction: Aluminum plates with paper dielectric
- Electrolyte: Non-conducting, chemically treated

Running Capacitors

Physical Characteristics

Running capacitors stay in the motor circuit for the entire cycle of operation. For this reason, they must have some means of dissipating the resulting heat. They do this by means of an oil-filled case.

Comparison to Starting Capacitors

- Larger physical size due to oil-filled case
- Smaller capacitance value
- Designed for continuous operation
- Better heat dissipation capabilities

Capacitors in Parallel

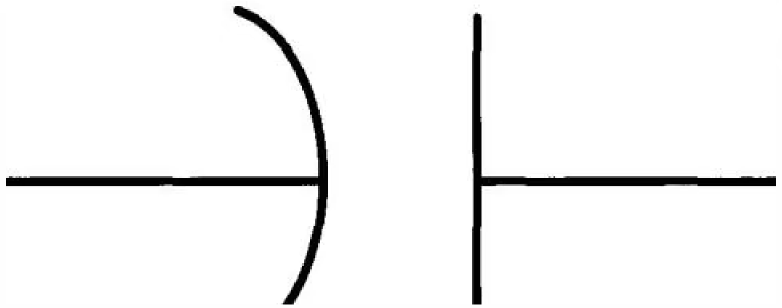
Calculation Method

The capacitance (e.g., μF) of two or more capacitors connected in parallel is the sum of the individual capacitances.

For capacitors in parallel:

Ctotal = C1 + C2 + C3 + ...

Figure 5-10
Parallel capacitance



This diagram shows how capacitors are connected in parallel and how their total capacitance is calculated.

Capacitors in Series

Calculation Method

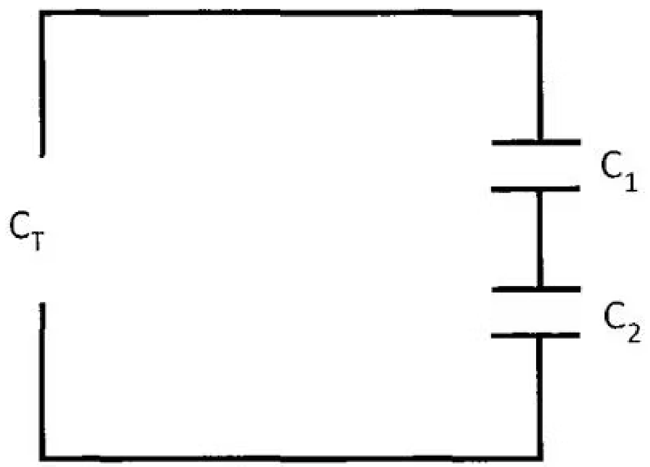
For capacitors in series, the total capacitance is calculated using the reciprocal formula:

$1/C_{total} = 1/C_1 + 1/C_2 + 1/C_3 + \ldots$

For two capacitors in series, this simplifies to:

$C_{total} = (C_1 \times C_2) / (C_1 + C_2)$

Figure 5-11
Series capacitance



This diagram shows how capacitors are connected in series and how their total capacitance is calculated.

Capacitor Calculation Example

Series Connection Example

For two capacitors in series with values of 10 μF and 15 μF:

Ctotal = (10 μF × 15 μF) / (10 μF + 15 μF)

Ctotal = 150 μF / 25 μF

Ctotal = 6 μF

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} \ldots}$$

or for 2 capacitors in series

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

Parallel Connection Example

For two capacitors in parallel with values of 10 μF and 15 μF:

Ctotal = 10 μF + 15 μF

Ctotal = 25 μF

Practical Applications of DC

Electronic Devices

Smartphones, tablets, computers, and other personal electronics typically operate on DC power, often supplied by batteries or AC adapters that convert AC to DC.

Automotive Systems

Vehicle electrical systems use DC power from the battery and alternator to operate lights, ignition systems, and other electrical components.

Small Appliances

Many portable appliances and tools use DC power from batteries or power adapters.

Solar Power Systems

Solar panels generate DC electricity which can be used directly or converted to AC for home use.

Practical Applications of AC

Residential Power

Homes are supplied with AC power for lighting, appliances, and other electrical needs.

Industrial Motors

Most industrial machinery uses AC motors due to their efficiency and power.

Power Transmission

Electrical grids transmit power over long distances using high-voltage AC.

HVAC Systems

Heating, ventilation, and air conditioning systems typically use AC power for their motors and controls.

Electrical Safety for Gas Technicians

Always Verify Power is Off

Use a properly rated multimeter to confirm power is disconnected before working on any electrical component.

Use Proper Personal Protective Equipment

Wear insulated gloves and use insulated tools when working with electrical components.

Know Your Limits

Only perform electrical work you are trained and qualified to do. Refer complex issues to licensed electricians.

Respect Electrical Hazards

Both AC and DC can be dangerous. Never underestimate the potential for electrical shock or arc flash.

Troubleshooting Capacitor Issues

Identify Symptoms

Motor fails to start, hums, runs slowly, or overheats. These can all be signs of capacitor problems.

Visual Inspection

Look for bulging, leaking, or other physical damage to the capacitor. A damaged capacitor must be replaced.

Test the Capacitor

Use a capacitor tester or multimeter with capacitance function to check if the capacitor is within its rated value range.

Replace if Necessary

Always replace with a capacitor of the same type, voltage rating, and capacitance value.

Measuring AC Voltage and Current

Digital Multimeters

Modern digital multimeters can measure both AC and DC voltage and current. When measuring AC, the meter typically displays the RMS value.

Always ensure the meter is set to the correct function (AC or DC) and an appropriate range before taking measurements.

Safety Precautions

- Use meters rated for the voltage being measured
- Use proper test leads with adequate insulation
- Keep hands behind protective barriers on test probes
- Avoid contact with conductive surfaces while testing

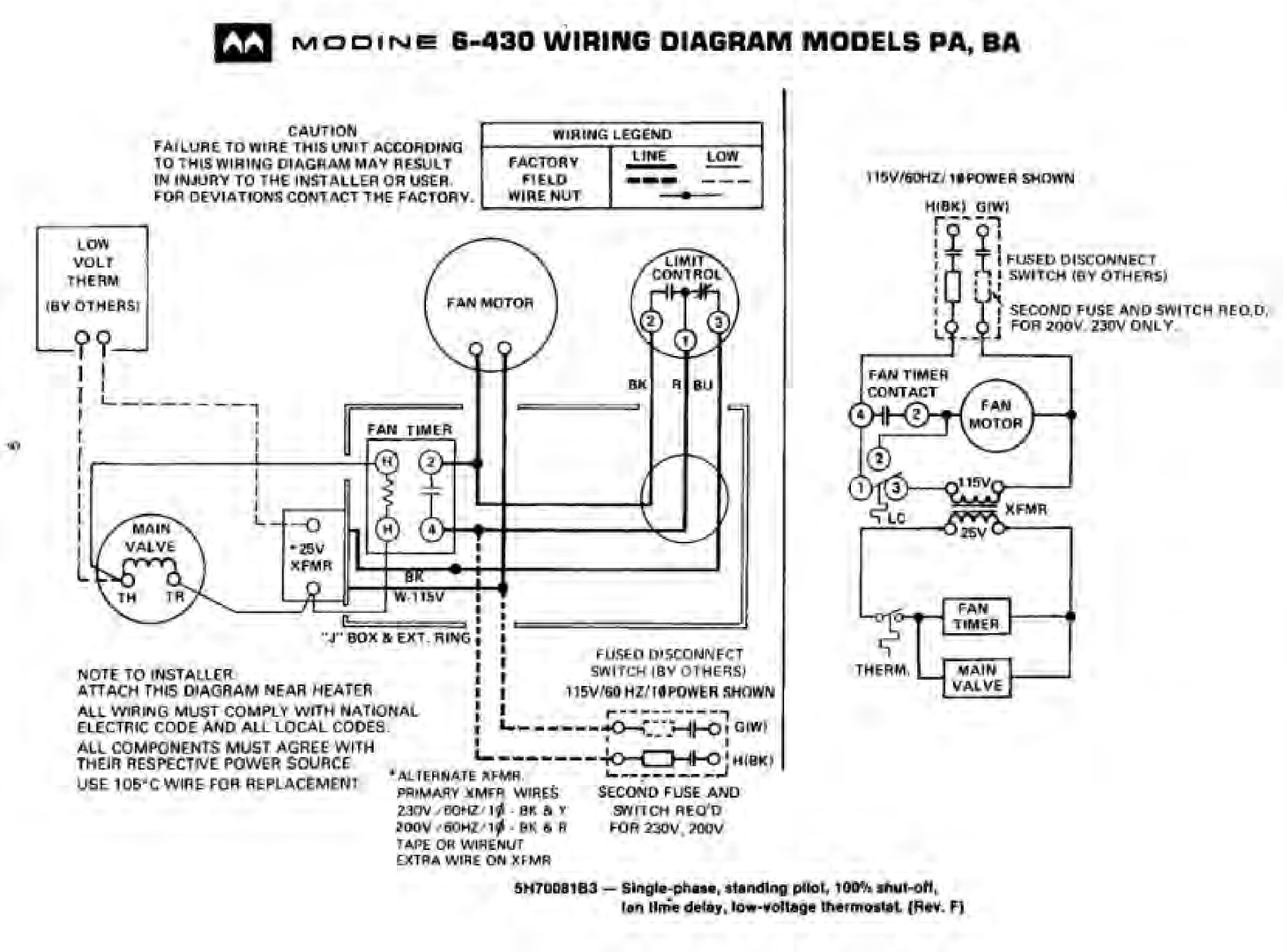
Electrical Diagrams for Gas Appliances

Reading Electrical Schematics

Gas technicians must be able to interpret electrical diagrams to troubleshoot and repair gas appliances with electrical components.

Common symbols include:

- Switches and relays
- Capacitors
- Motors
- Transformers
- Thermostats and sensors

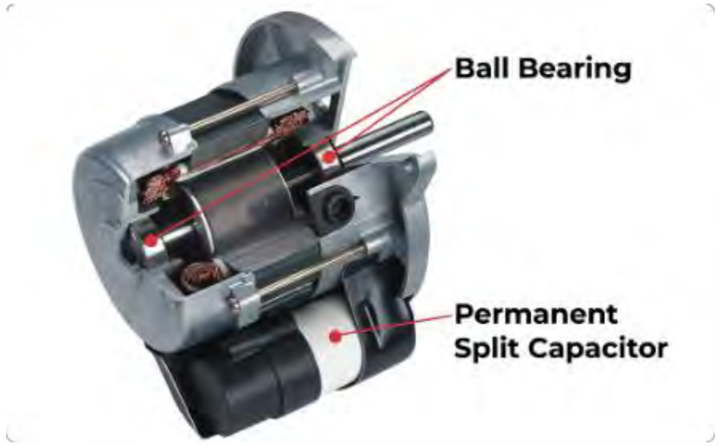


Electrical diagrams show the connections between components and help technicians understand how the electrical system functions.

Motor Types in Gas Appliances

Shaded Pole Motors

Simple, low-starting torque motors often used in fans and blowers. They have no capacitor and are the least expensive type of motor.



Permanent Split Capacitor (PSC) Motors

Use a running capacitor to create phase shift. More efficient than shaded pole motors and commonly used in furnace blowers and condenser fans.

Capacitor Start Motors

Use a starting capacitor to provide high starting torque. The capacitor is disconnected once the motor reaches about 75% of rated speed.

Transformers in Gas Appliances

Function and Purpose

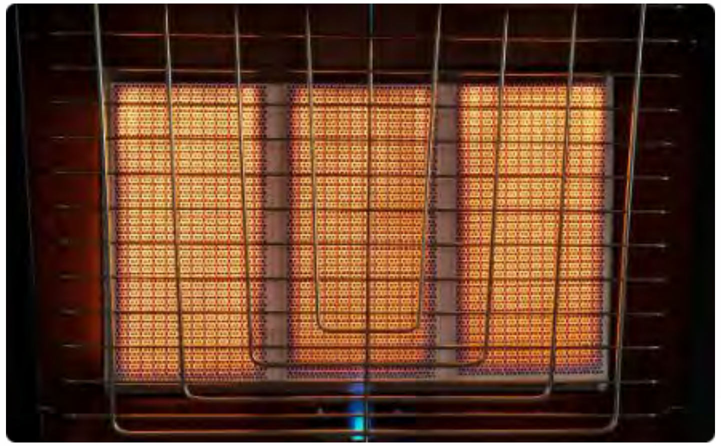
Transformers in gas appliances typically step down the supply voltage (120V or 240V AC) to lower voltages needed for control circuits (24V AC is common).

They work on the principle of electromagnetic induction between coils of wire.

Common Applications

- Powering electronic control boards
- Operating gas valves
- Supplying voltage to ignition systems
- Powering thermostats and other low-voltage controls

Ignition Systems in Gas Appliances



Standing Pilot Systems

Traditional system with a continuously burning pilot flame. Uses a thermocouple to generate a small DC voltage (25-30 millivolts) that keeps the gas valve open.

Intermittent Pilot Ignition

Uses AC voltage to create a spark that lights a pilot only when heat is called for. More efficient than standing pilot systems.

Direct Spark Ignition

Creates a high-voltage spark directly at the main burner without using a pilot. Requires AC power and electronic control circuits.

Thermocouples and Thermopiles

Thermocouple Operation

A thermocouple consists of two dissimilar metals joined together. When heated by a pilot flame, it generates a small DC voltage (typically 25-30 millivolts).

This voltage energizes an electromagnet in the gas valve, keeping it open as long as the pilot is lit. If the pilot goes out, the voltage drops and the valve closes for safety.

Thermopile Operation

A thermopile is essentially multiple thermocouples connected in series to generate a higher voltage (around 250-750 millivolts DC).

This higher voltage can operate more complex gas valves and sometimes power additional controls without requiring external electricity.

Electronic Control Boards

Function in Gas Appliances

Modern gas appliances often use electronic control boards that manage all aspects of operation, including:

- Ignition sequence timing
- Safety monitoring
- Temperature control
- Fan and motor operation
- Diagnostic functions

Power Requirements

Control boards typically operate on low-voltage AC (24V) supplied by a transformer, but may convert this to DC internally for microprocessor operation.

Some boards include capacitors for filtering and stabilizing the power supply.

Electrical Testing Equipment

Gas technicians use various electrical testing equipment to diagnose problems in gas appliances. Digital multimeters can measure voltage, current, resistance, and sometimes capacitance. Specialized tools like microamp meters measure flame sensing current, while capacitor testers verify proper capacitor operation.

Electrical Troubleshooting Process

Gather Information

Collect symptoms, history, and any error codes from the appliance

Visual Inspection

Look for obvious issues like damaged wires, burnt components, or loose connections

Check Power Supply

Verify proper voltage is reaching the appliance and its components

Component Testing

Test individual components like capacitors, motors, switches, and sensors

Repair or Replace

Fix the identified issues and verify proper operation

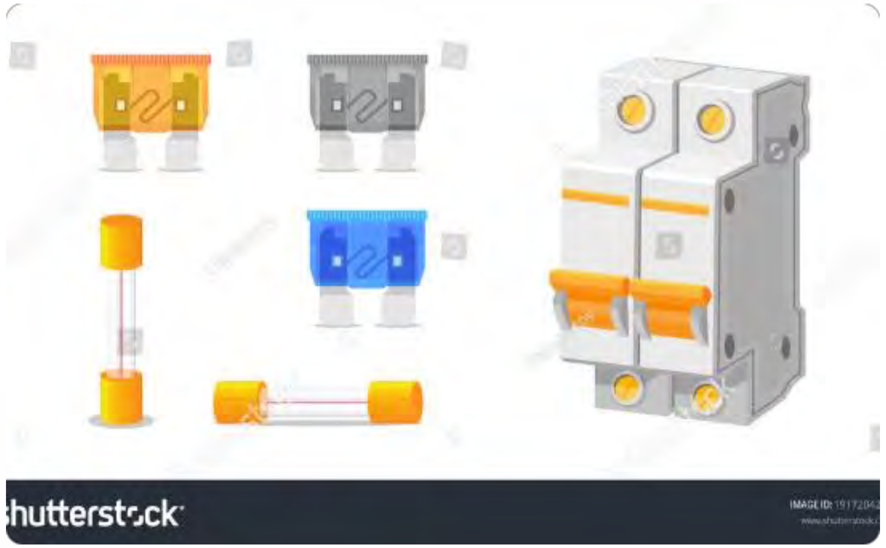
Electrical Safety Devices

Circuit Breakers

Protect against overcurrent conditions by automatically interrupting the circuit when current exceeds the rated value. They can be reset after tripping.

Ground Fault Circuit Interrupters (GFCIs)

Detect imbalances in current flow that could indicate a ground fault. They quickly disconnect power to prevent electrical shock hazards.



Fuses

One-time protection devices that contain a metal strip that melts when current exceeds the rated value. They must be replaced after blowing.

Electrical Grounding

Purpose of Grounding

Electrical grounding serves several important safety functions:

- Provides a path for fault current to safely return to the source
- Helps trip circuit breakers quickly during a fault
- Prevents metal parts of appliances from becoming energized
- Protects people from electrical shock

Grounding in Gas Appliances

Gas appliances with electrical components must be properly grounded according to local electrical codes and manufacturer specifications.

Improper grounding can lead to electrical shock hazards, erratic operation, and damage to electronic components.

Electrical Codes and Standards

National Electrical Code (NEC)

Sets the foundation for electrical safety in residential, commercial, and industrial installations.

Canadian Electrical Code (CEC)

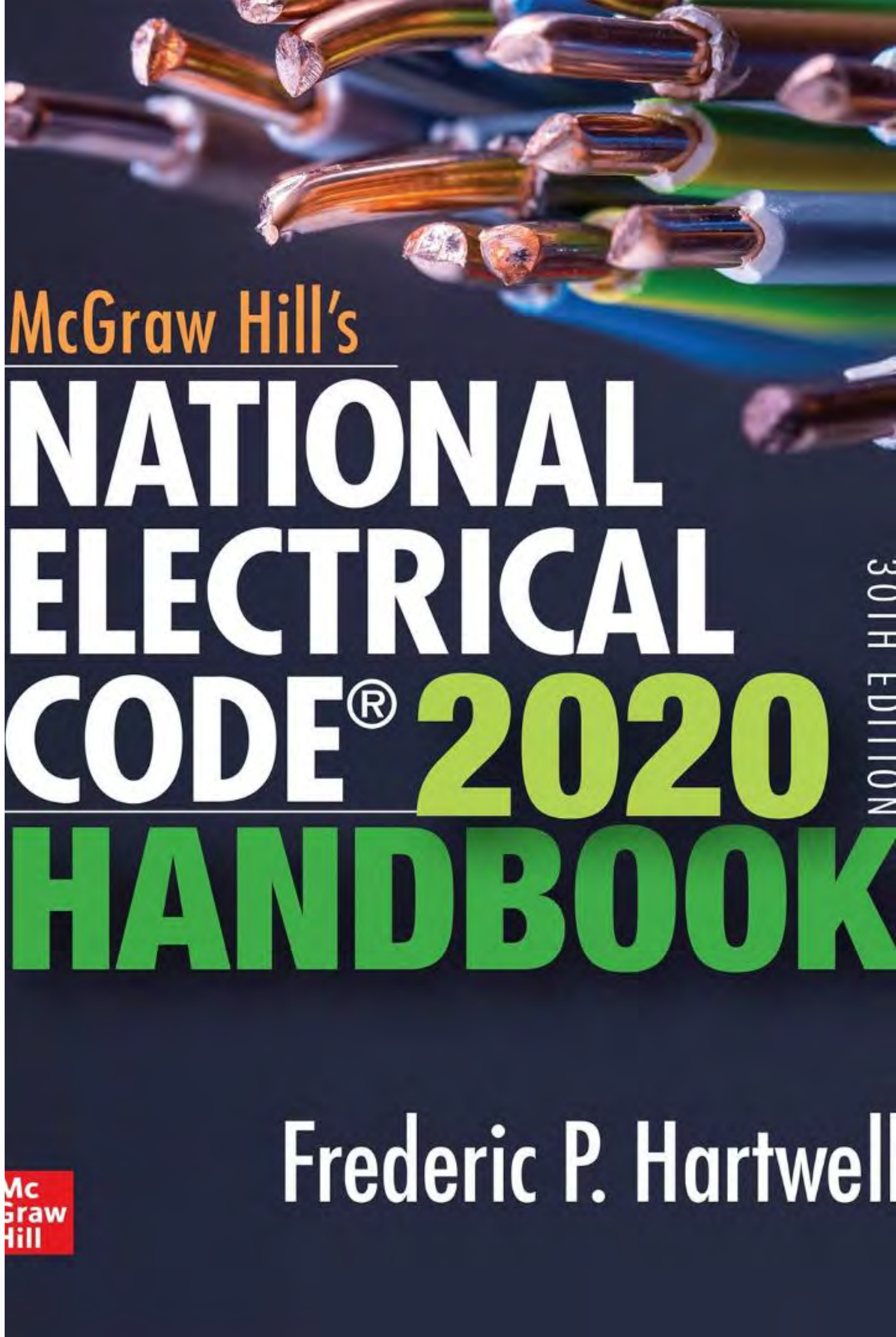
The Canadian standard for safe electrical installations, published by the Canadian Standards Association.

Local Codes

Many jurisdictions have additional requirements that supplement national codes.

Manufacturer Specifications

Equipment must be installed according to manufacturer instructions, which may have specific electrical requirements.



Power Quality Issues

Voltage Sags and Swells

Temporary decreases or increases in voltage that can affect equipment operation.

Harmonics

Distortions in the voltage or current waveform that can cause overheating and equipment malfunction.

Power Interruptions

Complete loss of power that can disrupt operation and potentially damage equipment during restart.

Transients/Surges

Brief, high-voltage spikes that can damage electronic components in gas appliances.

Energy Efficiency in Electrical Systems

Motor Efficiency

Modern high-efficiency motors use less electricity to produce the same mechanical output. They typically have:

- Better materials and design
- Lower resistance windings
- Improved bearings
- Better cooling

Variable Frequency Drives (VFDs)

VFDs allow motors to operate at variable speeds rather than just on/off, which can significantly reduce energy consumption in applications with varying load requirements.

They work by converting fixed-frequency AC power to variable-frequency output, allowing precise control of motor speed and torque.

Centimeters (cm)	0.3937	Inches (in)	2.54	Centimeters (cm)
Meters (m)	3.2808	Feet (ft)	0.3048	Meters (m)
Meters (m)	39.37	Inches (in)	0.0254	Meters (m)
Square Meters (m^2)	10.76	Square Feet (sq. ft.)	0.0929	Square Meters (m^2)

Electrical Measurements and Units

Quantity	Symbol	Unit	Unit Symbol
Voltage	V or E	Volt	V
Current	I	Ampere	A
Resistance	R	Ohm	Ω
Power	P	Watt	W
Frequency	f	Hertz	Hz
Capacitance	C	Farad	F
Inductance	L	Henry	H

Electrical Formulas for Gas Technicians

Ohm's Law

$V = I \times R$

$I = V \div R$

$R = V \div I$

Power Calculations

$P = V \times I$ (DC or AC with power factor = 1)

$P = V \times I \times PF$ (AC with power factor)

$P = I^2 \times R$

$P = V^2 \div R$

Reactance Formulas

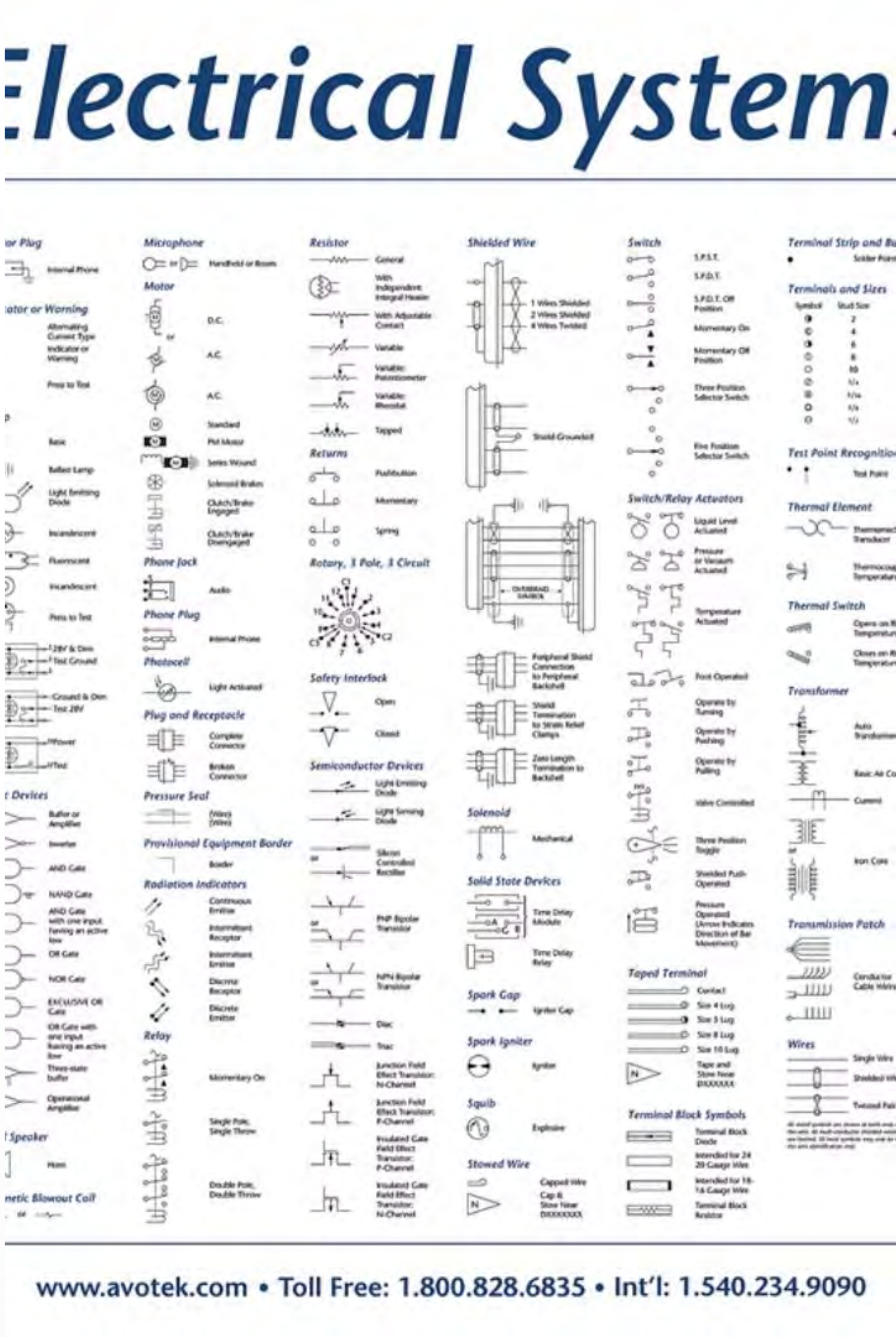
$XL = 2\pi fL$ (Inductive reactance)

$XC = 1/(2\pi fC)$ (Capacitive reactance)

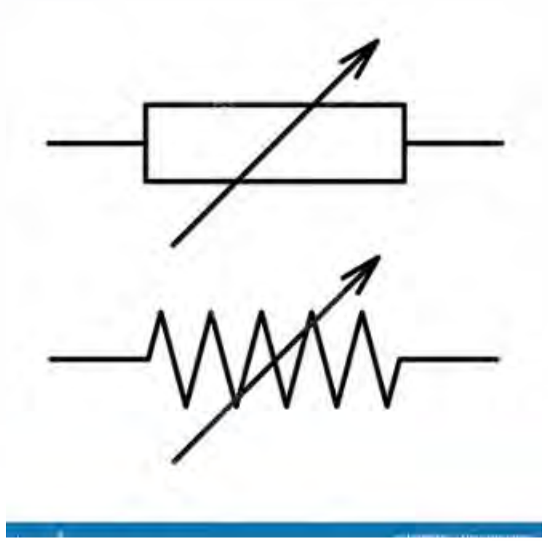
Impedance Calculations

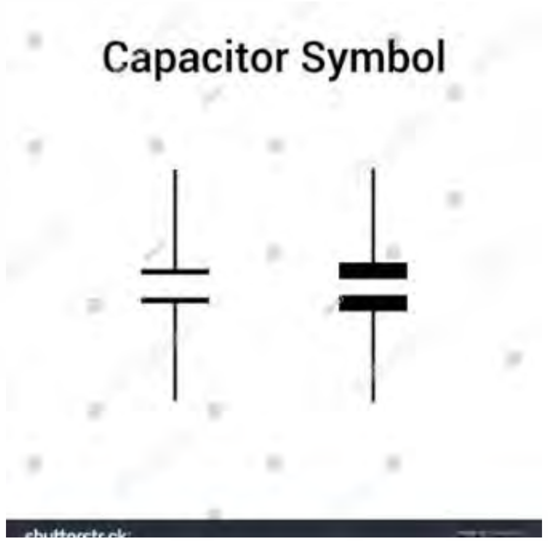
$Z = \sqrt{(R^2 + X^2)}$ (For simple circuits)

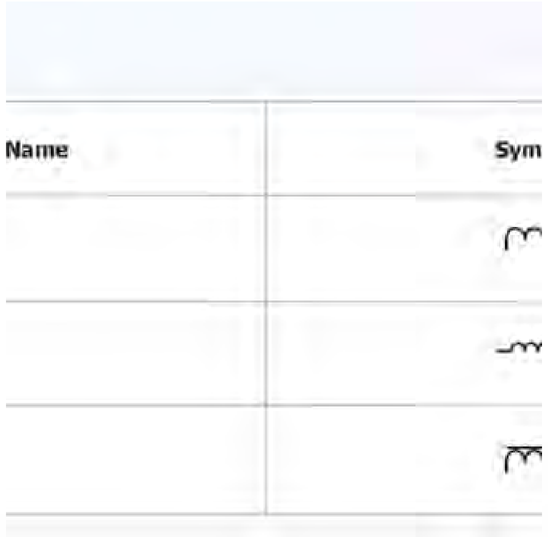
$Z = \sqrt{(R^2 + (XL - XC)^2)}$ (For RLC circuits)

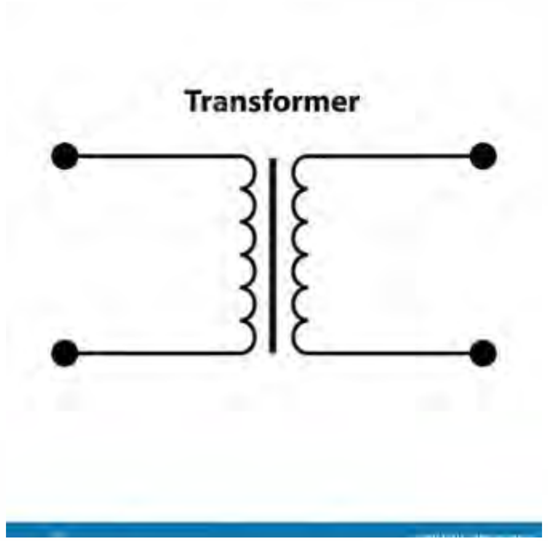


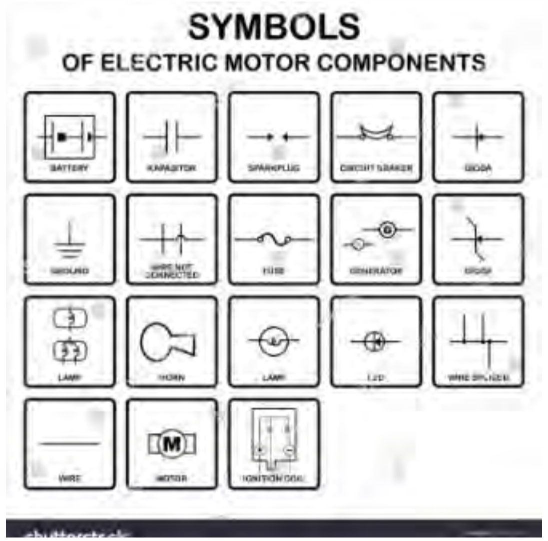
Electrical Symbols in Diagrams

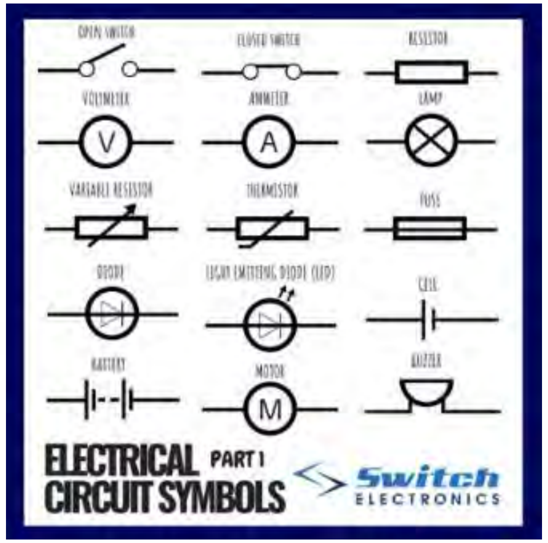


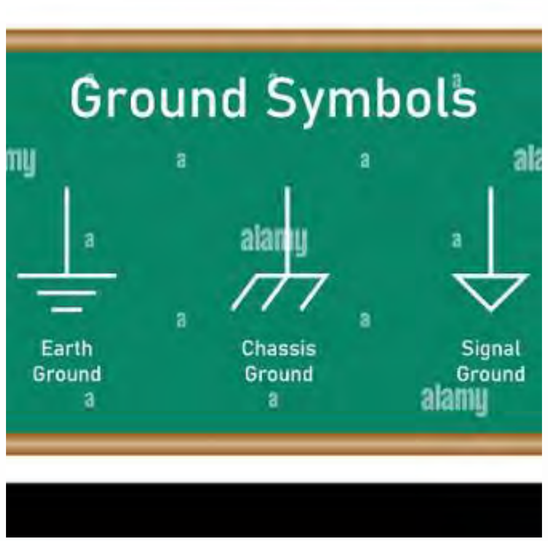












Gas technicians must be familiar with common electrical symbols used in wiring diagrams and schematics. These standardized symbols represent various components like resistors, capacitors, inductors, transformers, motors, switches, grounds, and fuses. Understanding these symbols is essential for properly interpreting diagrams when troubleshooting gas appliances with electrical components.

Review of Key Concepts

Direct Current

Flows in one direction only, often supplied by batteries

Alternating Current

Reverses direction periodically, standard for power distribution

Capacitance

Storage of electrical charge, important for motor operation

Phase Relationships

Leading and lagging between current and voltage in AC circuits

Summary and Application

Fundamental Knowledge

Understanding direct and alternating current theory is essential for gas technicians to properly work with electrical components in gas appliances.

Practical Application

This knowledge enables proper sizing, connection, and troubleshooting of electrical equipment encountered in the gas industry.

Safety Considerations

Electrical safety is paramount when working with gas appliances that incorporate electrical components.

Continuous Learning

As technology evolves, gas technicians must stay current with electrical theory and applications in modern gas equipment.

CSA Unit 5

Chapter 6
AC Power Supplies and Basic Transformer Theory

This presentation covers the fundamentals of 120-volt alternating current circuits typically present in residential applications, as well as transformer theory and operation. Gas technicians and fitters require this knowledge for proper sizing, connection, and troubleshooting of various types of transformers used in the gas industry.

Learning Objectives

Component Identification

Describe basic component identification characteristics in a 120-volt ac circuit

Transformer Principles

Describe the principles of transformer operation

Step-down transformer: Secondary voltage Vs < Primary voltage Vp

Formula for calculating voltages: $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

Step-down Transformer

Step-up Transformer

Key Terminology

Term	Abbreviation (symbol)	Definition
Transformer		Electrical device that transfers energy between two or more circuits through electromagnetic induction and commonly helps increase or decrease the voltages of alternating current in electric power applications

Electrical Distribution System

Generation

Electricity is generated at power plants

Transmission

High voltage transmission across long distances

Distribution

Voltages are stepped-down for local distribution

Consumption

120 volt AC reaches standard residential receptacles

120 Volt AC Receptacles

By the time electricity reaches a standard receptacle, such as that found in your home, the voltage has decreased to 120 volts ac from a much higher distribution voltage. Generally, electricity arrives at the receptacle inside a two-conductor cable and includes a ground wire.

Wire Color Identification

White or Natural Grey

Insulated, neutral conductors

Black (sometimes red or blue)

Insulated live or hot conductors

Green

Only for ground conductors

Receptacle Installation Requirements

Conductor Length

Each outlet must have at least 6 inches (150 mm) of free conductor for making joints or for the connection to receptacles

Terminal Identification

The neutral wire terminal has a metallic coating for identification, is made of metal that is substantially white (silvery) in colour, or has a "W" or "WHITE" marking adjacent to the terminal

Ground Terminal

The colour of the ground terminal (screw head, nut, or clamp) is green

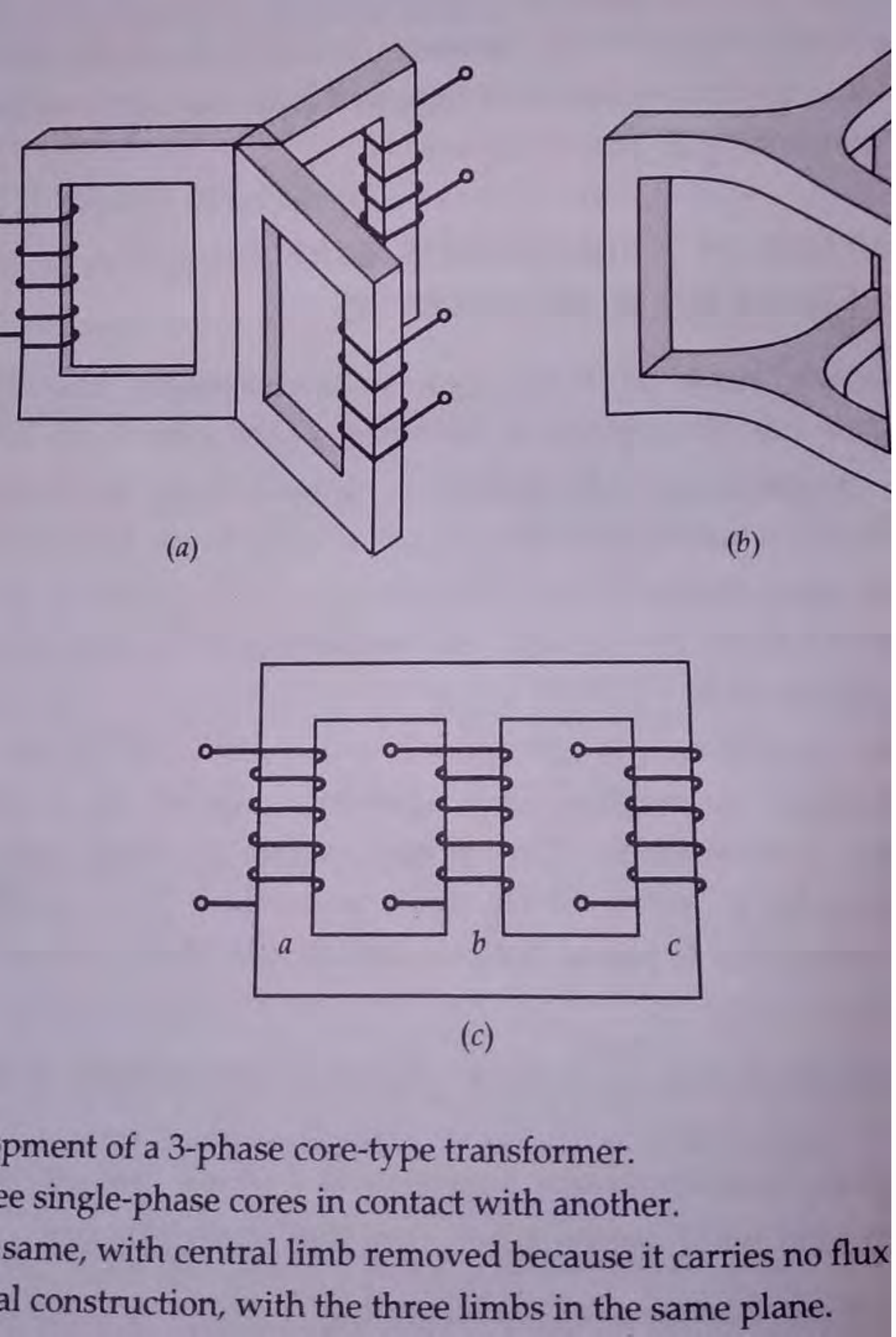
Introduction to Transformers

Definition

A transformer is an electrical device that transfers energy between two or more circuits through electromagnetic induction and commonly helps increase or decrease the voltages of alternating current in electric power applications.

Types

While most large-current transformers are three-phase, this presentation focuses on single-phase transformers for simplicity. The principle is the same for three phase, except that there are three sets of windings instead of just one.



Single-Phase Transformer Components

Primary Winding

The winding that receives the input voltage

Secondary Winding

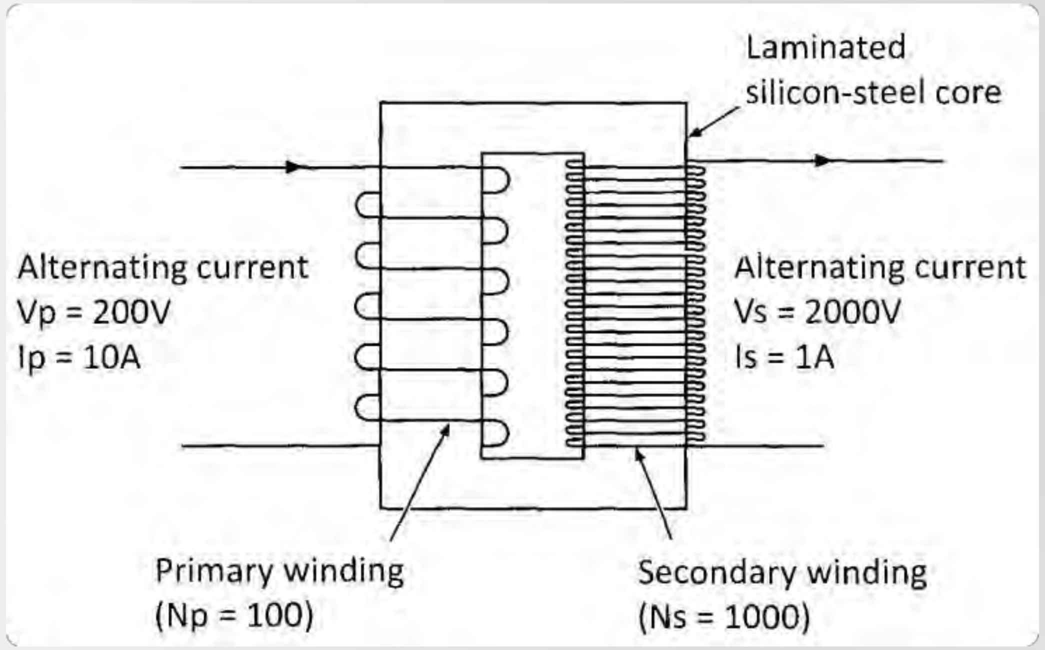
The winding that delivers the output voltage

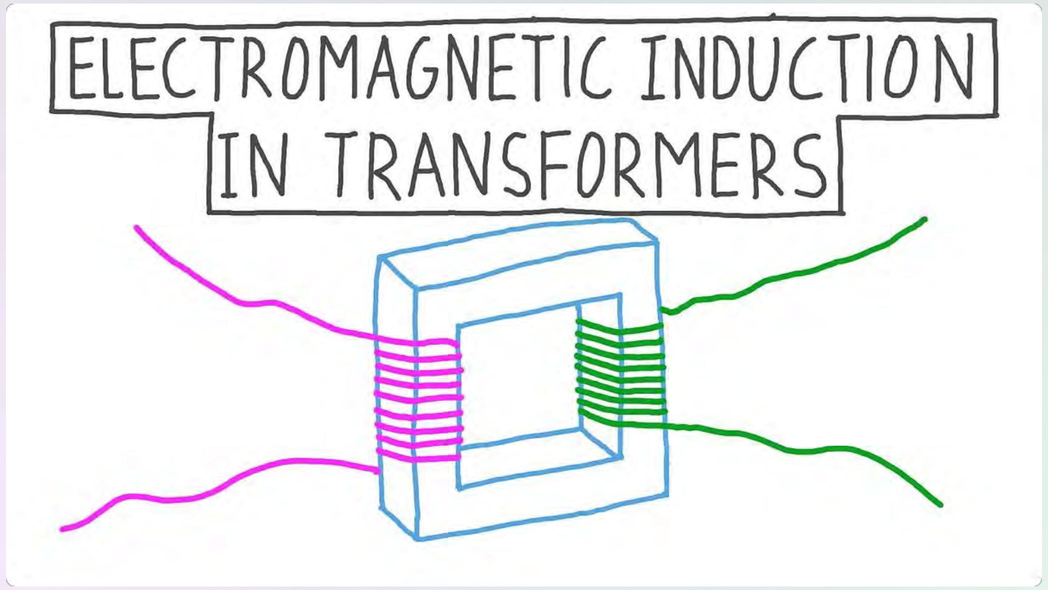
Core

Usually made of iron to concentrate the magnetic field

Single-Phase Transformer Operation

Figure 6-1 shows a transformer core with a primary winding and a secondary winding. The windings are actually wound around each other on a real transformer. However, for simplicity of understanding, the figure shows two separate windings. The current is supplied to the primary winding and the output is from the secondary winding. In this example, there are 100 turns (Np= 100) in the primary and 1000 turns (Ns = 1000) in the secondary.





Electromagnetic Induction in Transformers

Current Flow

When the primary winding of this transformer takes an alternating voltage, a current flows

Magnetic Field Generation

A magnetic field develops around the winding and fluctuates at 60 Hz

Flux Lines

The flux lines cut through the secondary winding

Voltage Induction

A voltage is induced into the secondary winding through electromagnetic induction

Step-Up Transformers

Definition

A step-up transformer has more turns in the secondary winding than in the primary winding, resulting in a higher output voltage than input voltage.

Example

In Figure 6-1, the secondary coil has 1000 turns and the primary has 100 turns. This means that the secondary voltage is 10 times the primary voltage (1000 ÷ 100). Since the primary voltage is 200 V, then the secondary voltage will be 2000 V (200 x 10).

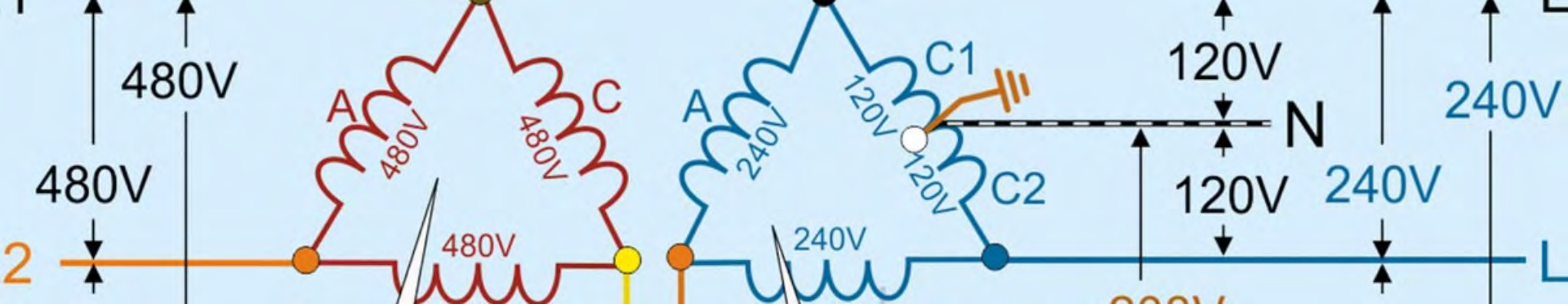
Step-Down Transformers

Definition

A step-down transformer has fewer turns in the secondary winding than in the primary winding, resulting in a lower output voltage than input voltage.

Operation

In a step-down transformer, the operation is exactly the same as a step-up transformer. However, the secondary winding has fewer turns than the primary winding so the secondary voltage is less than the primary voltage. Also, the secondary current is greater than the primary current.



Transformer Output Calculation

Voltage Ratio Formula

You can calculate the secondary (output) voltage of a transformer by multiplying the primary voltage by the ratio of turns in the secondary to primary coils.

$V_s/V_p = N_s/N_p$

Variables

V_s = secondary voltage

V_p = primary voltage

N_s = turns in secondary coil

N_p = turns in primary coil

Transformer Current Calculation

Power Conservation

Transformer efficiency is very high, so the output power is very close to the input power. Since power is a function of the voltage times the current, you can calculate the secondary current if you know the primary current.

$V_pI_p = V_sI_s$

Therefore: $I_s = (V_p/V_s) \times I_p$

Example

In the example, the primary current is 10 A. Since output voltage increases by ten times and the power remains the same, the current must decrease by ten times. The current in the secondary winding must therefore be 1 A.

Wire Size in Transformers

Step-Up Transformers

Since the secondary current is lower than the primary current in a step-up transformer, the size of the conductor in the secondary winding can be smaller

Winding Design

You can make the winding with the most turns of smaller-diameter wire

Step-Down Transformers

In step-down transformers, the secondary current is greater than the primary current, requiring larger wire for the secondary winding

HF transformer efficiency [%] with standard #43 ferrite cores
(Calculated with https://owenduffy.net/calc/toroid.htm)
09/01/2021 HB9BCB

0-43 . turns	FT-240-43 3 prim. turns	FT-140-43 2 prim. turns	FT-140-43 3 prim. turns	FT-114-43 2 prim. turns	FT-114-43 3 prim. turns	FT-82-43 2 prim. turns	FT-8 3 prim
7	85	59	82	28	68	23	6
9	86	62	83	33	70	28	6
1	87	64	84	38	72	33	7
3	88	66	85	41	74	37	7
5	89	68	86	45	76	41	7
5	89	69	86	46	76	43	7
6	89	70	87	47	77	44	7
6	89	70	87	49	77	45	7
7	90	71	87	50	77	46	7

ers with a coupling ratio of 50:2450 ohms (1:49) do not achieve a good antenna coupling at 80 m

Self-Regulation in Transformers

Load Change

As the current flow through the secondary winding changes

Primary Current Adjustment

The primary current also changes automatically

Power Balance

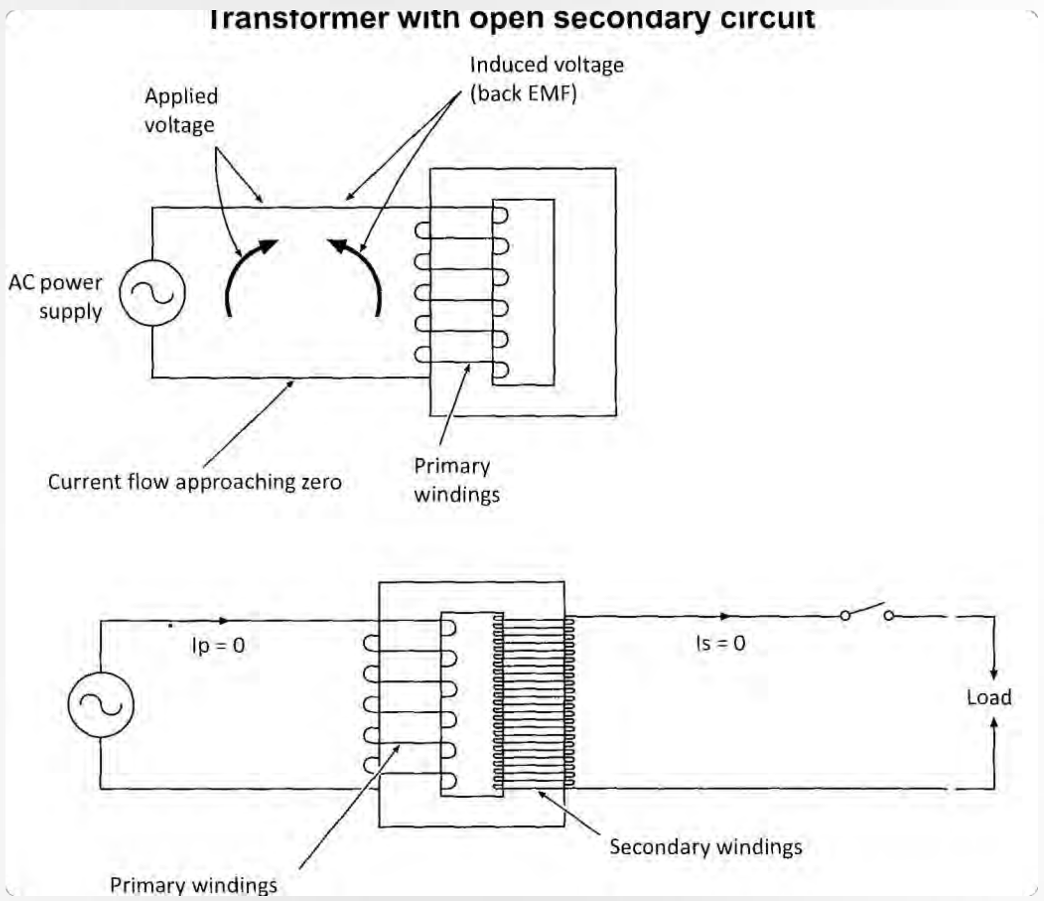
Input and output power remain balanced

Circuit Protection

If opening a switch or circuit breaker stops the secondary current, the primary current flow also stops

Transformer with Open Secondary Circuit

In the upper portion of Figure 6-2 is a simple coil of conductor that wraps around a steel core. An ac voltage applied to the coil normally results in a flow of current through the wire. In fact, since there are no resistors in this circuit, a large current flow results. This is the case in a de circuit. But in a properly designed alternating current circuit, very little current will flow.



Back EMF in Transformers

Alternating Current

The alternating current causes a magnetic field to build up and collapse around the coils 120 times per second

Flux Lines

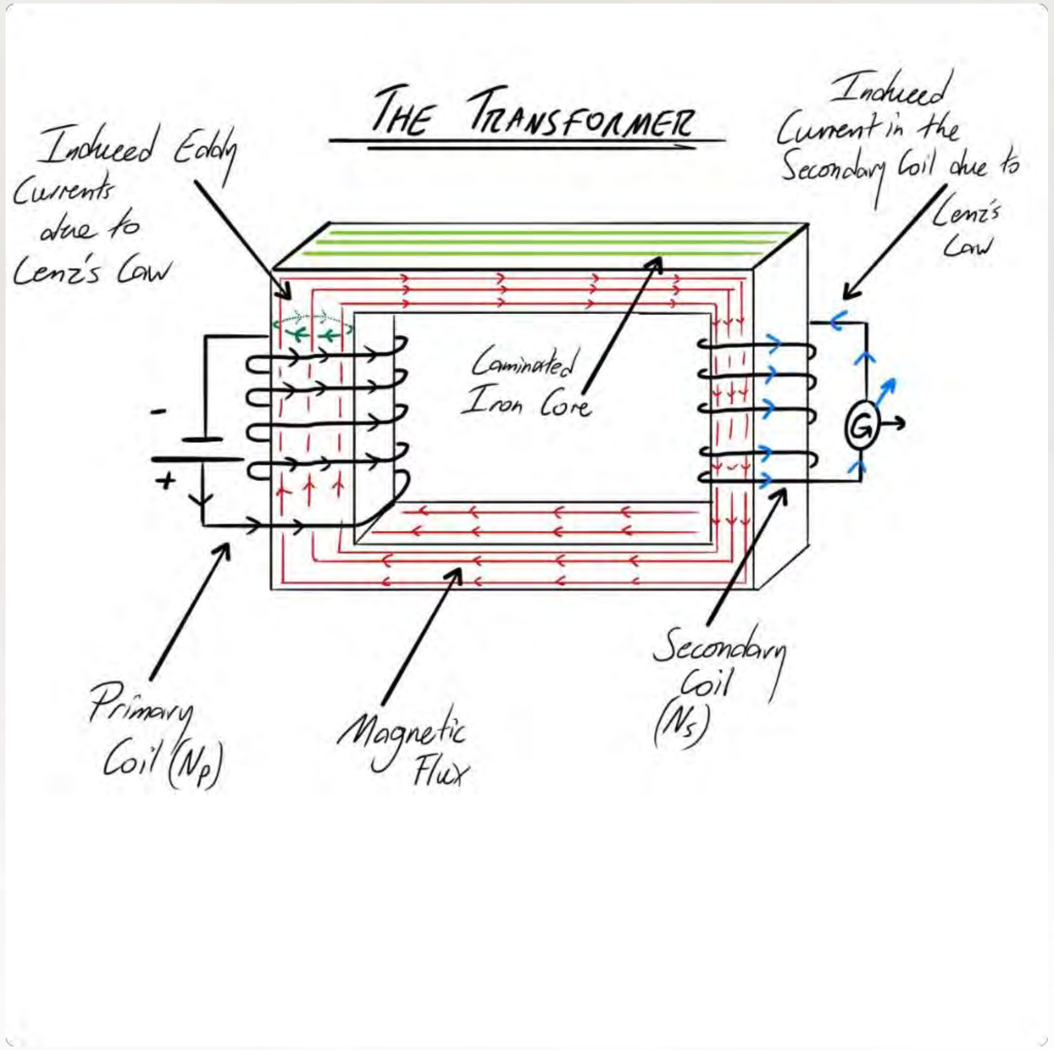
As the lines of flux pass through the primary winding, they induce a voltage in that winding

Induced Voltage

This induced voltage is the opposite of applied voltage and acts to limit applied voltage

Voltage Cancellation

The two voltages (applied and induced) very nearly cancel each other out, so only a very small current flows



Back EMF Example

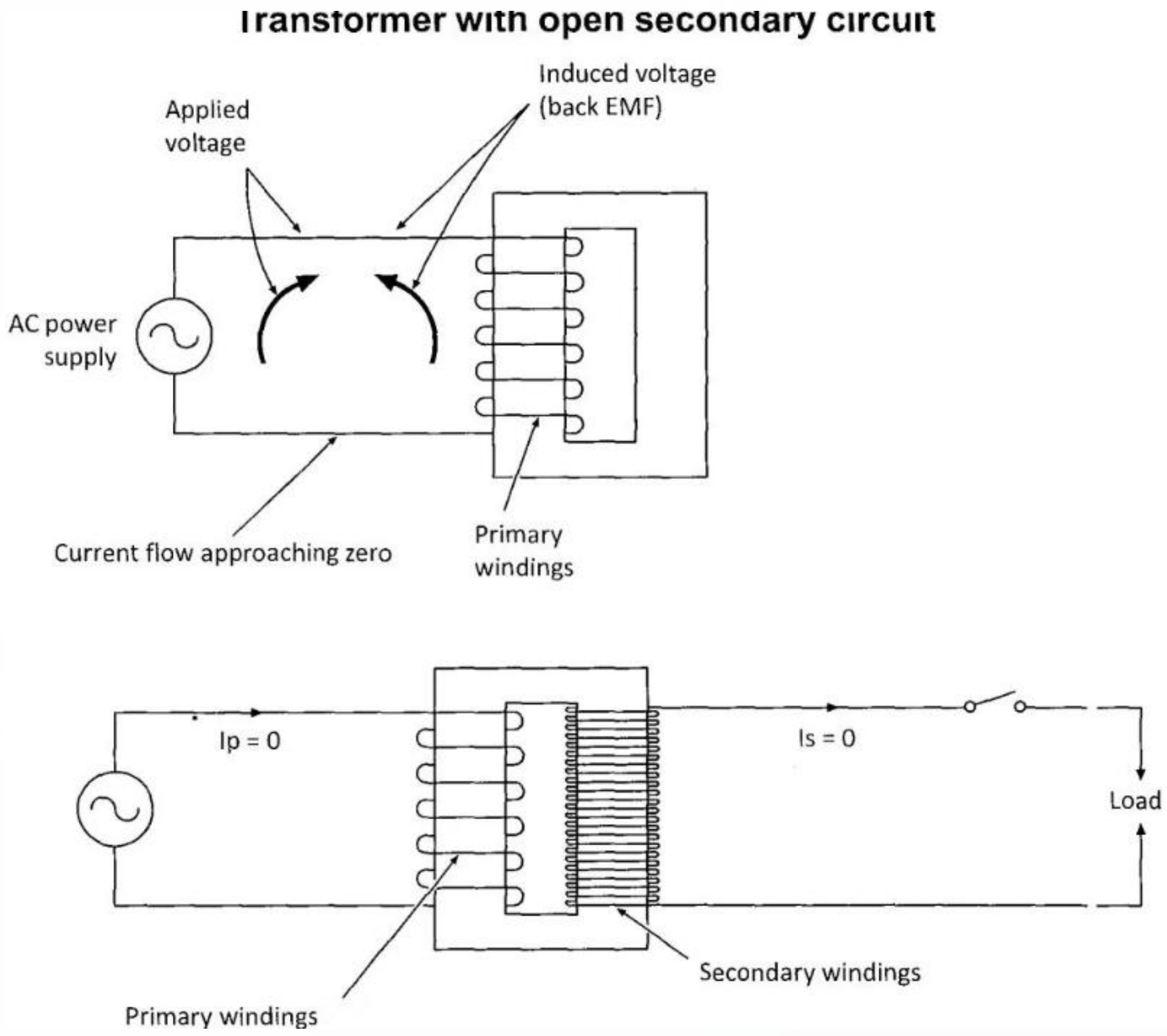
Example

If a 60 Hz supply is connected to the coil with a voltage of 220 V, the fluctuating magnetic field induces a voltage in the winding that is equal to the applied voltage, but in the opposite direction.

Terminology

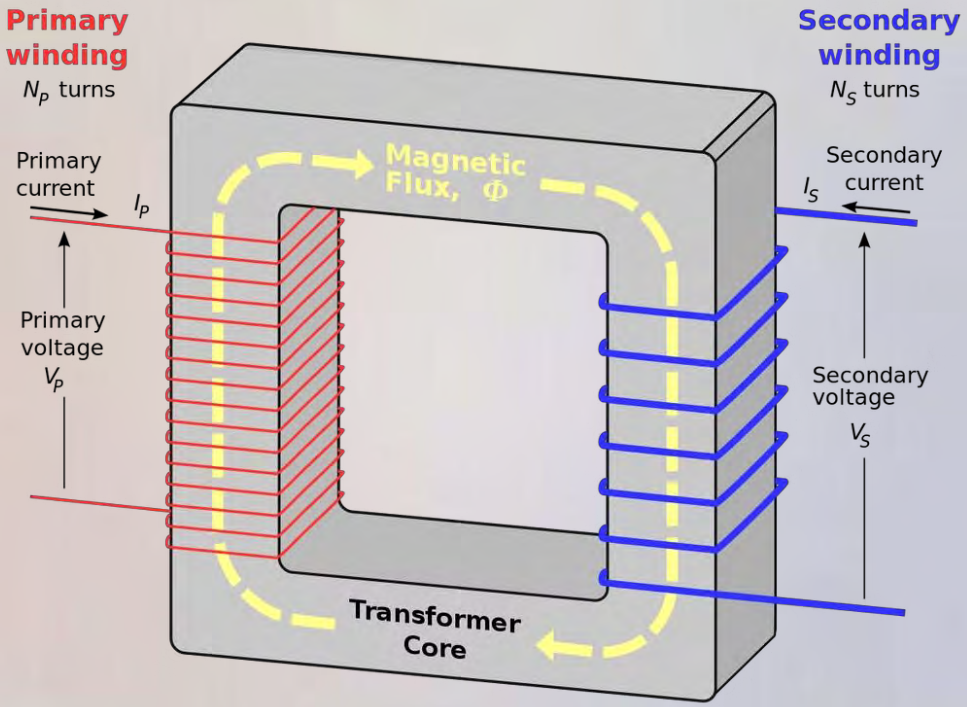
The induced voltage is often what you call back emf. Another term for source voltage is electromotive force (emf). Back emf plays an important part in limiting the current flow through electric machines.

Transformer with Open Secondary Circuit



The bottom part of Figure 6-2 shows a simple transformer with the secondary circuit open at the switch. Since no current flows through this circuit, it has no effect on the transformer, which operates as though there were only one coil.

Thus, when the secondary circuit is open, the primary current flow decreases to a very small value. Although there is no current flow in the secondary circuit, the field produced by the very small primary current maintains the terminal voltage of the transformer's secondary winding's terminal voltage.



Transformer Under Load

Switch Closure

When the switch is closed and a small load is placed across the secondary circuit, enough current flows to supply this load

Secondary Magnetic Field

This current flow in the secondary winding now produces a magnetic field of its own

Field Opposition

The magnetic field that the secondary winding current produced is opposite the magnetic field that the primary winding current produced

Primary Field Reduction

Because the secondary field opposes the primary field, the primary field is reduced

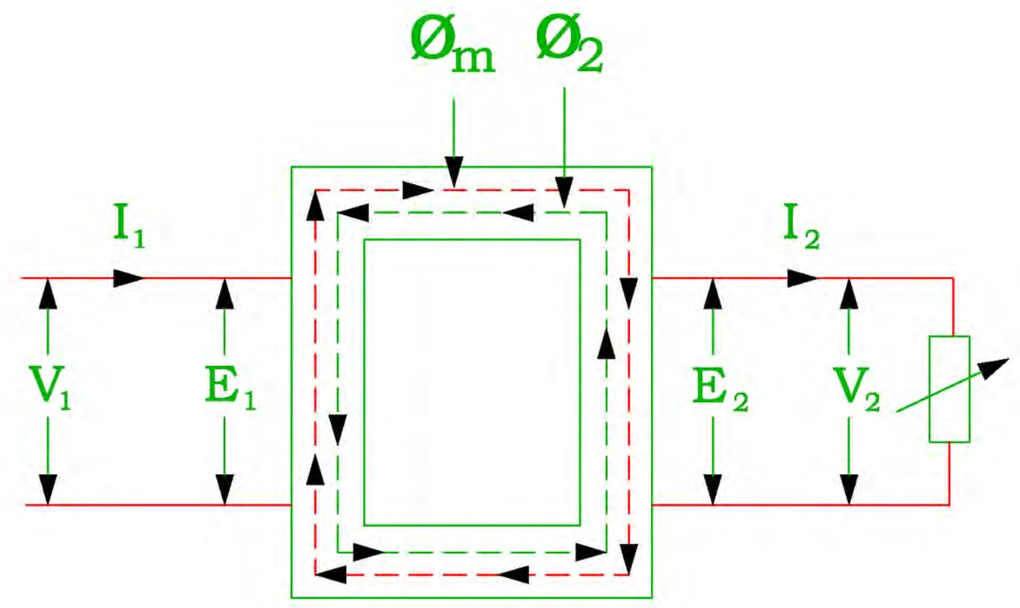


FIG A : TRANSFORMER ON LOAD

Back EMF and Current Flow

Reduced Primary Field

The primary field is reduced due to the opposing secondary field

2

Reduced Back EMF

This is the magnetic field that produced the back emf. Since the primary field is reduced, the back emf is reduced in the primary winding

Increased Primary Current

The reduction in the back emf causes more current to flow in the primary winding

Self-Regulation

Any increase in the secondary current flow results in a proportional increase in primary current flow

Load Increase Effects

Secondary Load Increases

As the secondary load increases

Secondary Current Increases

The current flow through the secondary winding increases

Secondary Field Strengthens

This increase in current strengthens the secondary field

Primary Field Weakens

The stronger secondary field further weakens the primary field

Primary Current Increases

This further reduces back emf and increases primary current flow

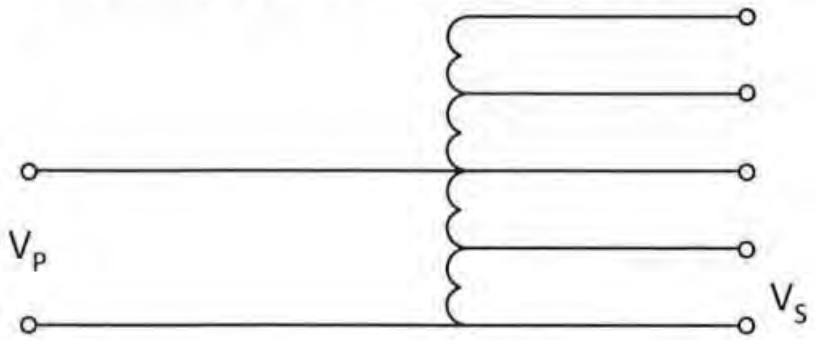
Autotransformers

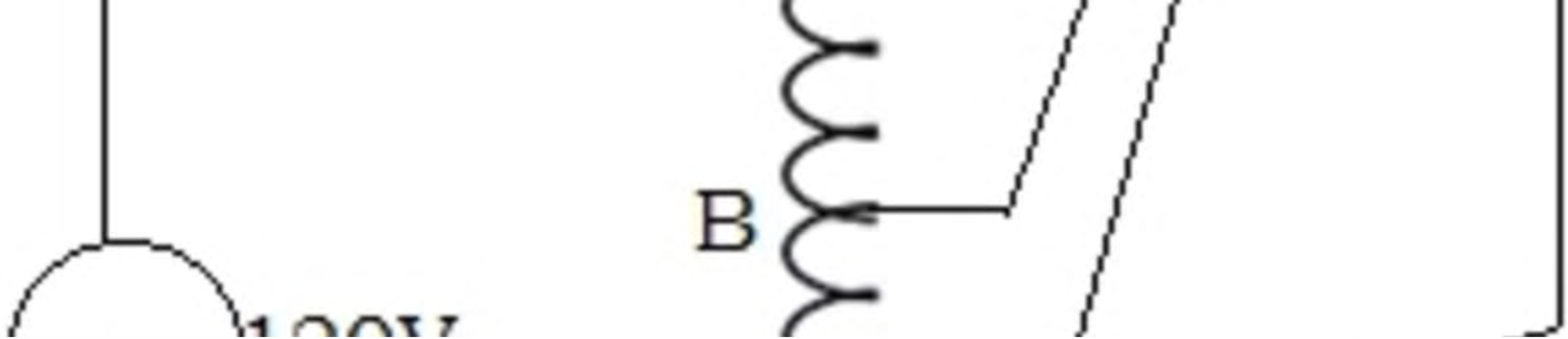
Definition

An autotransformer differs from the standard transformer in that it consists of a single coil, arranged as shown in Figure 6-3.

An autotransformer is a power transformer with one continuous winding, part of which serves as the primary winding and all of which serves as the secondary winding, or vice versa. Secondary voltages are supplied across any pair of a series of connections (taps).

Figure 6-3
Autotransformer connections





Autotransformer Characteristics

No Electrical Isolation

An important thing to note is that there is no electrical isolation between the primary and secondary of an autotransformer

Economic Advantage

For this reason, autotransformers are more economical to manufacture than other types

Safety Concern

For the same reason, they are also more vulnerable to catastrophic failure

Transformer Applications in the Gas Industry

Control Systems

Transformers power control systems for gas equipment

Ignition Systems

Step-up transformers provide high voltage for spark ignition

Sensors and Monitoring

Low-voltage transformers power sensors and monitoring equipment

Safety Systems

Transformers provide power for safety shutoff systems

Transformer Efficiency

95%

Typical Efficiency

Modern transformers have very high efficiency ratings

5%

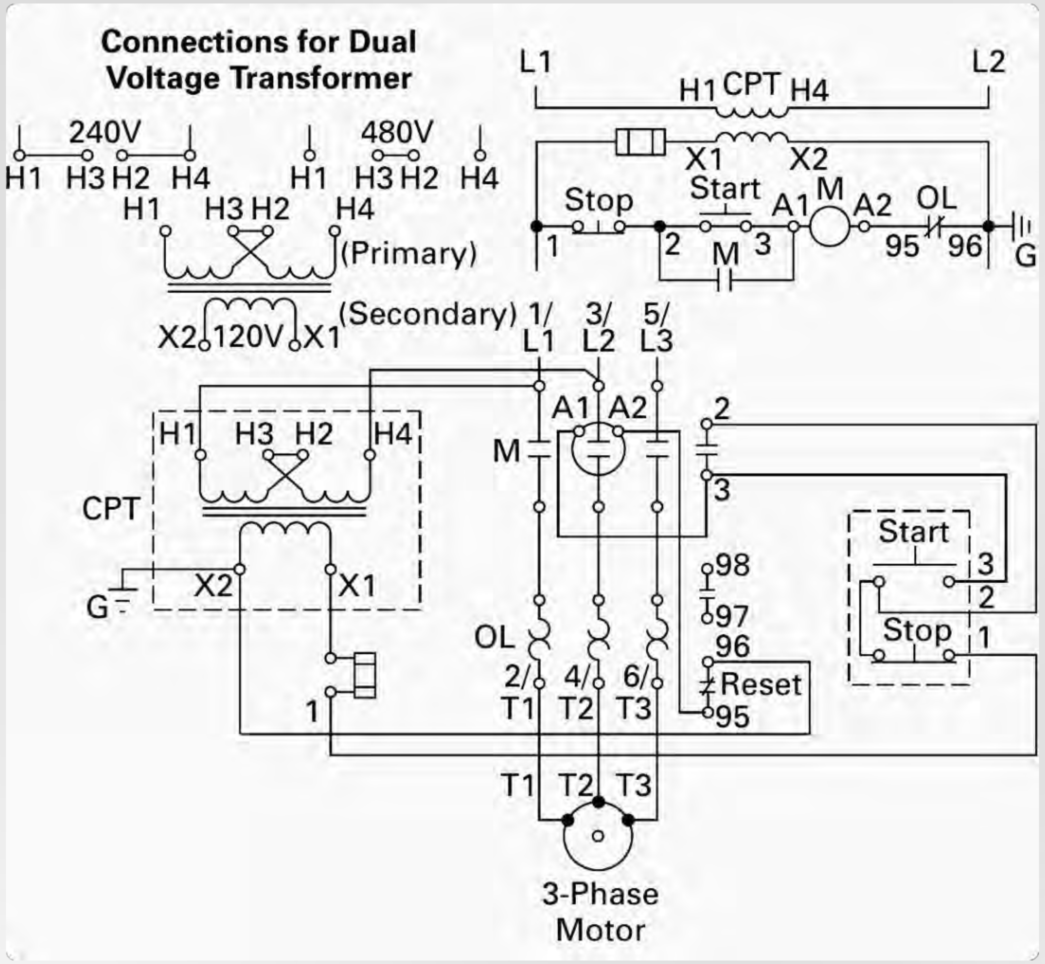
Power Loss

Small percentage of power is lost as heat

60Hz

Standard Frequency

North American power system frequency



Transformer Cooling Methods

Air-Cooled

Small transformers use natural air circulation for cooling

Forced-Air Cooled

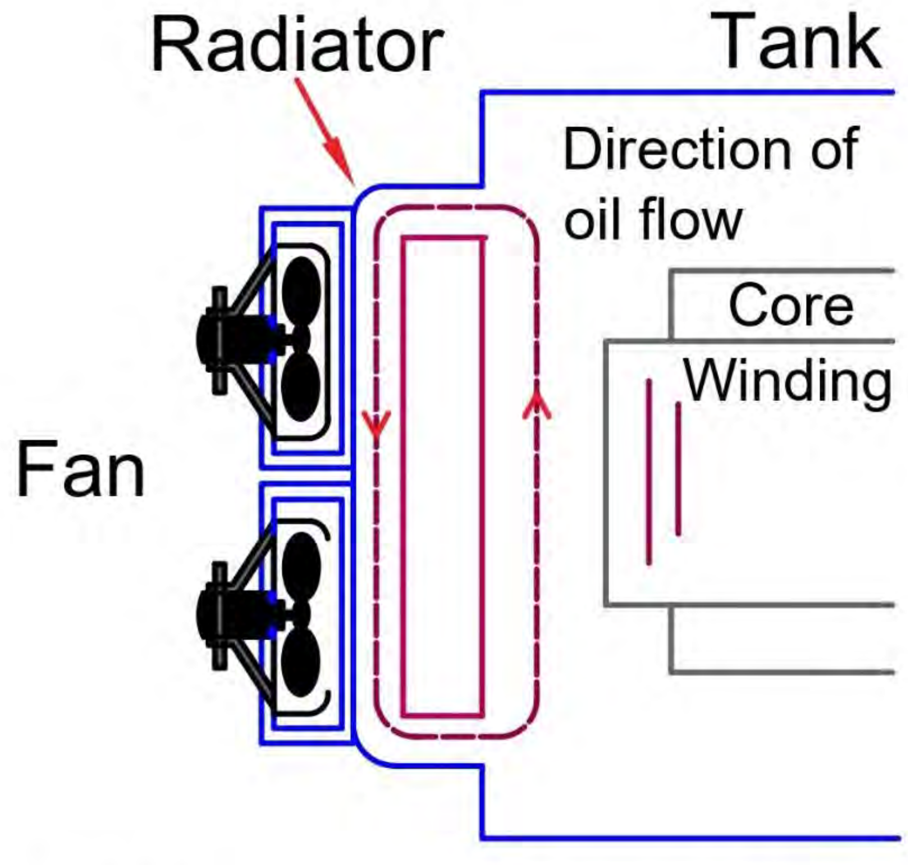
Medium-sized transformers use fans to enhance cooling

Oil-Immersed

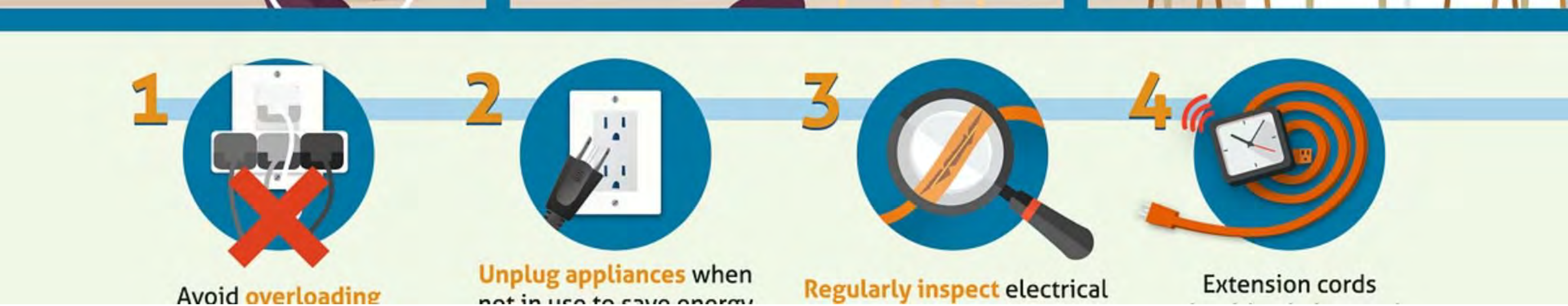
Larger transformers are immersed in oil for better heat dissipation

Water-Cooled

Very large transformers may use water cooling systems



Oil Natural Air Forced (ONAF) Cooling of Transformer



Transformer Safety Considerations

1 High Voltage Hazard

Transformers can produce lethal voltage levels

Heat Generation

Transformers generate heat during operation and require adequate ventilation

Heavy Equipment

Large transformers are extremely heavy and require proper handling equipment

Proper Grounding

All transformer installations must be properly grounded

Transformer Maintenance

Visual Inspection

Regularly check for physical damage, leaks, or corrosion

Cleaning

Remove dust and debris that can impede cooling

Connection Check

Ensure all electrical connections are tight and free of corrosion

Testing

Periodically test insulation resistance and turns ratio

Common Transformer Problems

Overheating

Can be caused by overloading, poor ventilation, or internal faults

Insulation Breakdown

Results from age, moisture, or excessive heat

Core Saturation

Occurs when operating above rated voltage

Connection Issues

Loose connections can cause arcing and heat damage

Transformer Troubleshooting

1

Measure Input Voltage

Verify proper input voltage is present

Check Output Voltage

Measure output voltage under no-load conditions

Test Winding Resistance

Measure resistance of primary and secondary windings

Insulation Testing

Check insulation resistance between windings and to ground

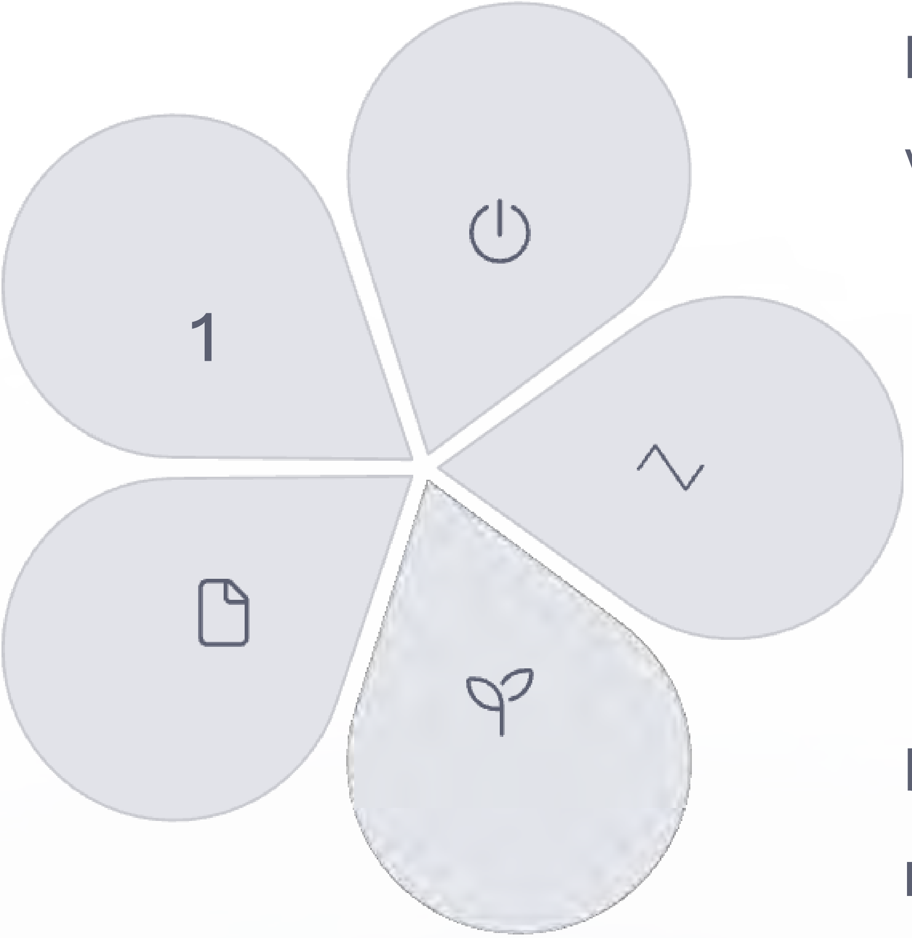
Transformer Selection Criteria

Voltage Requirements

Primary and secondary voltage ratings

Power Rating

VA or kVA capacity needed



Frequency

Operating frequency (typically 60 Hz in North America)

Efficiency

Energy efficiency requirements

Environment

Indoor/outdoor, temperature, humidity

Transformer Installation Best Practices

Proper Location

Install in well-ventilated areas away from combustible materials

Secure Mounting

Ensure transformer is securely mounted to prevent movement

Correct Wiring

Follow manufacturer's wiring diagrams precisely

Proper Grounding

Connect ground wire according to electrical code requirements

8 General Guidelines To Consider While Installing A Transformer

Bio link

https://sites.google.com/site/shaktielectricalcorporation/blog/transformer-installation-guidelines

Transformers play a very impressive role in a lot of industries. It is said that the manufacturing of a transformer is super difficult, but at the same time, the installation of the transformer is equally important. If the transformer installation is not done properly, then the operations will never be conducted smoothly by the transformer. There are a lot of steps that one needs to follow while installing a transformer and those guidelines are already fixed and mandatory to follow. Let's check out the steps in the guidelines, which have to

Transformer Types by Application

Power Transformers

Used in power generation, transmission, and distribution systems

Distribution Transformers

Step down voltage for final distribution to consumers

Instrument Transformers

Used for measurement in metering and protection systems

Control Transformers

Provide voltage for control circuits in industrial applications

Transformer Protection Devices

Fuses

Protect against overcurrent conditions

Circuit Breakers

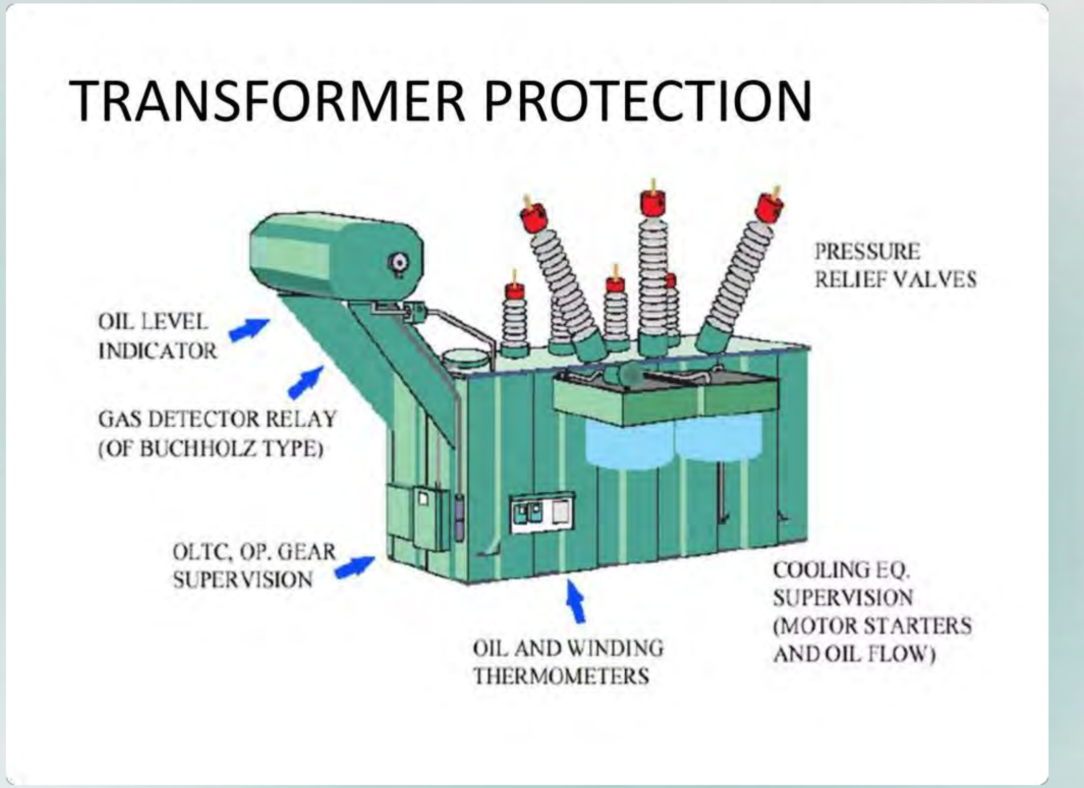
Provide resettable overcurrent protection

Thermal Protection

Monitors temperature and disconnects when overheating occurs

Surge Arresters

Protect against voltage spikes and lightning



Transformer Sizing for Gas Equipment

Calculate Total Load

Add up the power requirements of all connected devices

Apply Safety Factor

Multiply by 1.25 to allow for startup surges and future expansion

Select Transformer

Choose a transformer with a VA rating equal to or greater than the calculated value

Verify Voltage

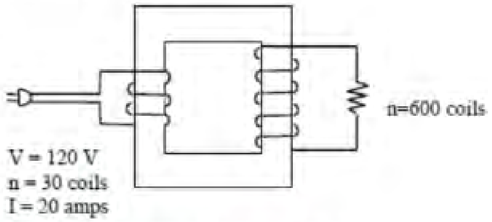
Ensure primary and secondary voltage ratings match your requirements

Name: ____________________ Date: ____________

Physics I Mr. Tiesler

Transformer Worksheet

Solutions to Physics I Transformer Worksheet



1.) Fill in the table below for the transformer shown above.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}, \quad V_S = \frac{N_S V_P}{N_P} = \frac{(600)(120\ V)}{30} = 2400\ V$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}, \quad I_S = \frac{N_P I_P}{N_S} = \frac{(30)(20\ A)}{600} = 1\ A$$

$$P_P = I_P V_P = (20\ A)(120\ V) = 2400\ W$$

$$P_S = I_S V_S = (1\ A)(2400\ V) = 2400\ W$$

	Primary	Secondary
Voltage	120 V	2400 V
Current	20 A	1 A
# of Coils	30	600
Power	2400 W	2400 W

2.) Is this a step up or step down transformer?

Step Up

Transformer Efficiency Calculation

Efficiency Formula

Efficiency (%) = (Output Power / Input Power) × 100

Output Power = Input Power - Losses

Losses in Transformers

Core losses (hysteresis and eddy current losses)

Copper losses (I^2R losses in the windings)

Stray losses (leakage flux, etc.)

Transformer Ratings

VA Rating

The apparent power capacity of the transformer, measured in volt-amperes (VA) or kilovolt-amperes (kVA)

Voltage Rating

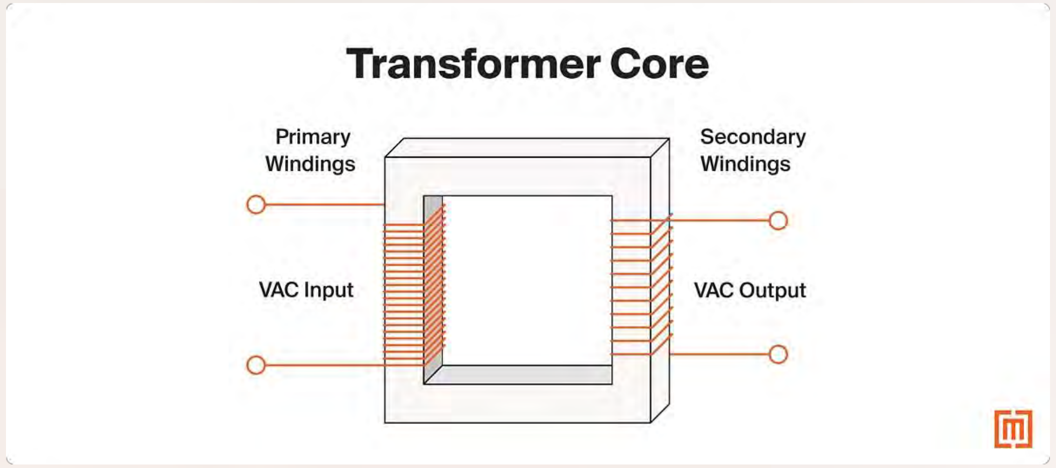
Primary and secondary voltage specifications

Frequency Rating

The frequency at which the transformer is designed to operate (typically 60 Hz in North America)

Temperature Rating

Maximum allowable operating temperature



Transformer Core Materials

Silicon Steel

Most common core material, with good magnetic properties and low losses

Amorphous Metal

Higher efficiency but more expensive, used in high-efficiency transformers

Ferrite

Used in high-frequency applications

Nickel-Iron Alloys

Used in special applications requiring high permeability

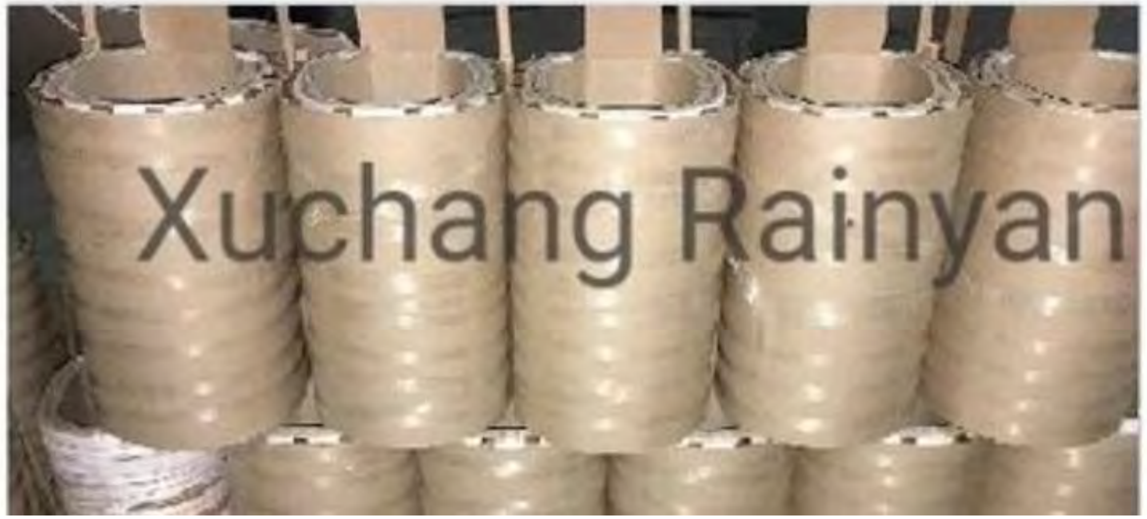
Transformer Winding Types

Concentric Windings

Primary and secondary windings are arranged in concentric cylinders, with one winding inside the other. This is the most common arrangement for power transformers.

Sandwich Windings

Primary and secondary windings are interleaved in alternating layers. This arrangement provides better coupling and is often used in high-voltage transformers.

Transformer Insulation Materials

Paper

Traditional insulation material, often impregnated with oil

Mineral Oil

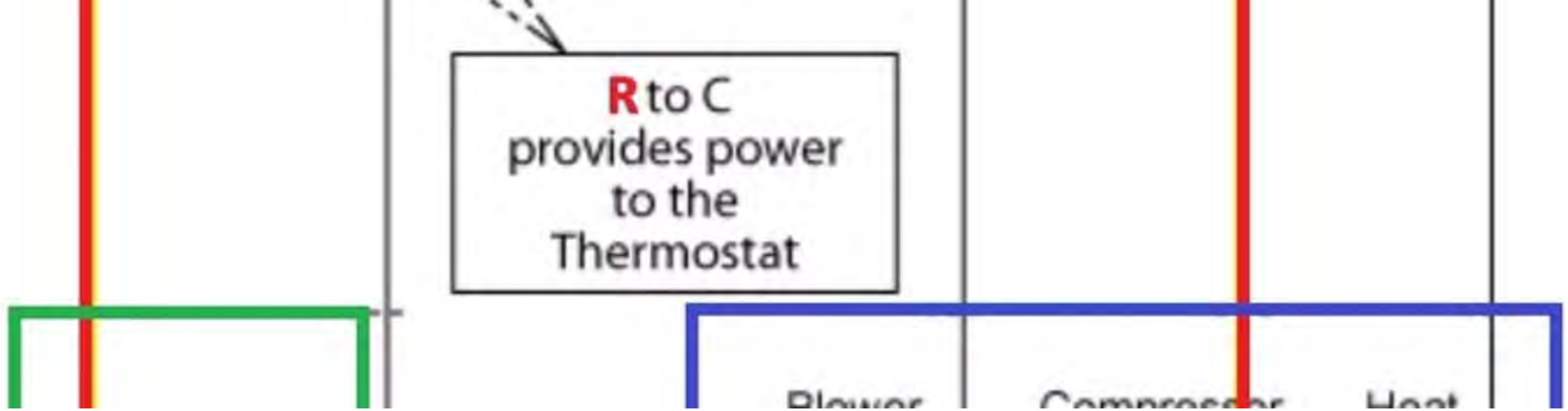
Provides both insulation and cooling

Synthetic Materials

Modern transformers use various synthetic insulation materials

Air/Gas

Dry-type transformers use air or other gases for insulation



Transformer Connections

Delta Connection

Windings are connected in a triangle configuration

Wye (Star) Connection

Windings are connected in a Y configuration with a common neutral point

Open Delta

A three-phase connection using only two transformers

Zigzag Connection

Special connection used for grounding and harmonic mitigation

Transformer Testing Methods

Winding Resistance Test

Measures the DC resistance of each winding

Turns Ratio Test

Verifies the ratio of primary to secondary turns

Insulation Resistance Test

Measures the resistance between windings and to ground

Oil Quality Test

Analyzes oil for contaminants and breakdown products

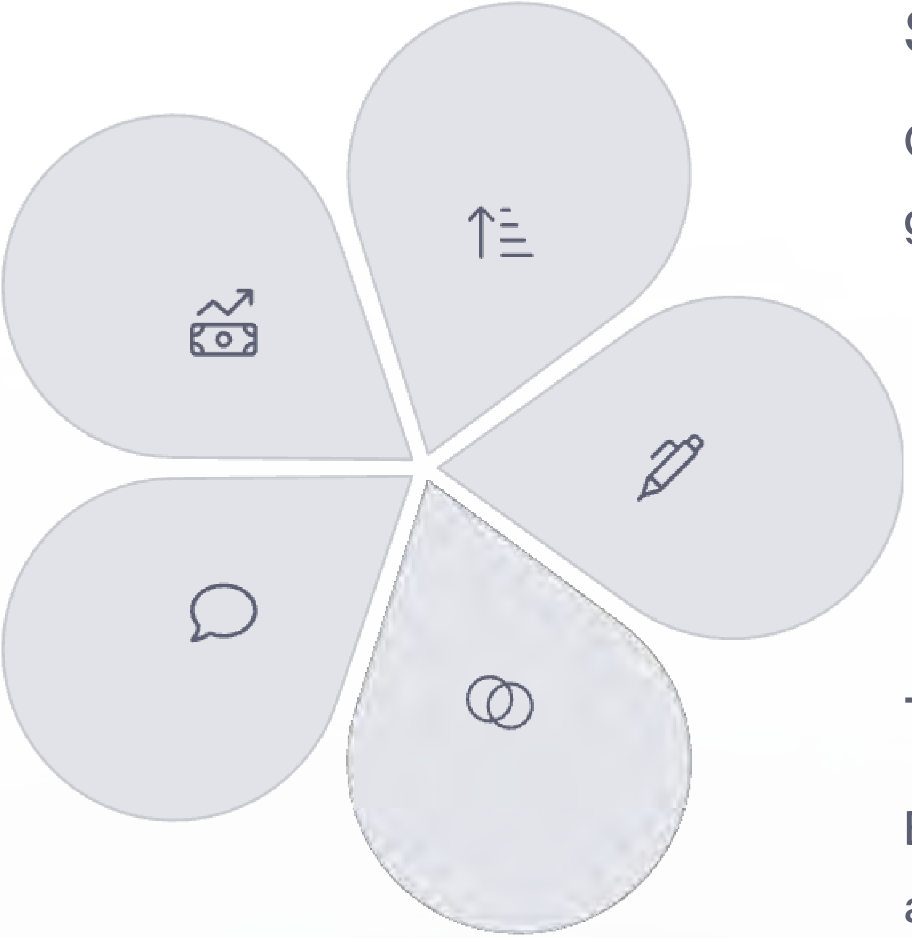
Transformer Failure Modes

Insulation Failure

Most common failure mode, often due to aging or overheating

Moisture Ingress

Water contamination reduces insulation effectiveness



Short Circuits

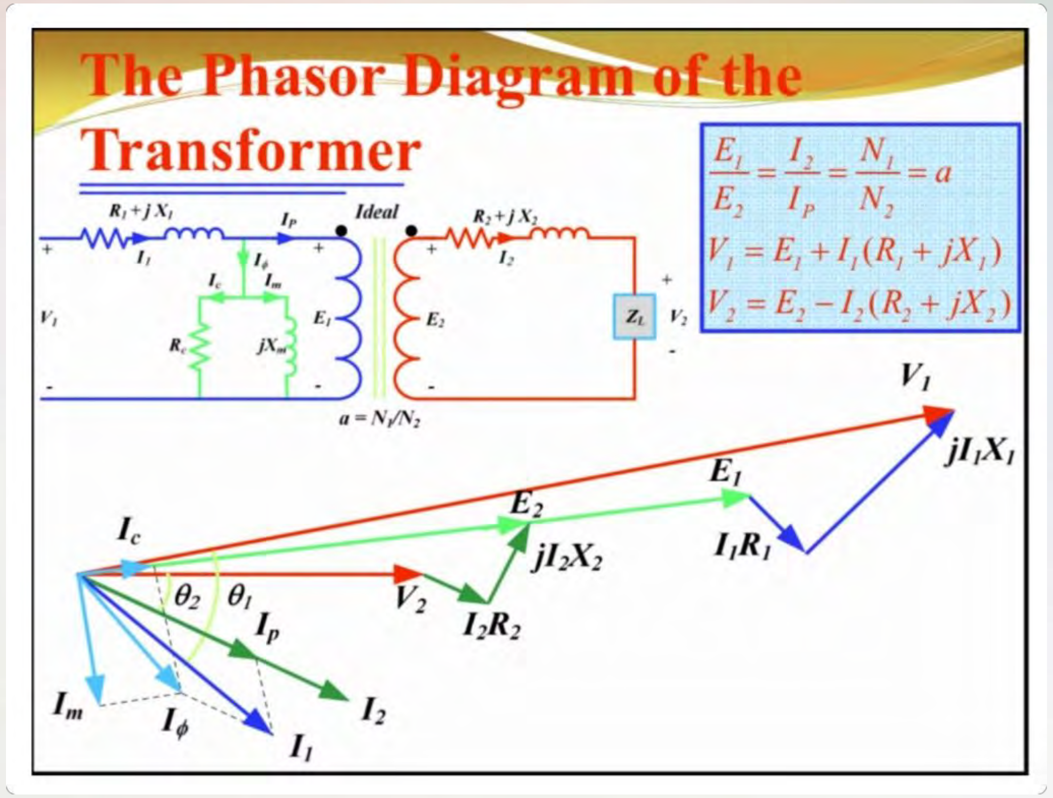
Can occur between turns, windings, or to ground

Mechanical Failures

Core or winding movement due to vibration or physical damage

Thermal Overload

Excessive heat damages insulation and accelerates aging



Transformer Life Expectancy

20-30

Years

Typical life expectancy of a well-maintained transformer

10°C

Temperature Rise

Each 10°C rise above rated temperature halves transformer life

2x

Maintenance Impact

Regular maintenance can double the service life

Transformer Standards and Regulations

IEEE C57

Standards for power and distribution transformers

NEMA ST 20

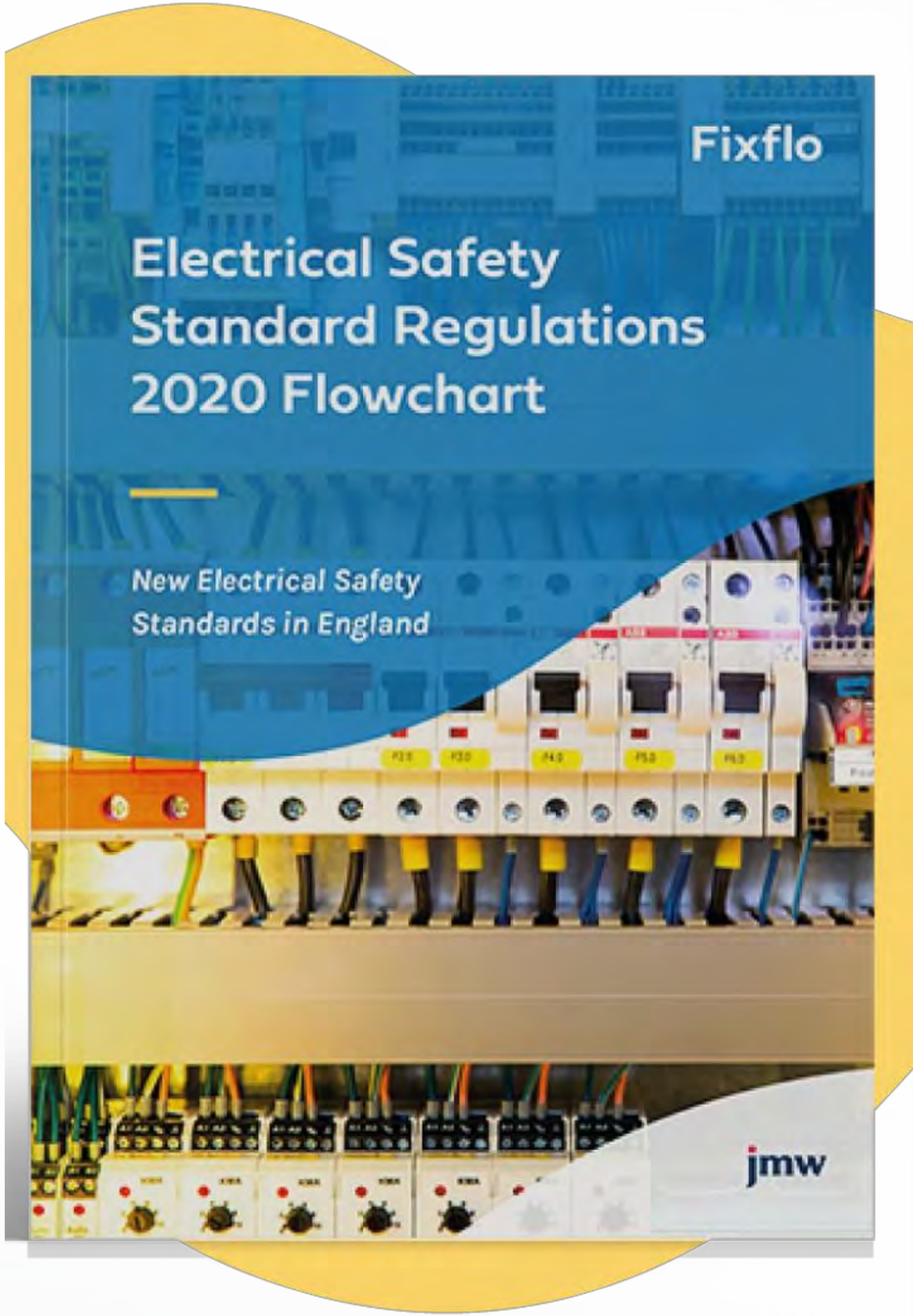
Dry-type transformer standards

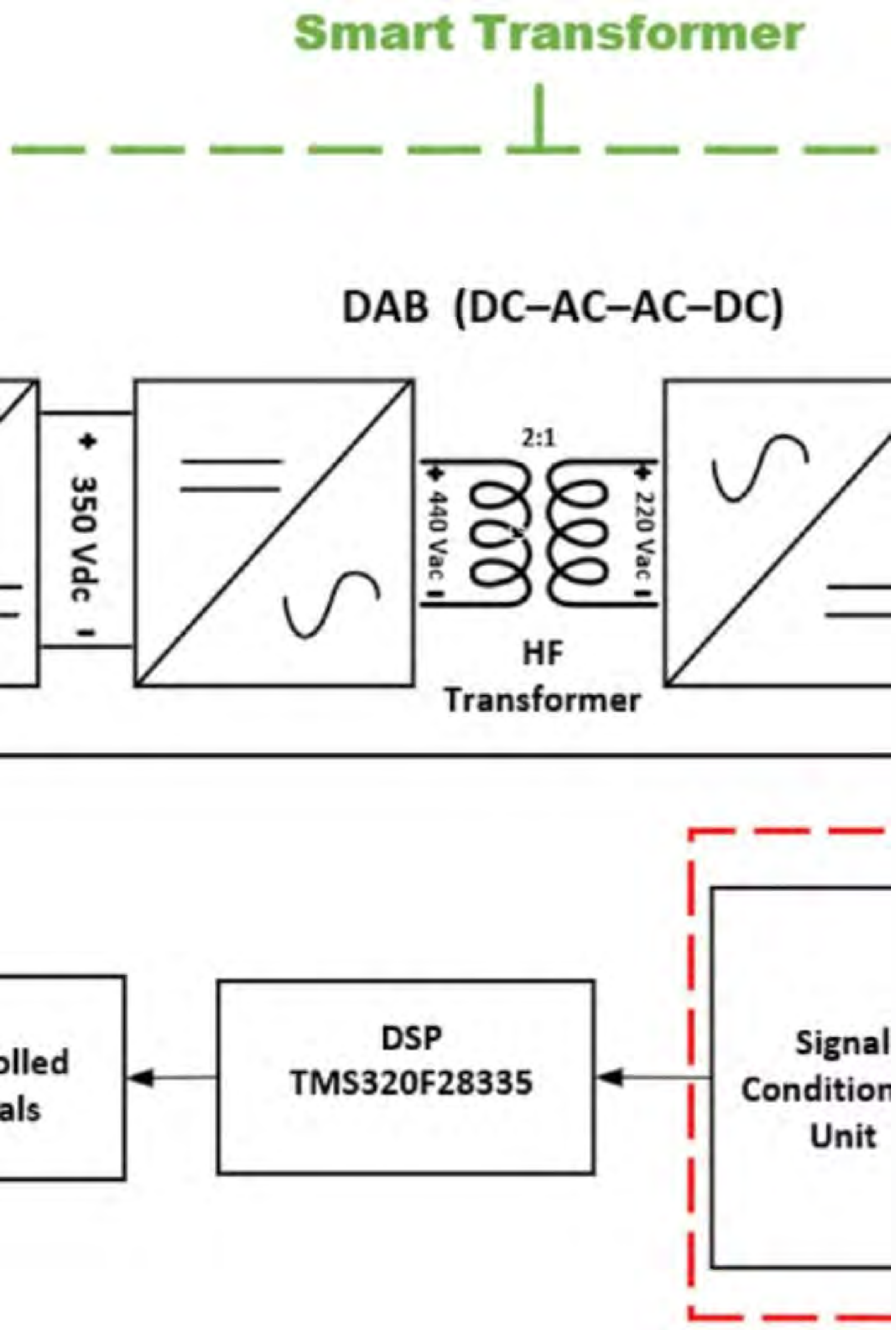
CSA C22.2

Canadian standards for transformers

DOE 10 CFR Part 431

Energy efficiency standards for distribution transformers





Future Trends in Transformer Technology

Higher Efficiency

Advanced materials and designs for reduced losses

Smart Transformers

Integrated monitoring and communication capabilities

Eco-Friendly Materials

Biodegradable oils and recyclable components

Compact Designs

Smaller footprint with higher power density

Summary: AC Power Supplies and Transformer Theory

AC Power Basics

120-volt AC circuits in residential applications use color-coded wiring for safety and proper identification

Transformer Operation

Transformers work through electromagnetic induction to transfer energy between circuits and change voltage levels

Transformer Calculations

Output voltage and current can be calculated using turns ratio and power conservation principles

Safety Considerations

Proper selection, installation, and maintenance of transformers is essential for safe and efficient operation

CSA Unit 5

Chapter 7
Electrical Measuring Instruments

The gas technician/fitter requires knowledge of electrical measuring instruments. It is important to understand how to safely use and interpret instrument readings to effectively troubleshoot the types of electrical equipment and circuits in the gas industry.

Learning Objectives

Identify and Select

Identify and select common electrical measuring instruments

Describe Usage

Describe how to use electrical measuring instruments

Read Measurements

Read electrical measuring instruments

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

Common Electrical Measuring Instruments

Voltmeter

Used to measure voltage

Ammeter

Used to measure current

Ohmmeter

Used to measure resistance and continuity

Multimeters: The All-in-One Solution

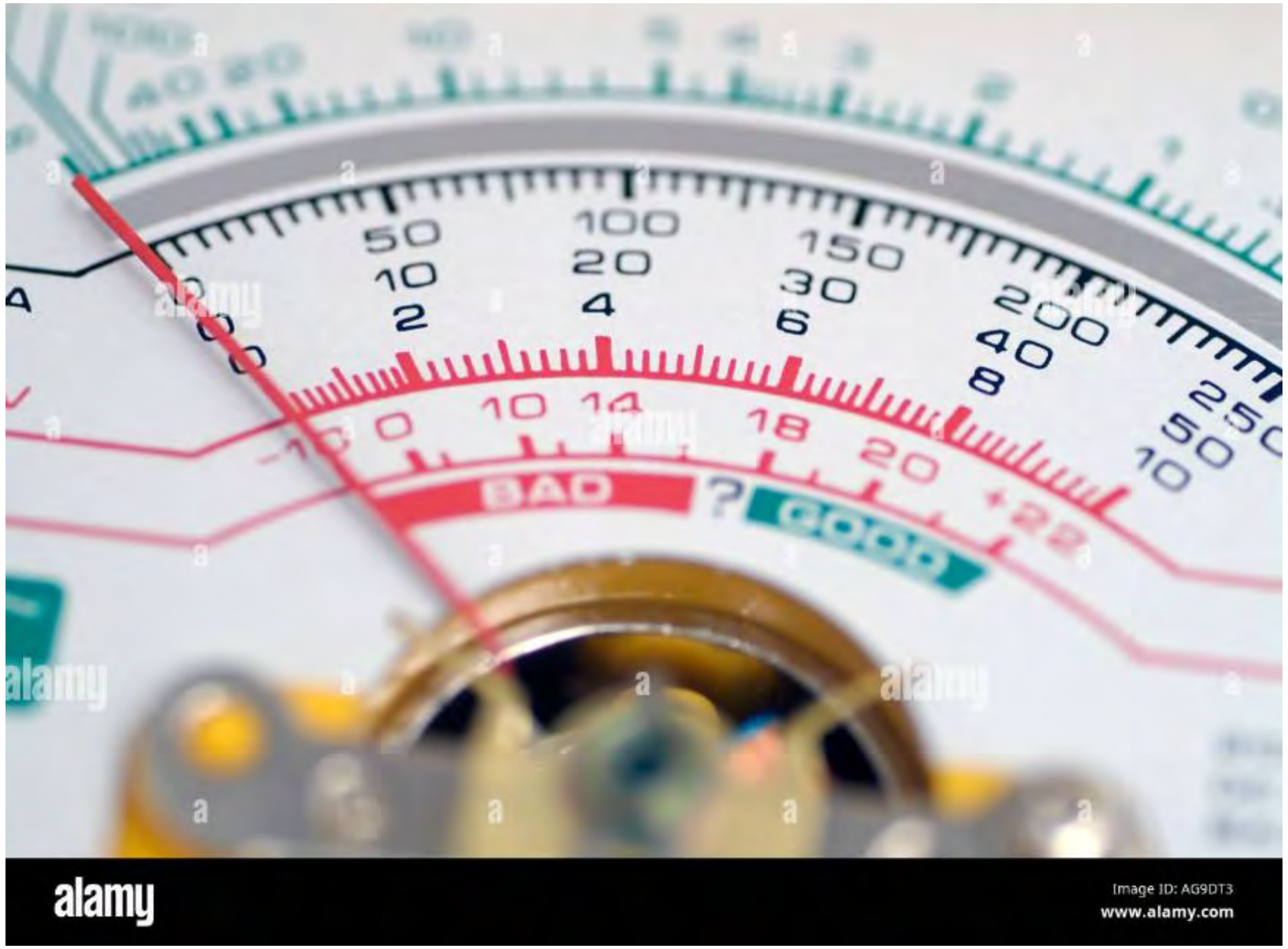
The functions of each individual instrument can be combined into a single versatile instrument called multimeter. Multimeters are more commonly used in the field and are often known by other names such as volt-ohm-milliammeter (VOM) and digital multimeter (DMM). A multimeter saves having to purchase numerous individual meters.

Analogue vs Digital Multimeters

Analogue Meters

Consist of a needle-type pointer that moves across a fixed scale

Somewhat delicate and requires placement on a horizontal surface to retain accuracy



Digital Meters

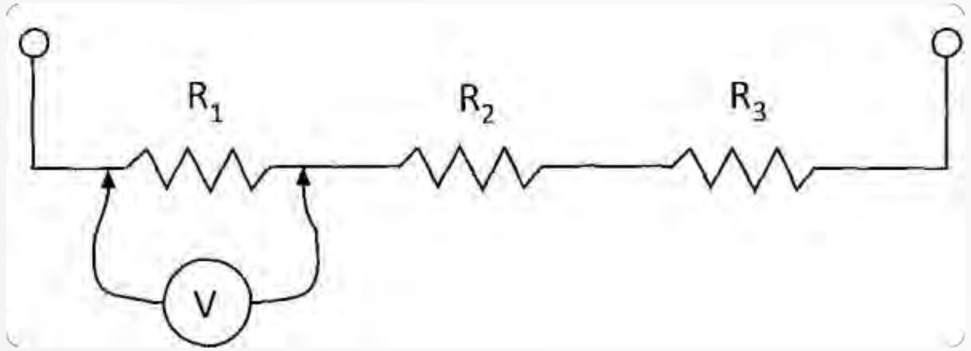
Display using liquid-crystal or light-emitting diodes (LED)

Often easier to read than analogue meters

Will retain their accuracy regardless of positioning

Digital Multimeter Variations

Digital multimeters can vary greatly in their operation and functions. Most multimeters can measure both alternating current (ac) and direct current (dc), whereas some voltmeters and ammeters can measure only one type of current. Always refer to the instrument's operating instruction booklet before using it to confirm its safe and proper use.



Measuring Voltage

Connect in Parallel

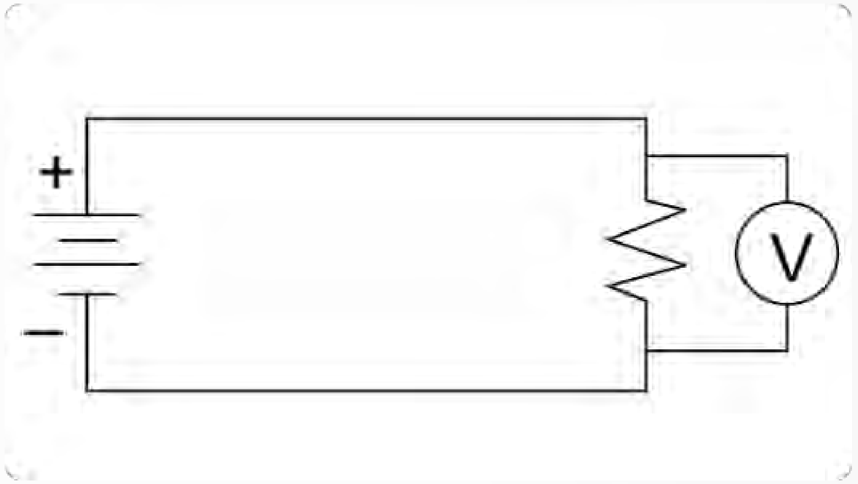
To measure voltage, you must connect a voltmeter across the two points in the circuit where the voltage appears, or in other words, in parallel with the part of the circuit under test.

Minimal Circuit Impact

It is very important that the addition of the voltmeter into a circuit has very little effect on the conditions normally existing in the circuit.

High Internal Resistance

A voltmeter must have a very high internal resistance, so that operating the instrument will draw very little current from that circuit.



Voltmeter Resistance Requirements

Maximum Accuracy

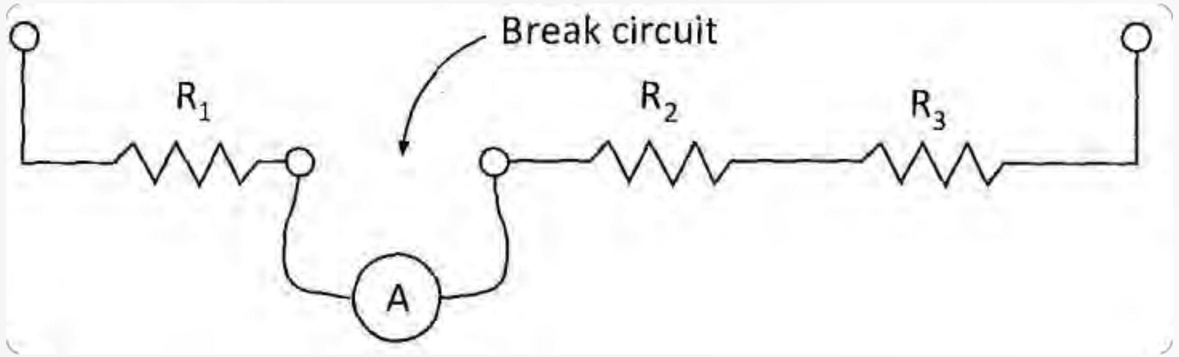
For maximum accuracy, a voltmeter's internal resistance should be many times higher than any resistance encountered in the circuit under test.

Analogue Voltmeters

Analogue voltmeters have internal resistances in the thousands of ohms.

Digital Voltmeters

Digital instruments often have internal resistances in the millions of ohms.



Measuring Current

Break the Circuit

In order to measure current, break down the circuit at the point where you will measure the current.

Insert in Series

Insert the ammeter in series with the circuit under test.

Safety First

Before breaking any circuit to insert an ammeter, it is first necessary to switch the circuit off to avoid danger.

Ammeter Characteristics

Low Internal Resistance

The internal resistance of the ammeter is very low, normally a fraction of an ohm.

Avoid Incorrect Connections

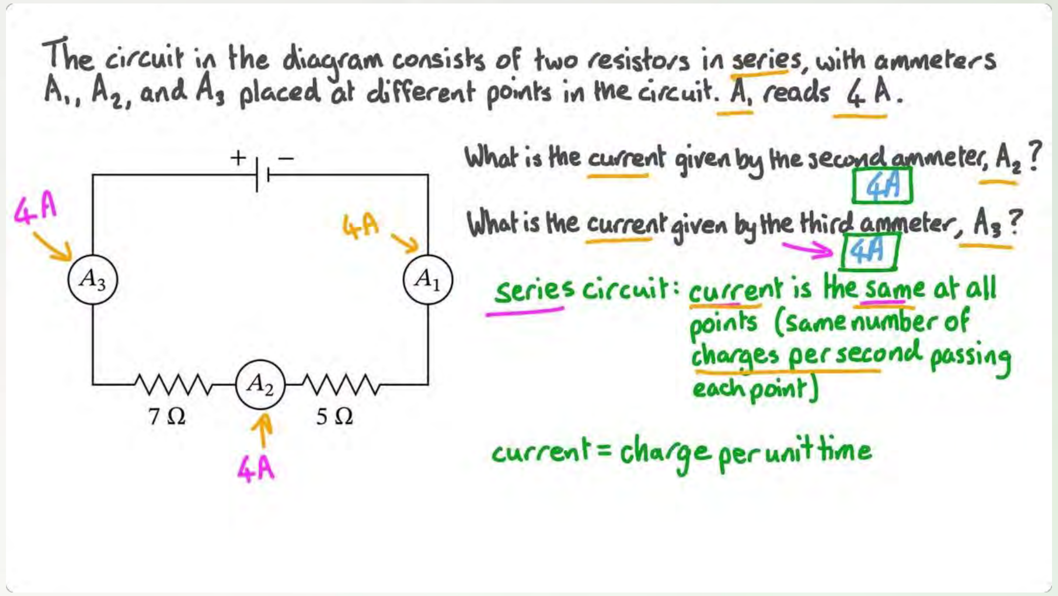
Due to the ammeter's low internal resistance, you must avoid connecting it across a load under test or the supply voltage itself.

Potential Damage

Incorrect connection would cause high current to flow through the ammeter, seriously damaging the instrument and possibly harming the operator.

Protection Features

Some ammeters come with a fuse or circuit-breaker for protecting the instrument, but you should never assume that this is adequate protection.

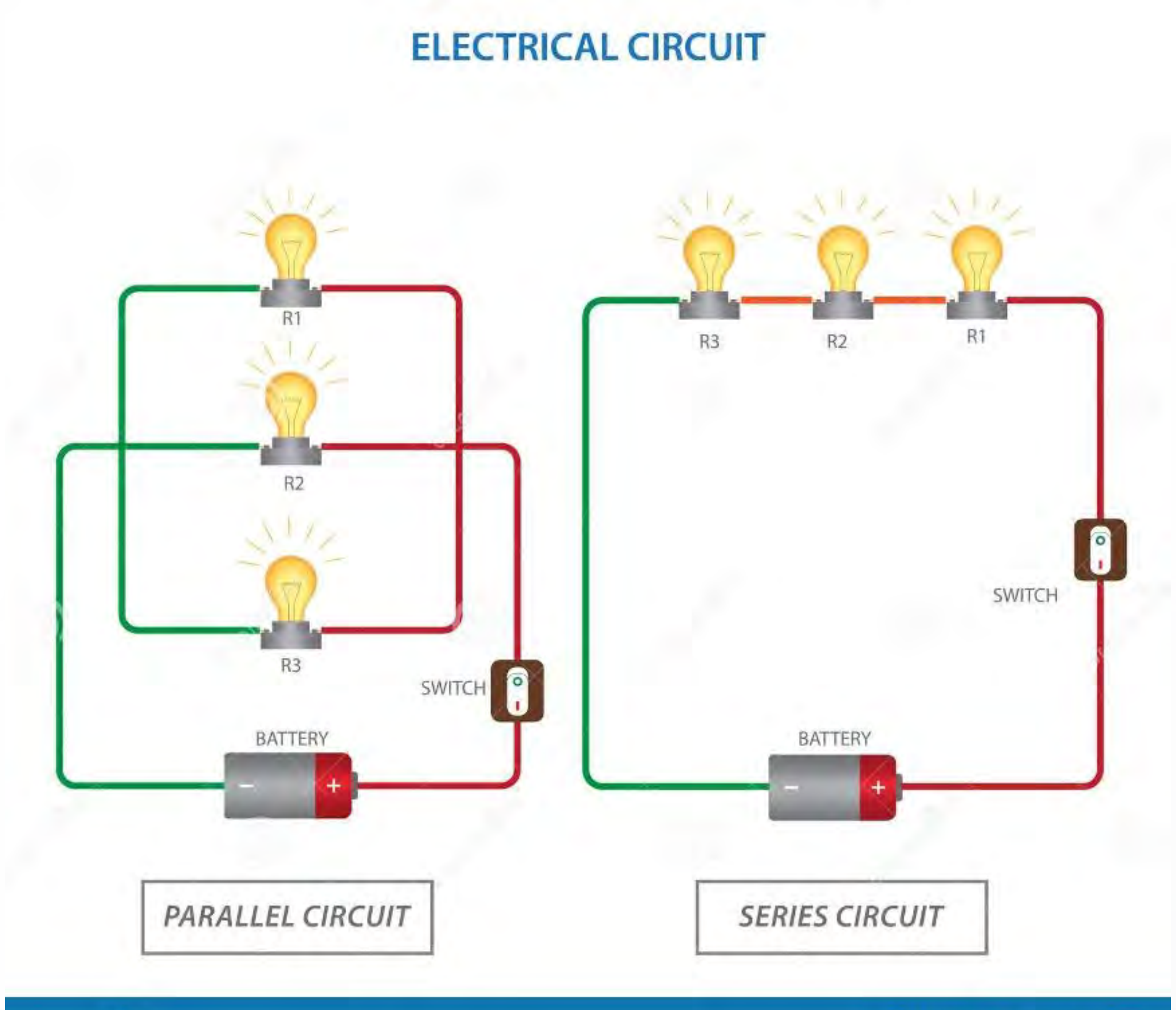


Understanding Ohm's Law

Ohm's law tells us that, with a fixed value of voltage across a circuit, the value of current flowing depends upon the resistance of that circuit:

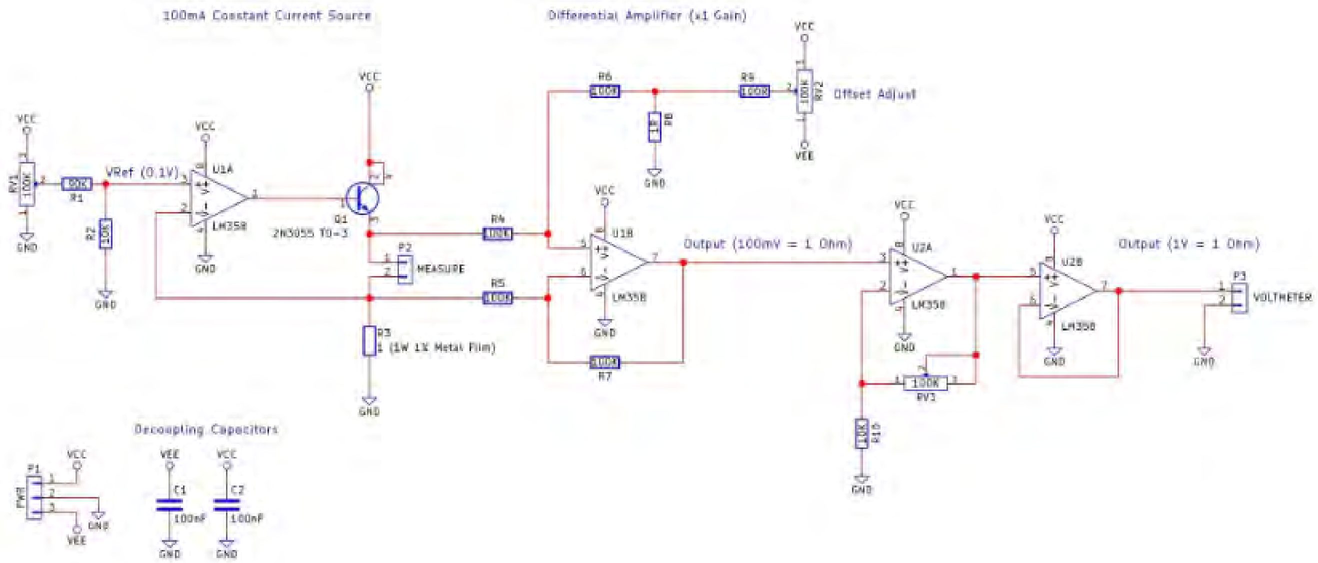
Higher Resistance

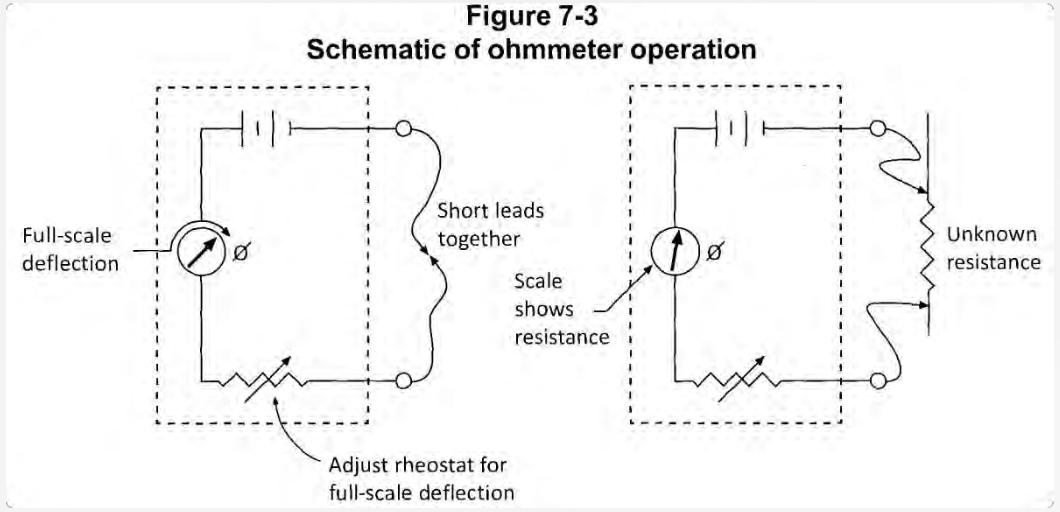
The higher the resistance, the lower the current flow.



Lower Resistance

The lower the resistance, the higher the current flow.





How an Ohmmeter Works

Connect Test Leads

The test-leads are connected to the instrument's terminals and are first short-circuited together.

Adjust Rheostat

Adjustment of rheostat occurs until the instrument registers full-scale deflection—this corresponds to zero ohms.

Test Circuit

Now, the test-leads are connected to the circuit or component under test.

Read Measurement

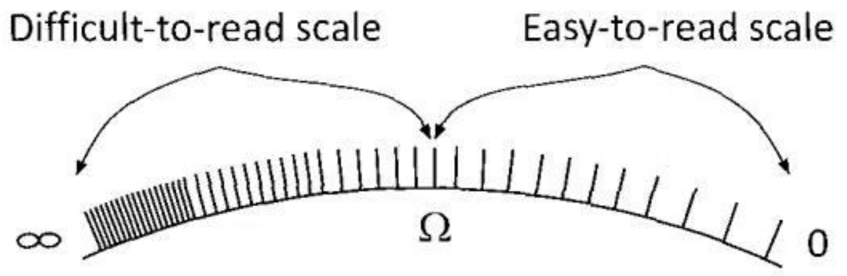
The resulting current through the ohmmeter will be lower than it was before, because of the added resistance, and the instrument's pointer will register somewhat less than full-scale deflection.

Analogue Ohmmeter Scale

Right to Left Reading

Unlike the voltmeter and the ammeter, the most noticeable thing about an analogue ohmmeter's scale is that you read it from right to left.

Figure 7-4
Non-linear, analogue ohmmeter scale



Non-Linear Scale

The scale is non-linear. This means that the graduations that represent the higher values of resistance (to the left side of the scale) are very close together, while those representing lower values (to the right side of the scale) have wider spacings.

Zero Ohms Adjustment

Perform Before Use

Using the built-in rheostat to adjust for full-scale deflection is what you call zero ohms adjustment. You must perform it before using the ohmmeter to measure resistance.

Battery Compensation

This compensates for any variation in the voltage of the instrument's battery.

Battery Check

If you cannot achieve zero ohms adjustment, it means the battery is too weak and needs replacement.

Ohmmeter Operating Precautions

Do

- Always be aware of inadvertently measuring the resistance of other components that are connected in parallel with the component under test.
- You may have to physically remove the component from the circuit before performing the test.
- Always switch an ohmmeter off when measurements are completed.

Do Not/Never

- Never connect an ohmmeter across a live load or the supply voltage itself.
- This would cause high current to flow through the ammeter, seriously damaging the instrument and possibly harming the operator!
- Never leave test-leads shorted together when the instrument is off, as the instrument's battery will very quickly discharge.

Checking Continuity

Technicians/fitters very often use ohmmeters to check for continuity—to confirm, for example, that a circuit, or component, is not open-circuited. When checking continuity, the actual resistance of the circuit or component is unimportant—a simple deflection of the pointer confirms continuity.

Variable Range Instruments

Extended Versatility

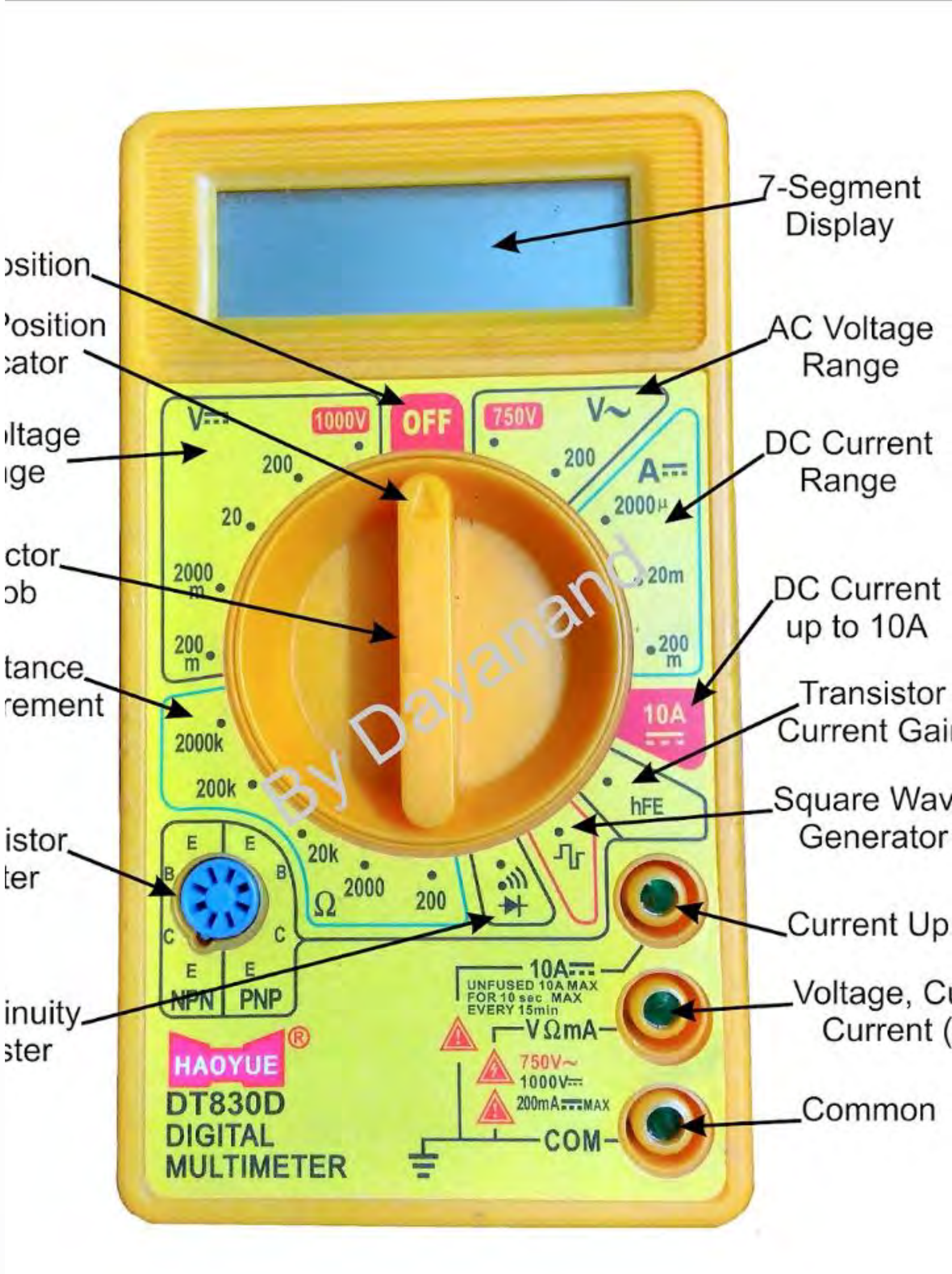
In order to extend their versatility, most electrical measuring instruments have several ranges.

Voltmeter Example

For example, you may adjust a voltmeter to read: 0 to 5 V, 0 to 10 V, 0 to 25 V, and 0 to 100 V.

Multiple Scales

An analogue voltmeter may have four separate scales or only one scale (say, 0 to 5 V), in which case you must multiply its reading by factors of x2, x5, or x20, according to the selected range.



Multimeter Settings

Scale Selection Methods

Analogue Instruments

The method for selecting the range on such an instrument varies from manufacturer to manufacturer, with the most common being a rotary knob that aligns with ranges engraved onto the case.

Digital Instruments

Modern digital instruments often select the appropriate range automatically.

Range Selection Best Practices

Start High

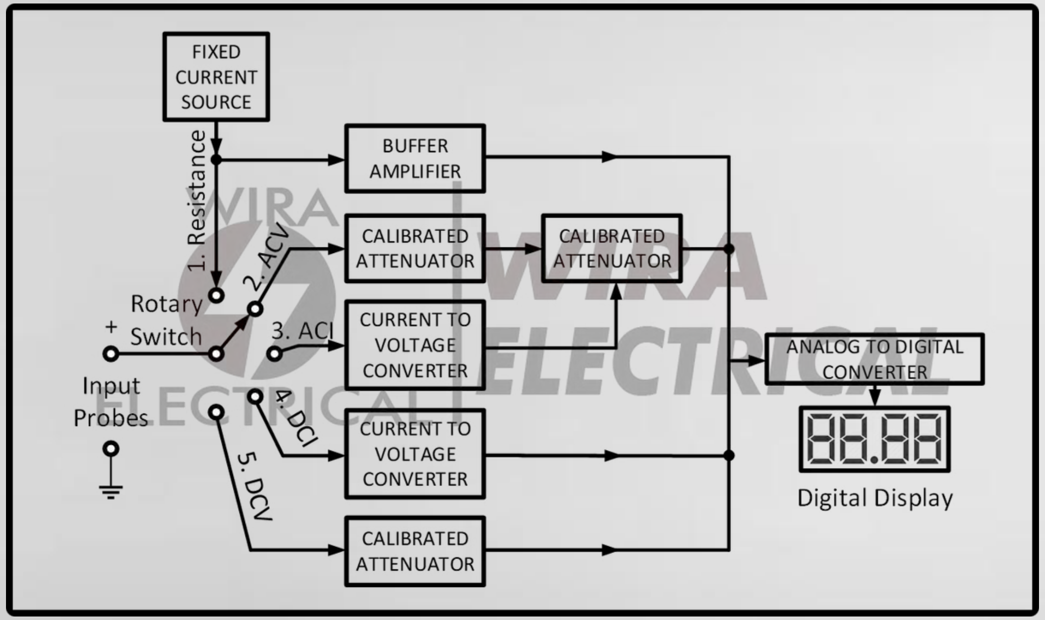
If you are unsure of the value of voltage or current that you are about to measure, always start with the highest range and work down until you achieve the greatest readable deflection of the pointer.

Estimate First

Always estimate the likely value of voltage or current before performing the test, just in case it is beyond even the highest range of the instrument.

Maximize Accuracy

For maximum accuracy with analogue instruments, always select the range that gives the greatest readable deflection because all instruments are calibrated to give maximum accuracy at full-scale deflection.



Understanding Instrument Accuracy

For example, suppose a 100 V voltmeter is manufactured to an accuracy of ±5%. This accuracy applies to the instrument's full-scale deflection. In other words, it is accurate to ±5 V at its 100 V reading. So, when it indicates 100 V, the actual voltage could be anywhere between 95 V and 105 V. However, when the same instrument indicates, say, only 10 V, it is still accurate to ±5 V, so the actual voltage could range from 5 V to 15 V!

Ohmmeter Range Adjustment

Adjust for Zero Ohms

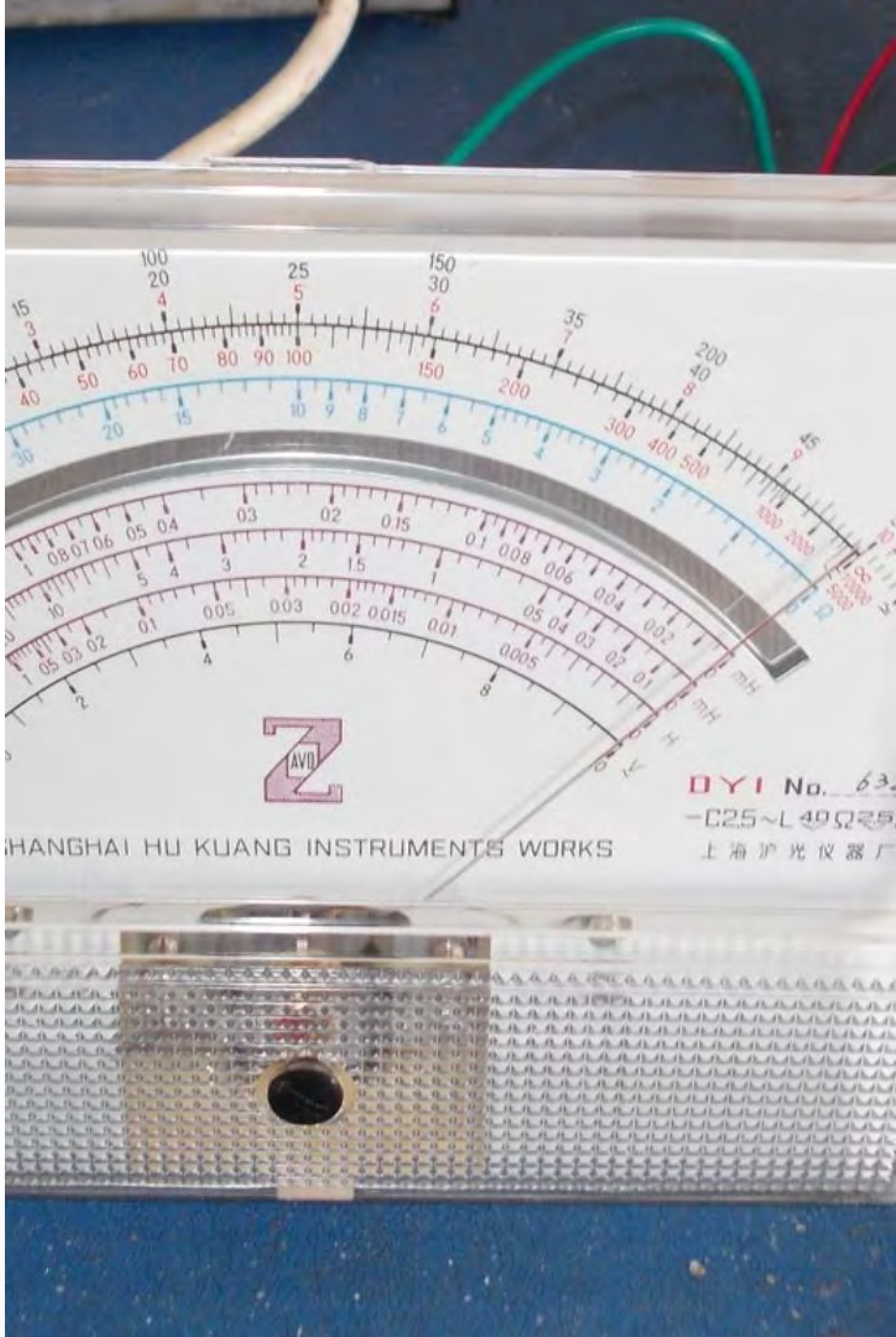
In the case of an ohmmeter, you must adjust the instrument for zero ohms each time its range is changed.

Prepare Before Measurement

You must also adjust for zero ohms before you use the ohmmeter to take a measurement.

Verify Battery Condition

If zero adjustment cannot be achieved, check and replace the battery if necessary.

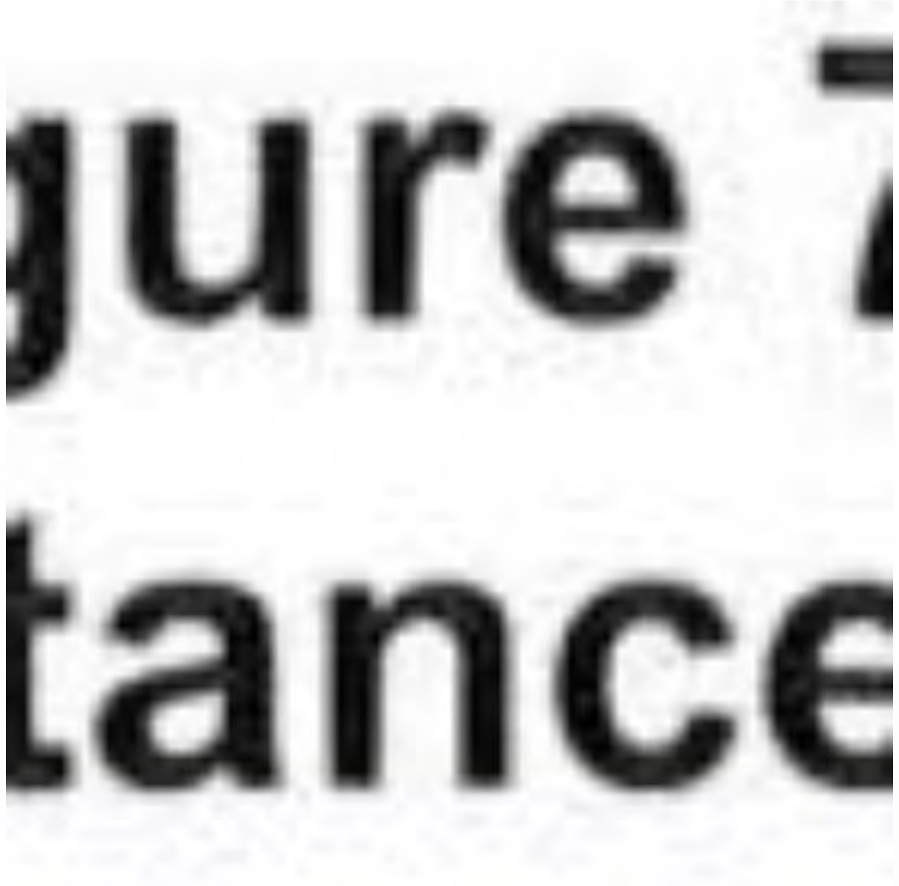


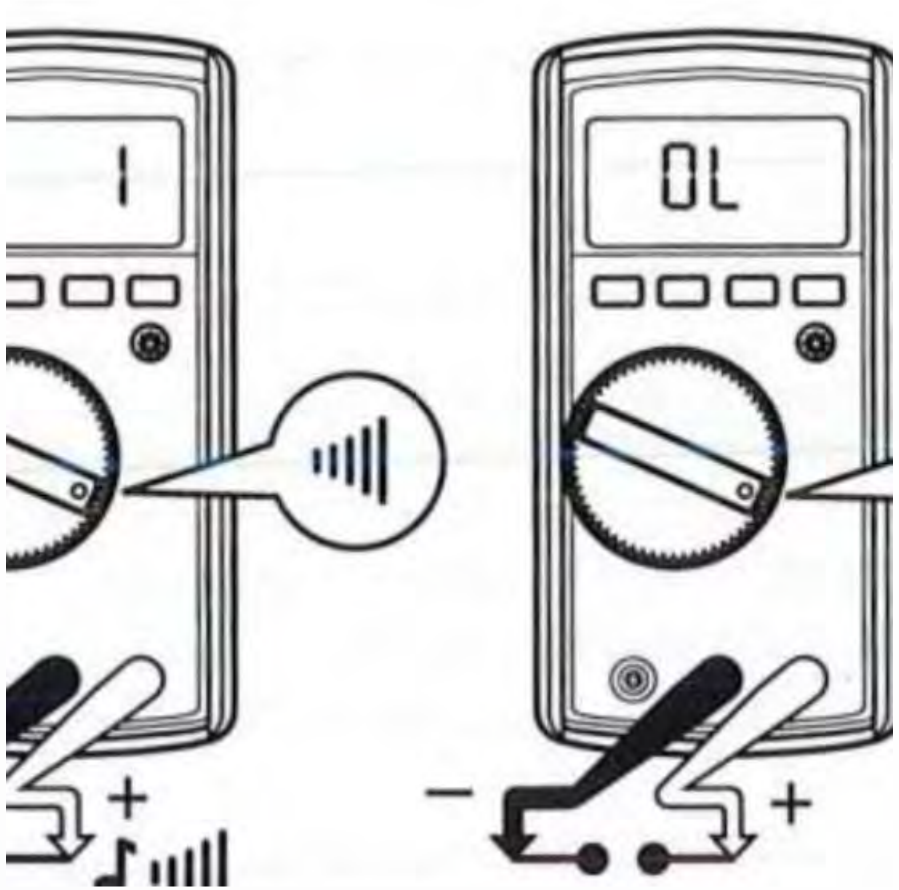
Digital Multimeter (DMM) Overview

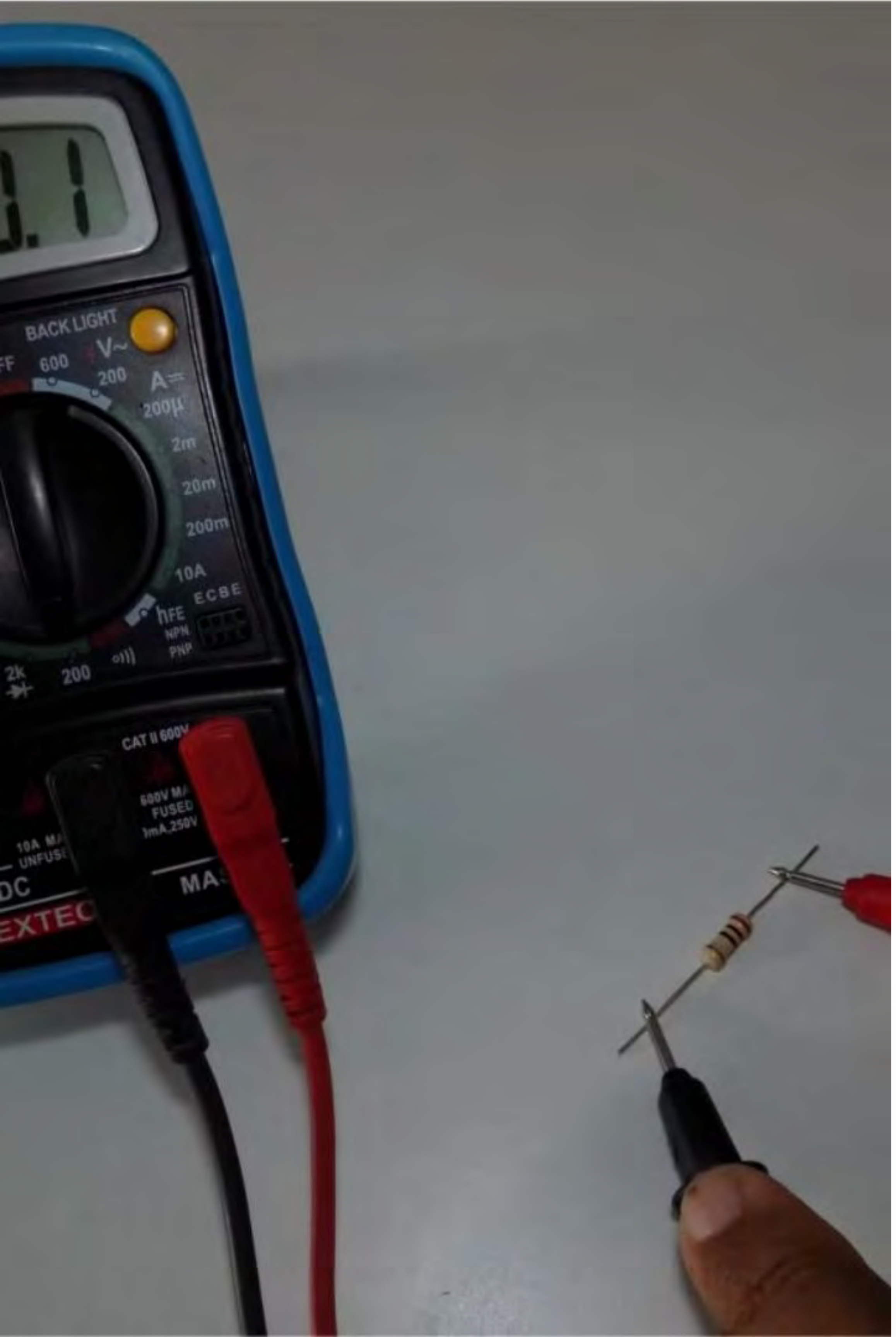
As discussed in Unit 2 Fasteners, Tools and Testing Instruments, Chapter 6. Electrical Testing Instruments, a digital multimeter has all the functions of an analogue multimeter plus advanced features. The primary difference to the technician/fitter is the way the user reads the data. DMMs have extended features depending on the make and model.

Field Service Technician's Multimeter

The following illustrations from a user's manual give typical examples of taking measurements with a common digital multimeter.







Measuring Resistance Safely

Disconnect Power

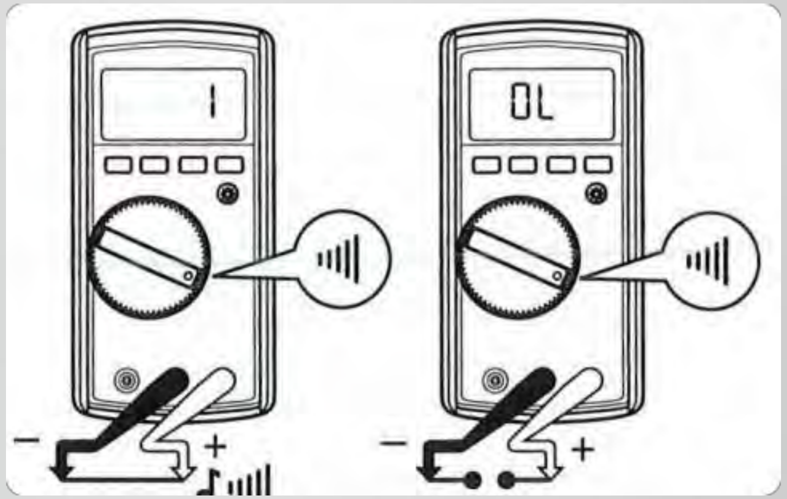
To avoid electric shock, injury, or damage to the meter, disconnect circuit power before testing.

Discharge Capacitors

Discharge all high-voltage capacitors before testing resistance, continuity, diodes, or capacitance.

Follow Procedures

Always follow proper safety procedures when working with electrical circuits.



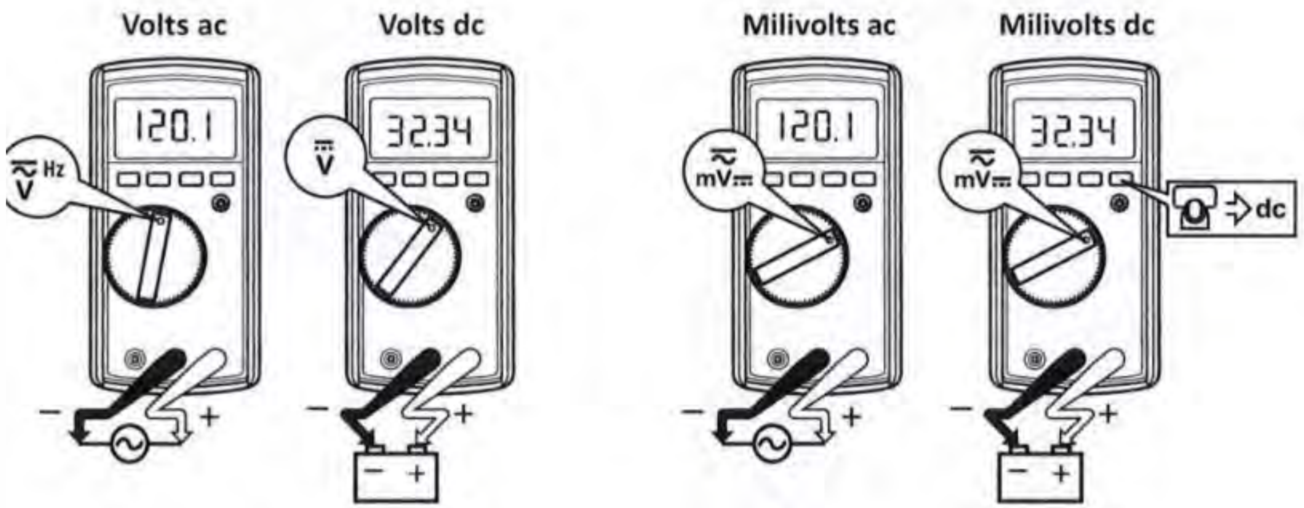
Testing for Continuity

Note: The continuity function works best as a fast, convenient method to check for opens and shorts. For maximum accuracy in making resistance measurements, use the meter's resistance (Ω) function.

Measuring AC and DC Voltage

Using Auto Volts Selection

With the function switch in the **A~~~-V** position, the meter automatically selects a dc or ac voltage measurement based on the input applied between the **V** or + and **COM** jacks.



This function also sets the meter's input impedance to approximately 3kΩ to reduce the possibility of false readings due to ghost voltages.

Measuring AC and DC Millivolts

With the function switch in the m~V position, the meter measures ac plus dc millivolts. Press D to switch the meter to dc millivolts.

Measuring AC or DC Current

Safety Warnings

To avoid personal injury or damage to the meter:

- Never attempt to make an in-circuit current measurement when the open-circuit potential to earth is >600V.
- Check the meter's fuse before testing.

Proper Setup

Use the proper terminals, switch position, and range for your measurement.

Avoid Parallel Connections

Never place the probes in parallel with a circuit or component when the leads are plugged into the A (amps) terminals.

Current Measurement Procedure

Power Off

Turn circuit power off before beginning.

Break Circuit

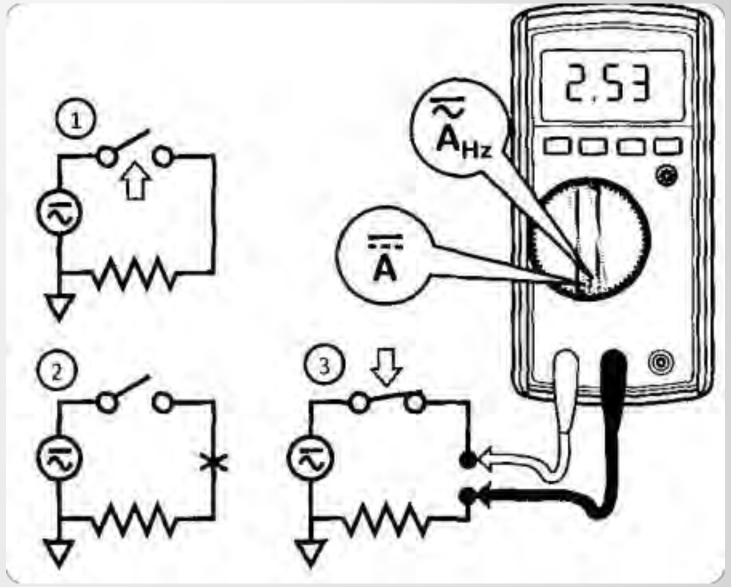
Break the circuit at the point where you want to measure current.

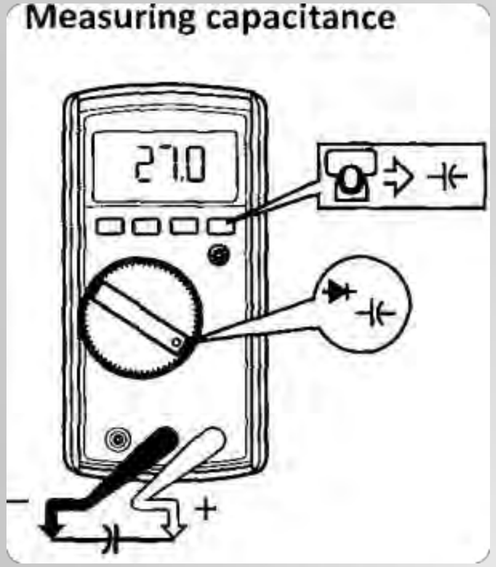
Insert Meter

Insert the meter in series with the circuit.

Power On

Turn circuit power on to take the measurement.



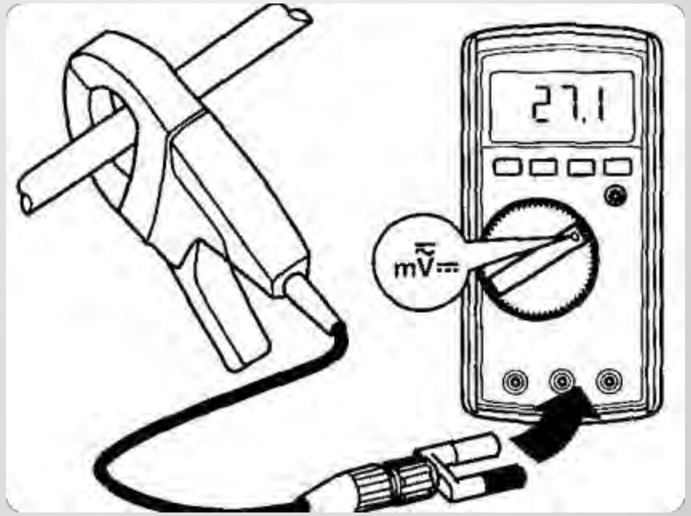


Measuring Current Above 10 Amps

The millivolt and voltage function of the meter can be used with an optional mV/A output current probe to measure currents that exceed the rating of the meter. Make sure the meter has the correct function selected, ac or dc, for your current probe. Refer to a catalog or contact a representative for compatible current clamps.

Measuring Capacitance

Digital multimeters can also measure capacitance, which is the ability of a component to store an electrical charge. This is useful when testing capacitors in electrical circuits.



Multimeter Safety Guidelines

Inspect Before Use

Always inspect the multimeter, test leads, and accessories for damage before use. Do not use if damage is visible.

Verify Operation

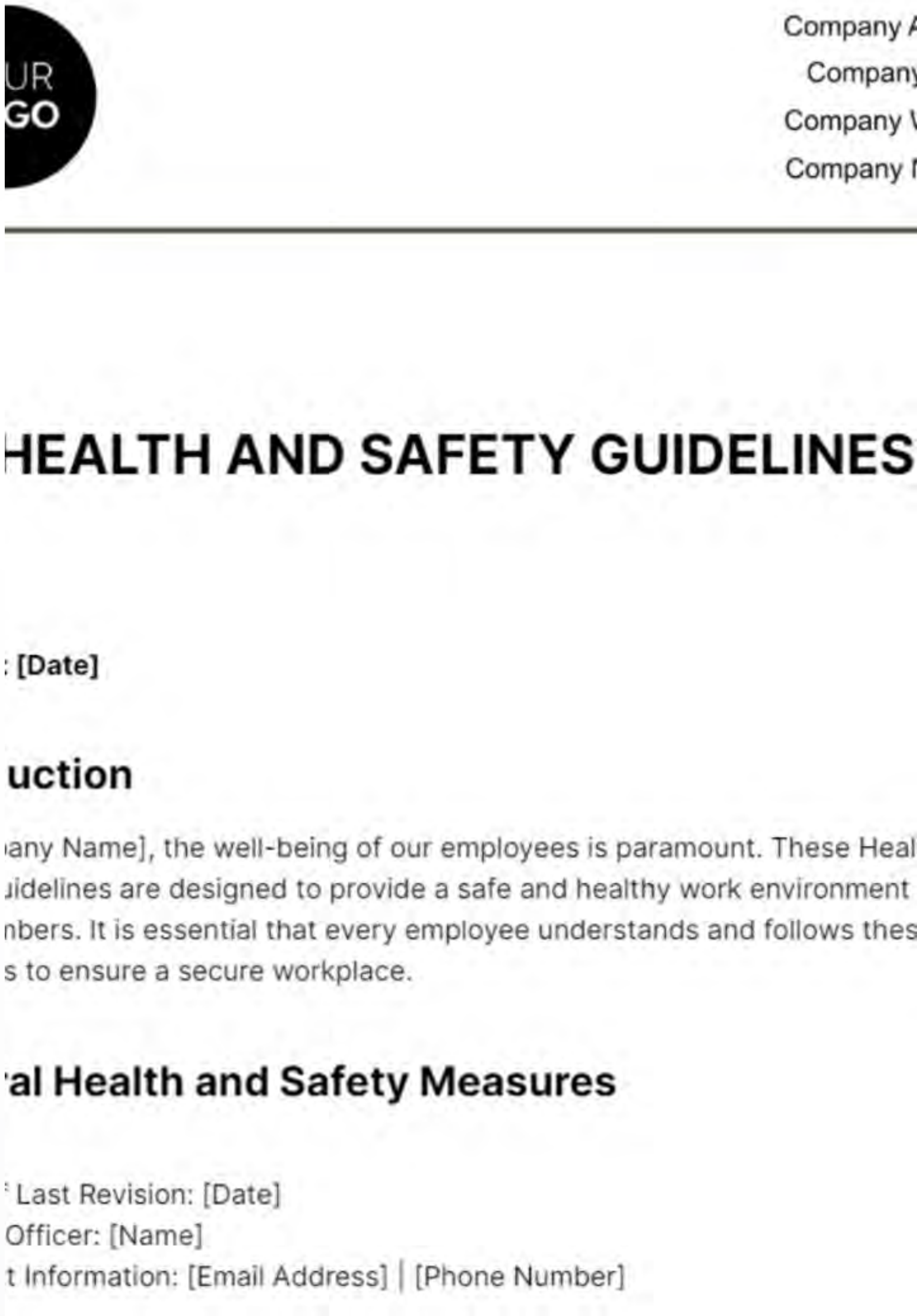
Test the meter on a known live circuit to verify it's working properly before taking measurements.

Use Proper Category Rating

Ensure your meter has the appropriate category rating (CAT) for the environment you're working in.

Follow Manufacturer Instructions

Always read and follow the specific instructions provided by the manufacturer for your model.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HEALTH AND SAFETY GUIDELINES

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any Name], the well-being of our employees is paramount. These Heal
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s to ensure a secure workplace.

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Last Revision: [Date]
Officer: [Name]
t Information: [Email Address] | [Phone Number]

Proper Hand Positioning

Correct Technique

When using a multimeter, keep your fingers behind the finger guards on the test probes.

This helps prevent accidental contact with live circuits and reduces the risk of electrical shock.

Selecting the Right Multimeter

Identify Requirements

Determine what measurements you'll need to take most frequently

Research Options

Compare features, specifications, and price points

Verify Specifications

Ensure the meter meets your accuracy and safety requirements

Purchase and Test

Buy from a reputable source and test functionality

Multimeter Maintenance

Battery Replacement

Replace batteries when low battery indicators appear to ensure accurate readings.

Regular Cleaning

Keep the meter clean and free of dust, especially the terminals and display.

Test Lead Inspection

Regularly check test leads for wear, damage, or loose connections.

Calibration

Have the meter calibrated according to manufacturer recommendations to maintain accuracy.

Common Multimeter Symbols

V

Voltage (Volts)

A

Current (Amperes)

Ω

Resistance (Ohms)

⏄

Diode Test

))))

Continuity Test

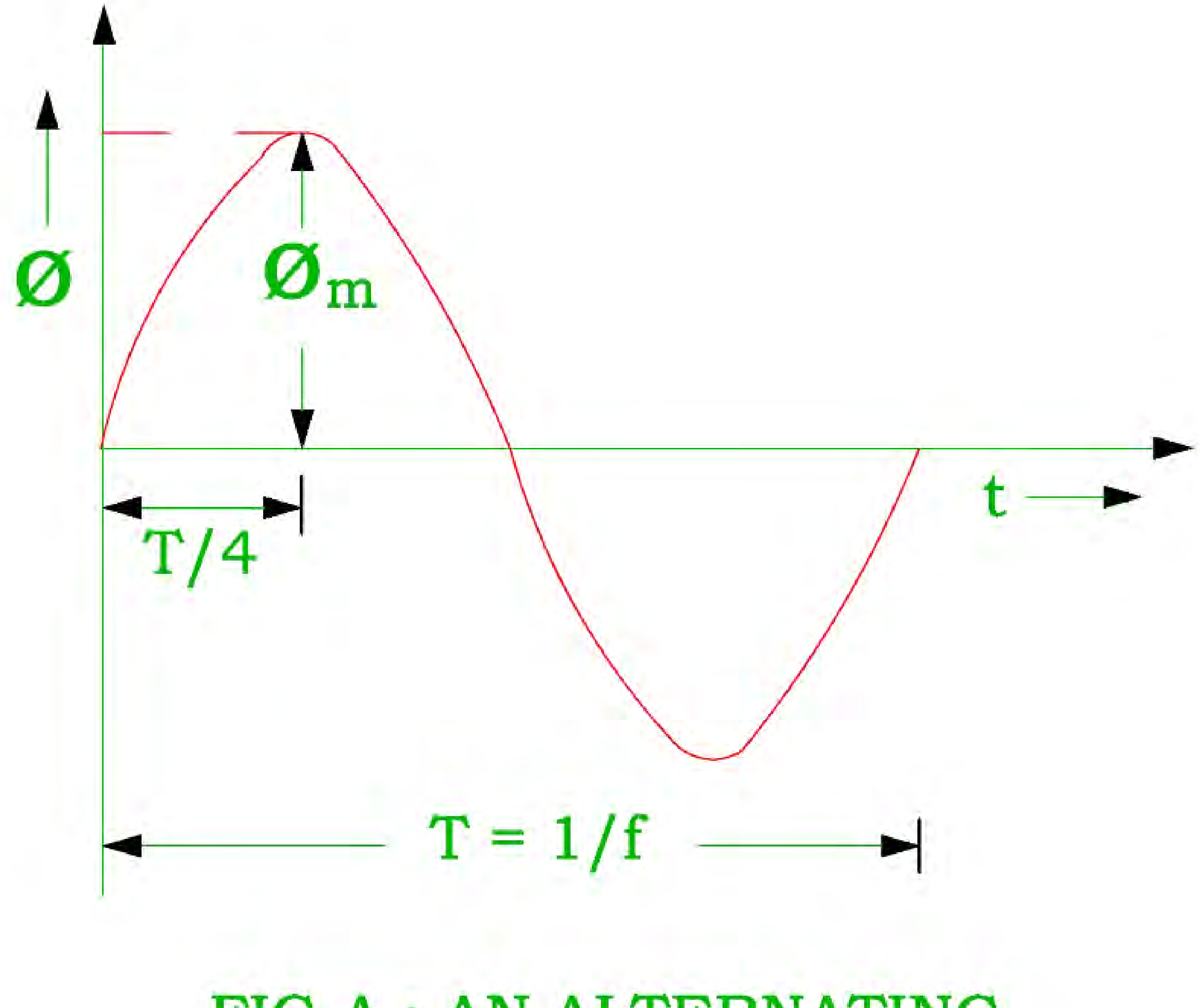
AC vs DC Measurement

AC (Alternating Current)

Typically indicated by ~ symbol

Used for household power, most appliances

Current periodically reverses direction

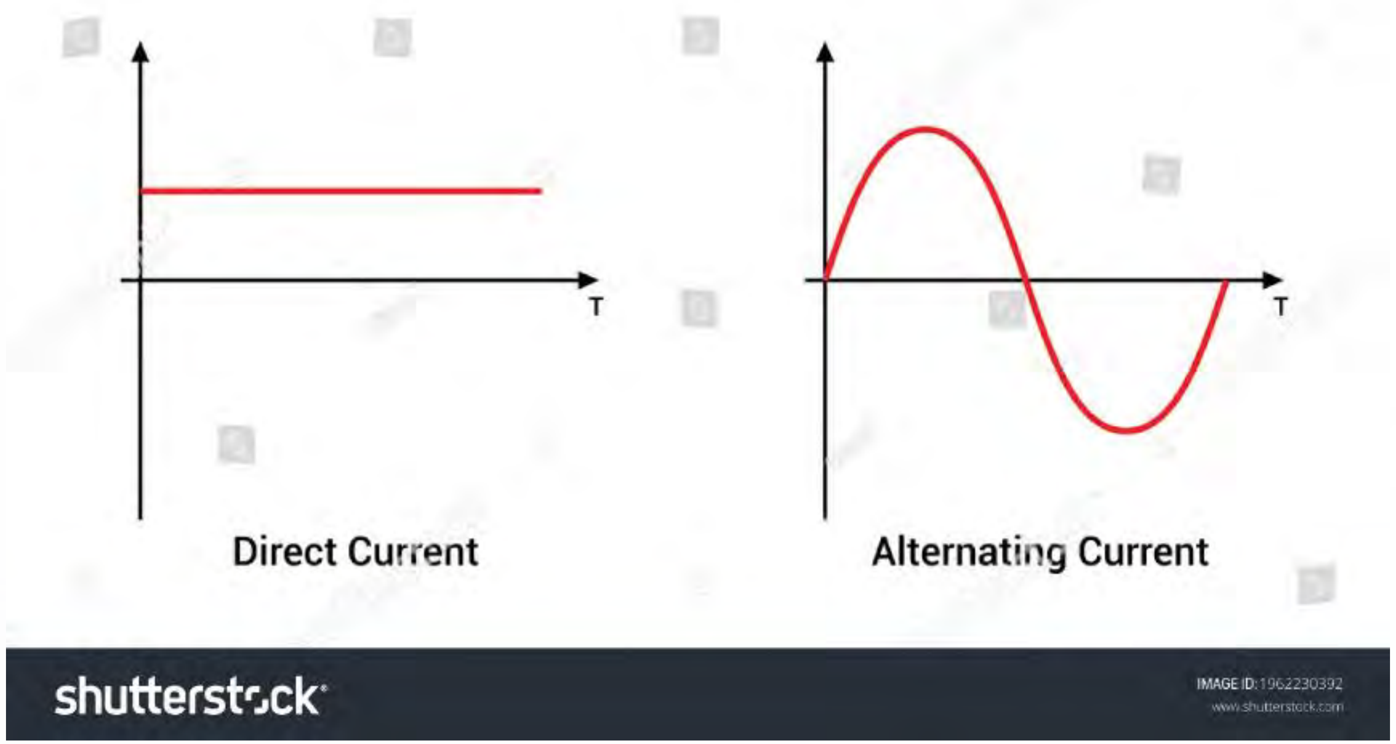


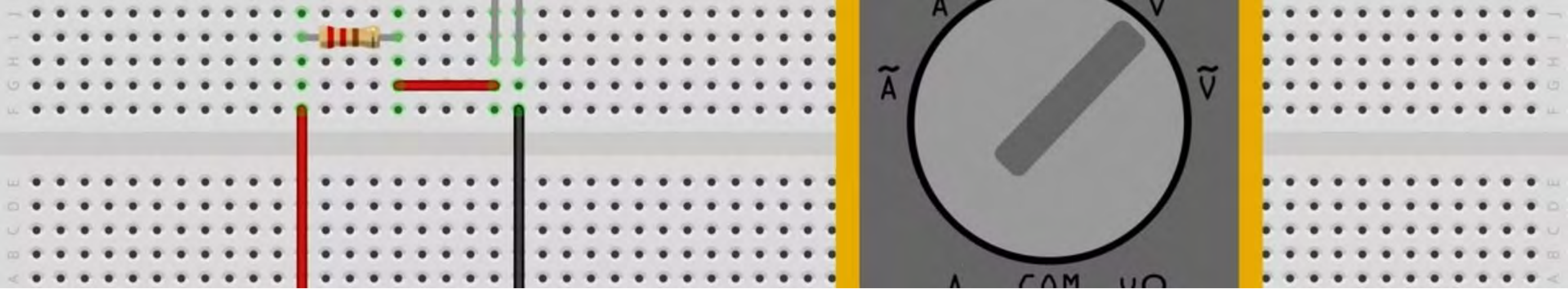
DC (Direct Current)

Typically indicated by ⎓ symbol

Used in batteries, electronics, automotive

Current flows in one direction only





Measuring Voltage in Gas Appliances

Identify Test Points

Locate the appropriate terminals or connections on the gas appliance control board.

Set Multimeter

Select the appropriate voltage range and AC or DC setting based on the appliance specifications.

Connect Probes

Connect the probes to the test points, ensuring proper polarity for DC measurements.

Read and Interpret

Compare the reading to the manufacturer's specifications to determine if the voltage is within acceptable range.

Testing Gas Valve Solenoids

Resistance Testing

Use the ohmmeter function to measure the resistance of the solenoid coil. Compare with manufacturer specifications to determine if the solenoid is functioning properly.

Continuity Check

Use the continuity function to verify there are no breaks in the solenoid circuit. A continuous circuit should produce a beep or indication on the meter.

Voltage Verification

With the system running, use the voltmeter function to confirm the solenoid is receiving the correct voltage when activated.

Troubleshooting Ignition Systems

Check Power Supply

Verify proper voltage to the ignition control module

Test Igniter

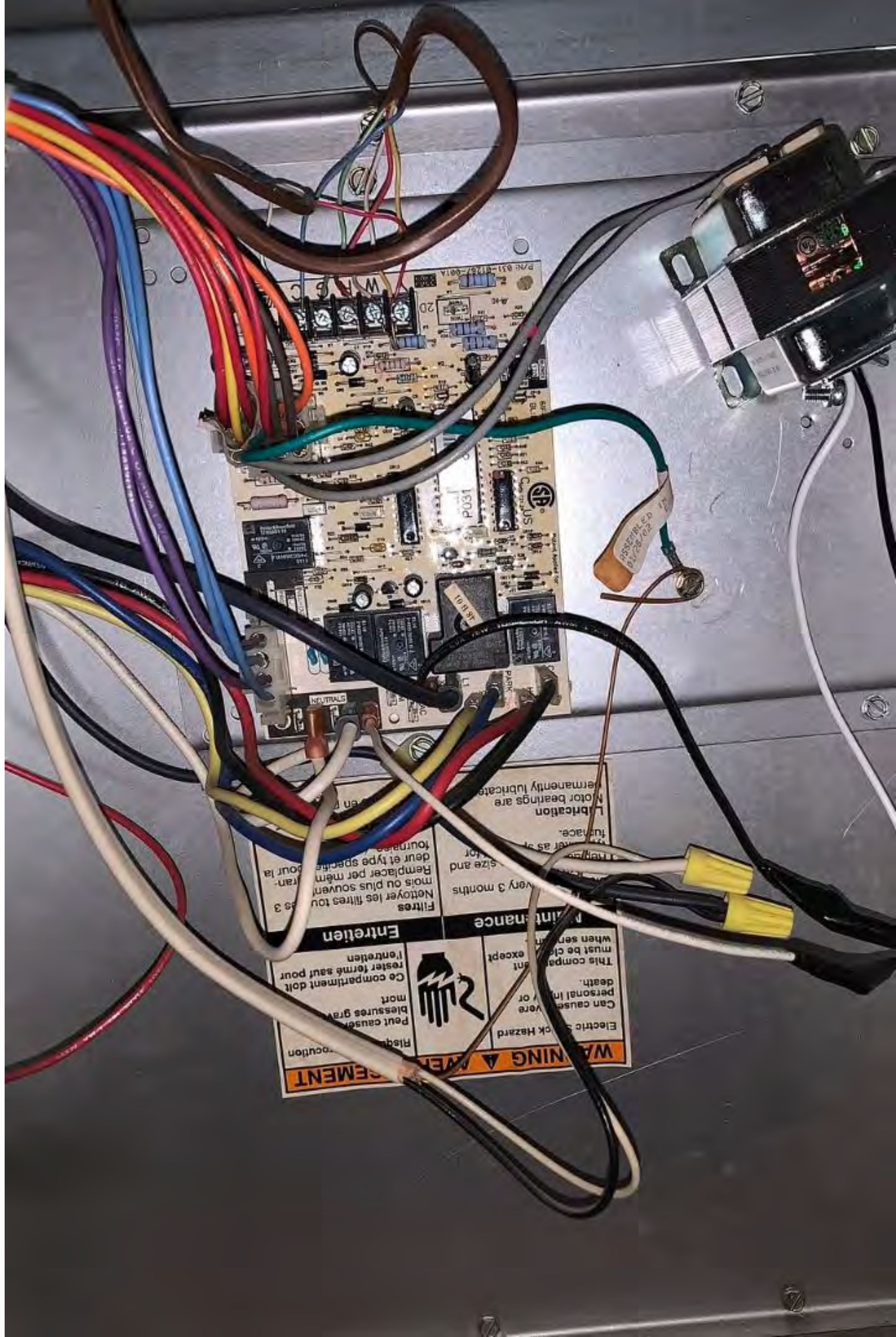
Measure resistance of igniter or spark electrode

Verify Flame Sensor

Check flame sensor circuit for proper microamp reading

Inspect Wiring

Test for continuity in all wiring connections



Measuring Thermocouple Output

Thermocouples are safety devices used in gas appliances to verify the presence of a pilot flame. A properly functioning thermocouple should generate a small DC voltage (typically 25-30 millivolts) when heated by the pilot flame.

Set Multimeter

Set the multimeter to DC millivolts (mV) range.

Connect Probes

Connect the negative probe to the thermocouple sheath and the positive probe to the copper lead.

Heat Thermocouple

With the pilot lit and heating the thermocouple, take the reading.

Interpret Results

A reading below 20mV typically indicates a failing thermocouple that should be replaced.

ITS-90 Table for Type K Thermocouple (Ref junction 0°C)

Thermoelectric voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096

Testing Pressure Switches

Function

Pressure switches in gas appliances verify proper venting and air flow before allowing gas valve operation.

They are normally open (NO) switches that close when proper pressure differential is detected.

Testing Method

Set multimeter to continuity or resistance mode.

Connect probes to the pressure switch terminals.

With the system running and proper pressure applied, the switch should show continuity (closed circuit).

Without proper pressure, the switch should show no continuity (open circuit).

Checking Fan Motor Circuits

Verify Power Supply

Measure voltage at the motor terminals to confirm proper supply voltage.

Test Motor Windings

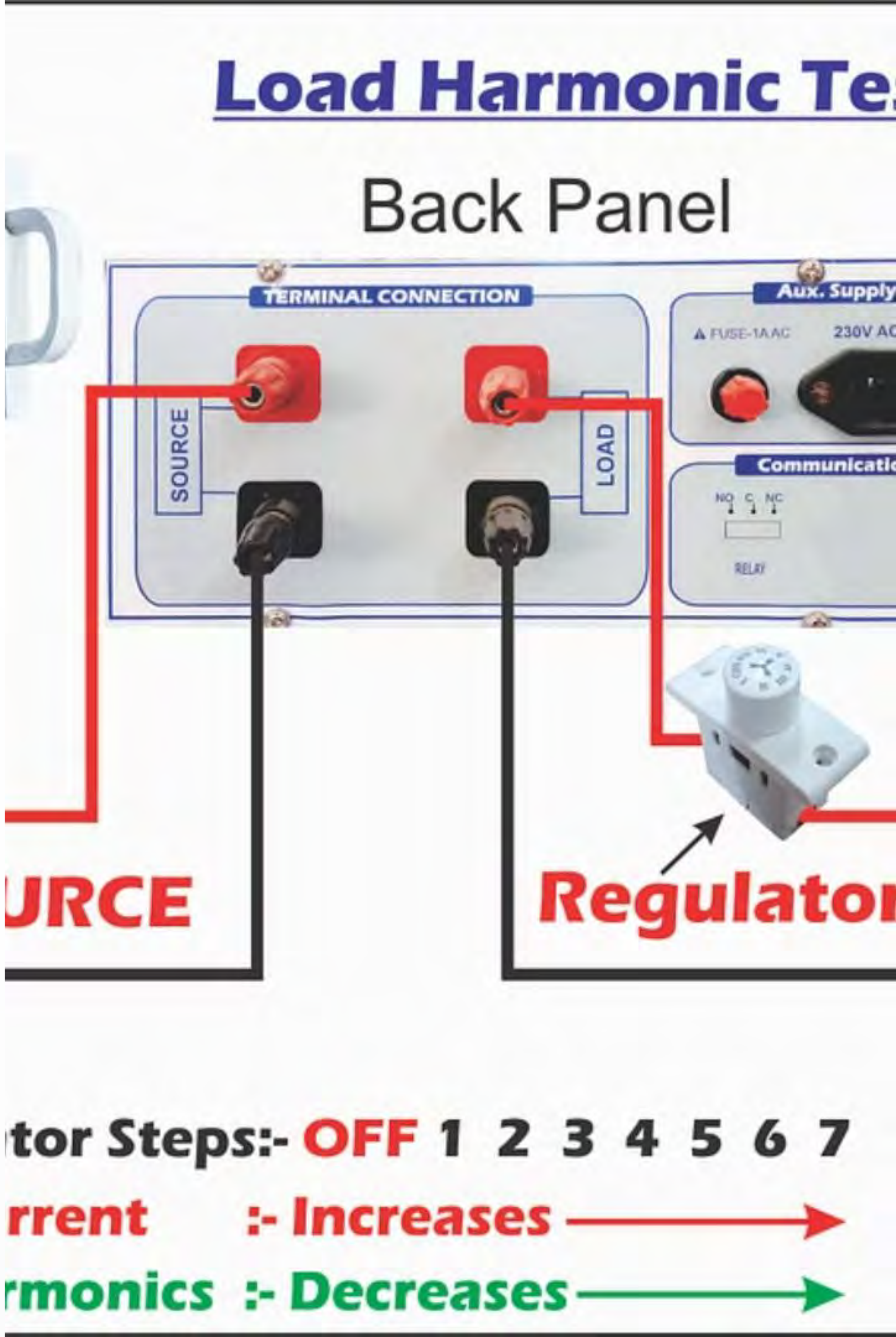
Measure resistance of motor windings to check for opens or shorts.

Check Capacitor

Test capacitor using the capacitance function of the multimeter.

Measure Running Current

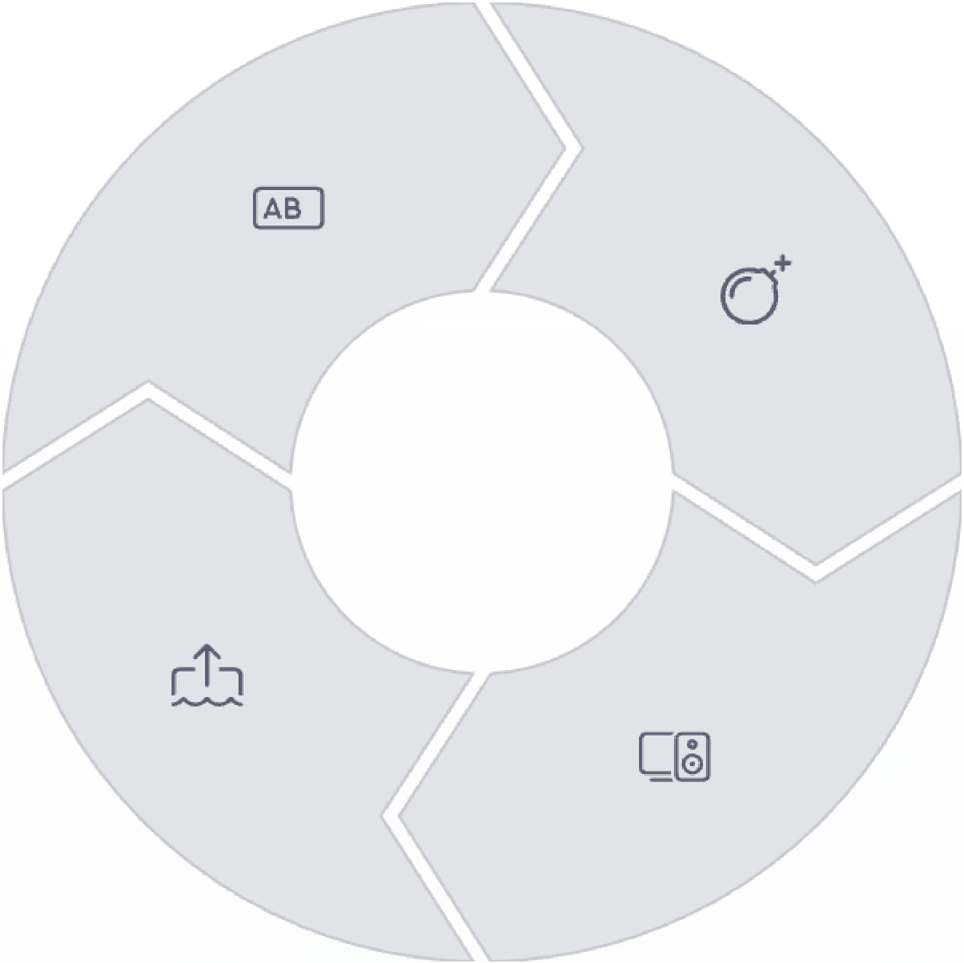
Use clamp meter or ammeter function to verify motor is drawing proper current.



Diagnosing Control Board Issues

Check Input Voltage

Verify proper voltage is reaching the control board



Test Fuses/Circuit Protection

Check continuity of fuses and circuit protection devices

Verify Output Signals

Measure voltage at output terminals during operation sequence

Inspect Ground Connections

Test continuity of ground connections to ensure proper grounding

Measuring Flame Rectification Current

Modern gas appliances often use flame rectification to verify flame presence. This system produces a small DC current (typically 2-10 microamps) when a flame is present.

Set Multimeter

Set the multimeter to DC microamps (μA) range.

Break Circuit

Disconnect one wire from the flame sensor and connect the multimeter in series.

Operate System

Start the appliance and allow it to ignite.

Read Current

A stable flame should produce a reading of at least 2 microamps. Lower readings indicate a problem with the flame sensor or grounding.

Testing Limit Switches

Function

Limit switches are safety devices that open when temperature exceeds safe levels, shutting down the heating system.

Normal Operation

Under normal temperature conditions, limit switches should show continuity (closed circuit).

Testing Method

Set multimeter to continuity or resistance mode and connect probes to the switch terminals. A reading of near zero ohms indicates a properly functioning switch.

Troubleshooting

If a limit switch shows no continuity at normal temperatures, it may be defective or may have tripped due to overheating conditions that need to be addressed.

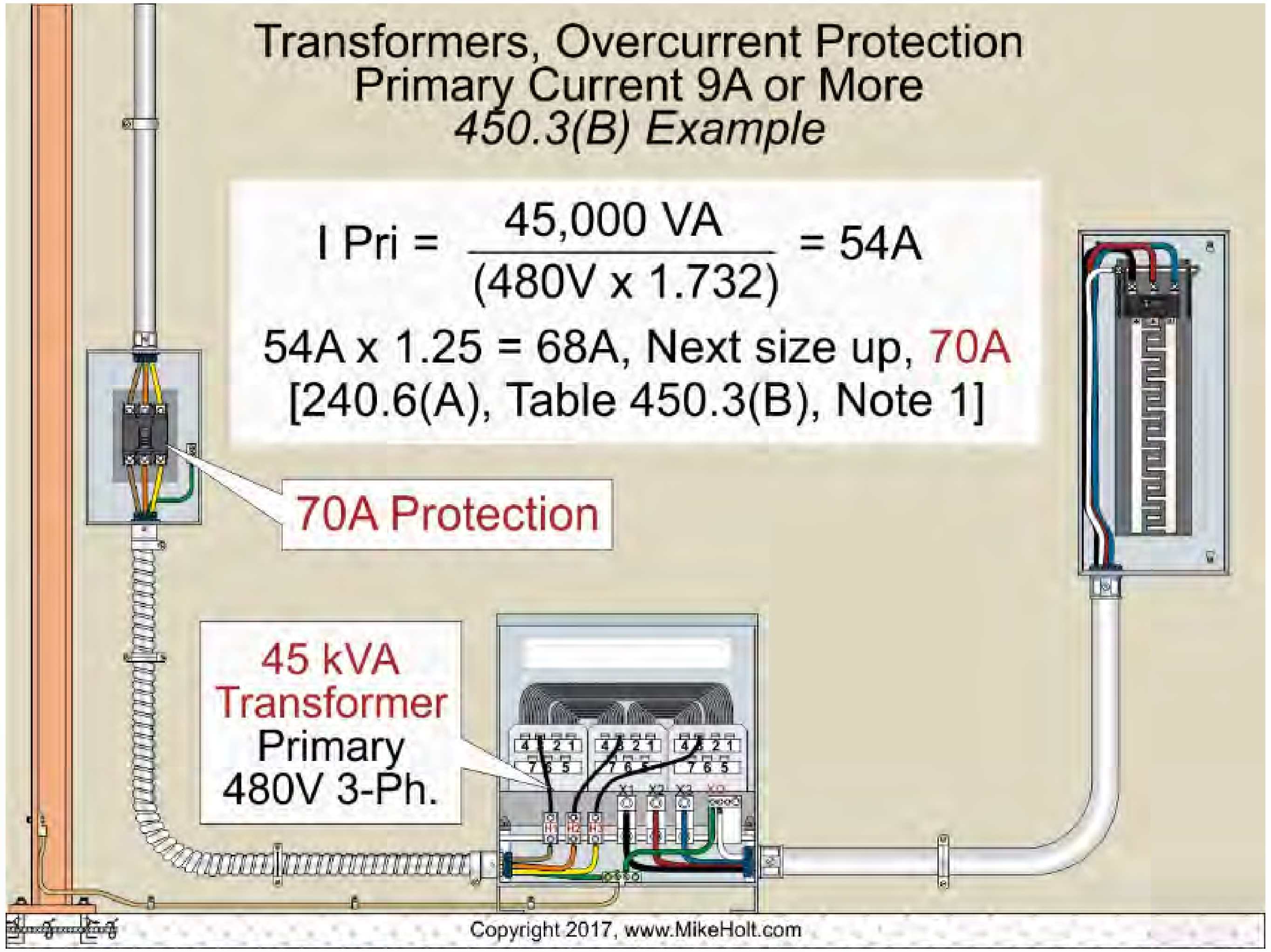
Checking Transformer Output

Primary Side

Set multimeter to AC voltage and measure across the primary terminals of the transformer. This should match the input voltage (typically 120V or 240V).

Secondary Side

Set multimeter to AC voltage and measure across the secondary terminals. This should match the expected output voltage (typically 24V for control circuits in gas appliances).



Verifying Proper Grounding

Importance

Proper grounding is essential for both safety and correct operation of electronic control systems in gas appliances.

Testing Method

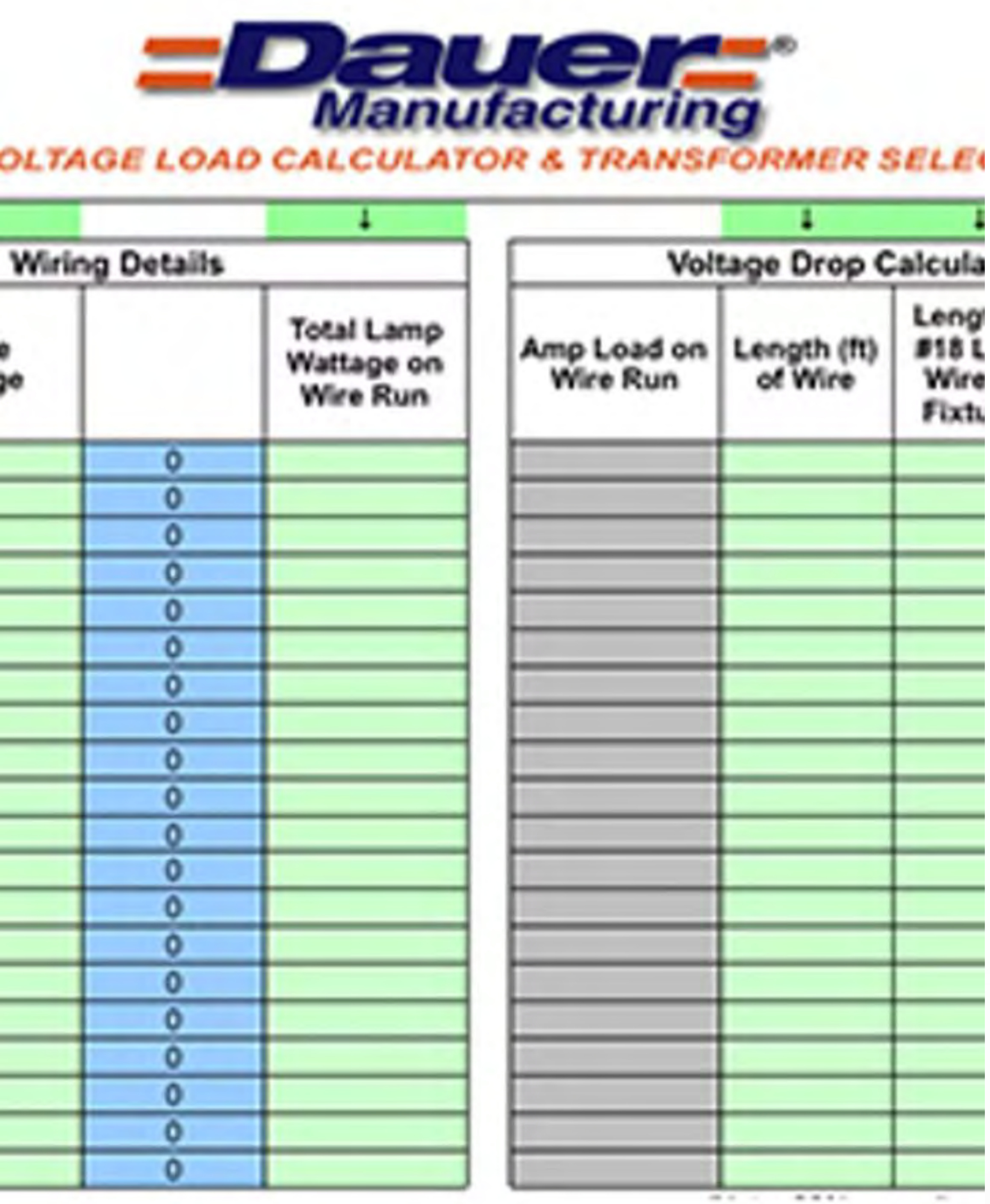
Set multimeter to continuity or resistance mode and check for continuity between the ground terminal and the appliance chassis.

Voltage Check

Set multimeter to AC voltage and measure between the neutral wire and ground. A properly grounded system should show very low voltage (less than 2V).

Resistance Verification

The resistance between the ground terminal and chassis should be very low (less than 1 ohm).



Measuring Voltage Drop

Voltage drop testing can help identify poor connections or excessive resistance in circuits that may cause operational issues.

Set Multimeter

Set the multimeter to DC voltage for DC circuits or AC voltage for AC circuits.

Connect Probes

Connect the probes across the component or wire section being tested.

Operate Circuit

Ensure the circuit is operating and current is flowing.

Interpret Results

A significant voltage drop across a connection or wire indicates excessive resistance that should be addressed.

Testing Relay Circuits

Coil Testing

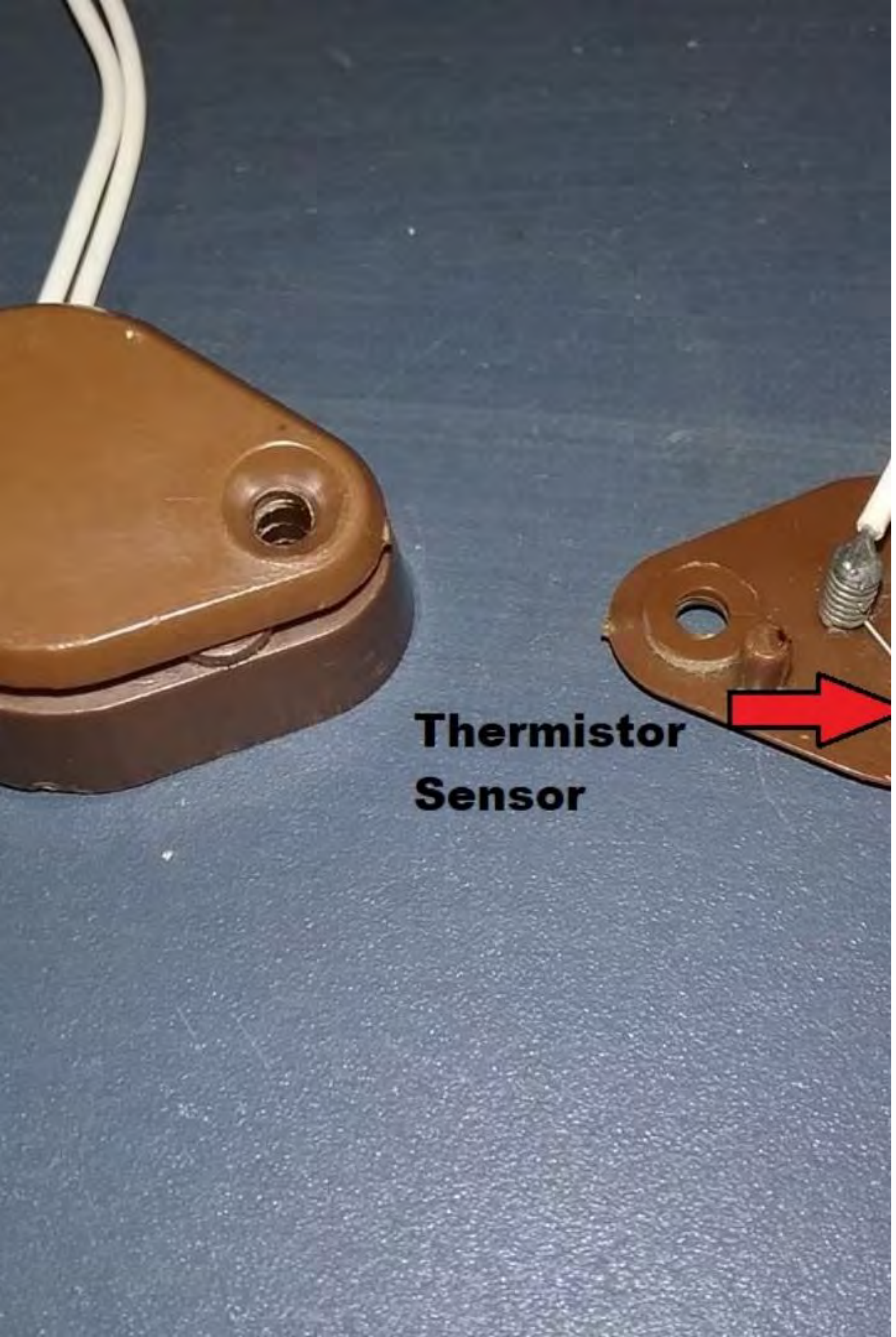
Set multimeter to resistance mode and measure across the relay coil terminals. The reading should match the manufacturer's specifications (typically a few hundred ohms).

Alternatively, set to DC voltage and verify the coil is receiving the correct voltage when activated.

Contact Testing

Set multimeter to continuity mode and check the relay contacts in both energized and de-energized states:

- Normally open (NO) contacts should show no continuity when de-energized and continuity when energized
- Normally closed (NC) contacts should show continuity when de-energized and no continuity when energized



Checking Thermistor Sensors

Thermistors are temperature sensors used in modern gas appliances to monitor various temperatures. Most are negative temperature coefficient (NTC) type, meaning their resistance decreases as temperature increases.

Resistance Testing

Set multimeter to resistance mode and measure across the thermistor terminals. Compare the reading to the manufacturer's temperature/resistance chart.

Temperature Correlation

Measure the actual temperature at the sensor location and verify the resistance reading corresponds to that temperature according to specifications.

Circuit Verification

Check for proper voltage supply to the sensor circuit and verify the control board is receiving the sensor signal.

Diagnosing Intermittent Issues

Monitor Over Time

Use a multimeter with min/max recording capability to capture fluctuations

Check Under Vibration

Test connections while gently flexing wires to identify loose connections

Test at Different Temperatures

Monitor circuit behavior as components heat up during operation

Verify Under Load

Test circuit performance when the system is under full operational load

Measuring Insulation Resistance

For testing high-resistance insulation in motors and wiring, a specialized insulation tester (megohmmeter) is often required, as standard multimeters cannot measure very high resistance values accurately.

Safety First

Always disconnect power and discharge capacitors before testing insulation resistance.

Specialized Equipment

Use a proper insulation resistance tester (megohmmeter) for this test.

Testing Method

Connect one lead to the conductor and the other to ground, then apply the test voltage and read the resistance value.

Interpretation

Good insulation typically shows resistance in the megohm range. Low readings indicate insulation breakdown.

Testing Capacitors

Discharge First

Always discharge capacitors before testing by shorting the terminals with an insulated resistor.

Set Multimeter

Set the multimeter to capacitance mode if available.

Connect Probes

Connect the probes to the capacitor terminals, observing polarity for polarized capacitors.

Read Value

Compare the measured value to the rated capacitance. It should be within the tolerance specified (typically ±10%).

Checking for Voltage Leakage

Voltage leakage can occur when insulation breaks down or when moisture creates conductive paths between circuits.

Testing Method

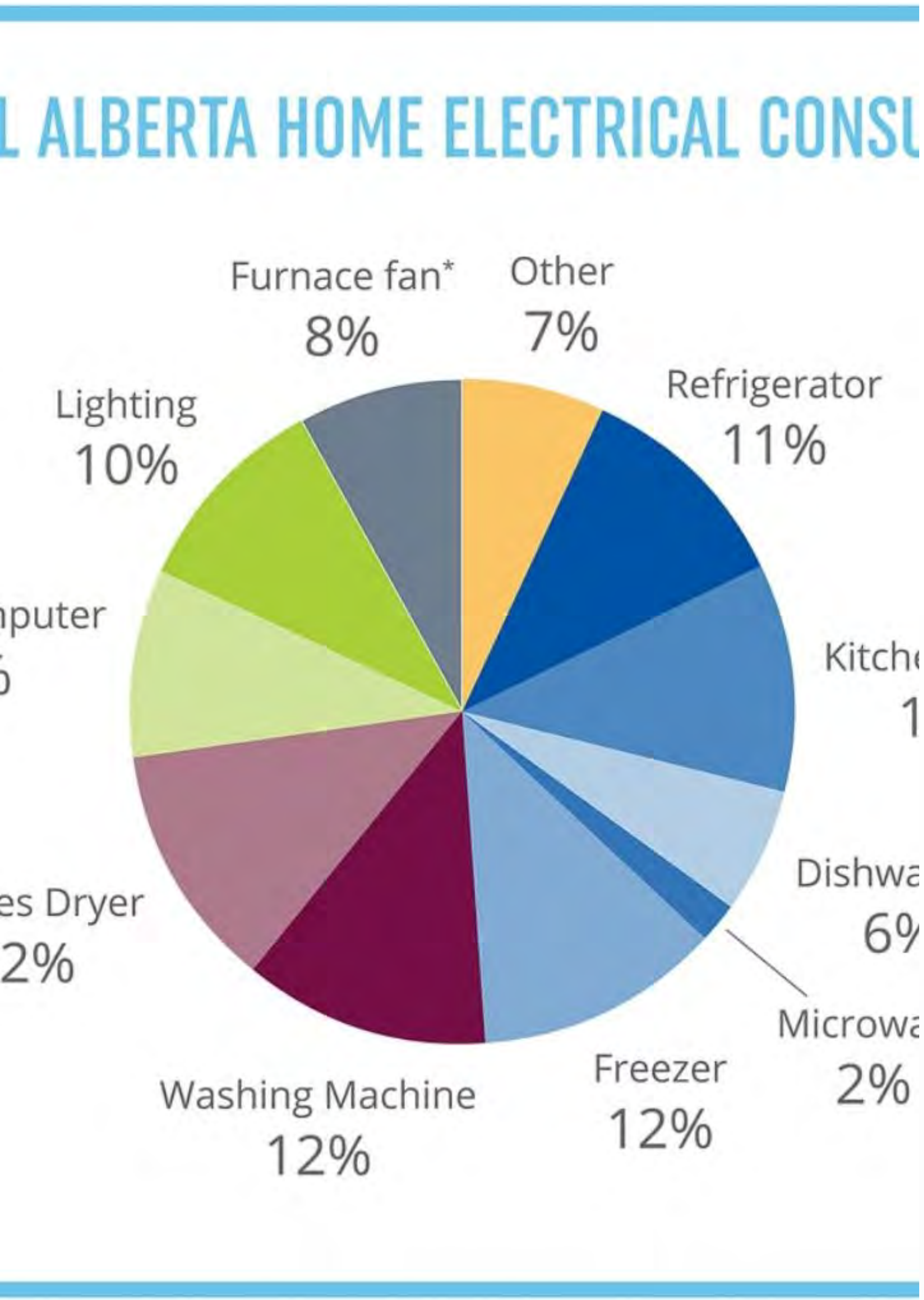
Set multimeter to the highest DC or AC voltage range.

Connect one probe to the suspected leakage source and the other to ground or another circuit.

Any significant voltage reading indicates leakage that should be addressed.

Common Causes

- Damaged wire insulation
- Moisture or corrosion on circuit boards
- Failed component insulation
- Improper grounding



Measuring Power Consumption

Understanding the power consumption of gas appliances can help diagnose efficiency issues and verify proper operation.

Voltage Measurement

Measure the voltage across the power supply terminals.

Current Measurement

Measure the current draw using the ammeter function or a clamp meter.

Calculate Power

For DC circuits: Power (watts) = Voltage × Current

For AC circuits: Power (watts) = Voltage × Current × Power Factor

Compare to Specifications

Compare the calculated power consumption to the manufacturer's specifications.

Advanced Multimeter Features

Frequency Measurement

Measures the frequency of AC signals, useful for testing control circuits.

Temperature Probe

Many DMMs can measure temperature with an appropriate thermocouple probe.

Data Logging

Records measurements over time to help diagnose intermittent issues.

Wireless Connectivity

Some modern DMMs can connect to smartphones or computers for data analysis.

Multimeter Accuracy Specifications

Measurement Type	Typical Basic Accuracy	Factors Affecting Accuracy
DC Voltage	±(0.5% + 2 digits)	Input impedance, temperature
AC Voltage	±(1.0% + 3 digits)	Frequency response, waveform
DC Current	±(1.0% + 2 digits)	Temperature, fuse resistance
AC Current	±(1.5% + 3 digits)	Frequency response, waveform
Resistance	±(0.8% + 2 digits)	Contact resistance, temperature

Summary: Electrical Measuring Instruments

Mastery

Effective troubleshooting of complex gas systems

Practice

Regular use and application of measurement techniques

Knowledge

Understanding instrument functions and limitations

Safety

Following proper procedures and precautions

Gas technicians and fitters must develop proficiency with electrical measuring instruments to effectively diagnose and repair modern gas appliances. By understanding how to select the appropriate instrument, use it correctly, and interpret readings accurately, technicians can ensure safe and efficient operation of gas equipment.