

FUNDAMENTALS OF ELECTRICITY

**Second Edition —
Manual and Workbook COMBINED**

Prepared by



Operations & Engineering Department

for

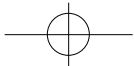
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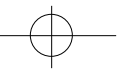
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Second Edition

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FOREWORD

This manual was prepared under the direction of the American Gas Association and Gas Appliance Manufacturers Association Joint Committee for Customer Service. It was written by James C. Griffiths, Senior Research Engineer, and J. Fred Parr, Manager of Engineering Services, American Gas Association Laboratories, Cleveland, Ohio.

The purpose of the manual is to provide a text for self study. Hopefully, it will become a useful tool to vocational-technical schools, appliance service and repairmen, and utility customer service programs. The text has been prepared so that only a moderate knowledge of mathematics and science is required for understanding. In an effort to assist in the reinforcement of the material found in the text, this edition combines the text of the Fundamentals of Electricity Manual, XH0175, and the Fundamentals of Electricity Workbook, XH1281. Answers to all chapter reviews can be found on pages 108–113 of this book.

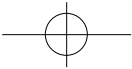
This is the third manual of the original series. The first, “Fundamentals of Gas Combustion”, was published in January 1973. The second, “Fundamentals of Gas Appliance Venting and Ventilation” was published in May 1974.

Other texts in this series cover the following fundamental subject areas:

- Gas Appliances
- Gas Controls
- Customer Service

At the end of the text is a glossary of terms used in basic electricity. It is suggested that the student familiarize herself/himself with these terms so that the text material will be meaningful. Words that appear in the text in bold face appear in the glossary.

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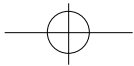


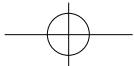
TABLE OF CONTENTS

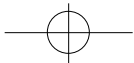
I. INTRODUCTION 1
Historical Background on Discovery of Electricity 1
Use of Gas and Electricity Together to Improve the Way of Life for Everyone ..2
CHAPTER REVIEW 3

II. HOW ELECTRICITY IS SUPPLIED 5
Potential Difference, Electromotive Force (EMF) or Voltage 5
Devices to Provide an Electromotive Force (Voltage) 7
 The Chemical Cell or Battery 7
 Mechanical Generators 9
 Thermoelectric Sources of Voltage 12
 Piezoelectric Sources of Voltage 13
CHAPTER REVIEW 15

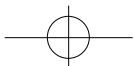
III. ELECTRICAL TERMS 18
The Volt 19
 Millivolt Systems (DC) 19
 24-Volt Systems 19
 120-Volt, 240-Volt Systems 20
 High Voltages 20
The Ampere 20
The Ohm 20
 Conductors 22
 Resistors 22
 Insulators 22
Capacitance 23
Inductance 28
The Watt (Electrical Power) 29
CHAPTER REVIEW 30

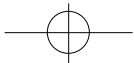
IV. ELECTRICAL RELATIONSHIPS 34
Ohm’s Law 34
Series and Parallel Circuits 36





Series Circuits	36
Parallel Circuits	37
Impedance	39
Watt’s Law	39
Formula Circle	41
CHAPTER REVIEW	42
 V. BASIC ELEMENTS OF ELECTRICAL CIRCUITS	 44
Source	44
Line Voltage Sources	44
Thermoelectric Voltage Sources	45
Current Control Devices - Switches and Resistors	45
Electrical Switches	45
Electrical Resistors	46
Load	46
CHAPTER REVIEW	47
 VI. CIRCUIT COMPONENTS AND THEIR GRAPHIC SYMBOLS	 49
Receptacles and Plugs	49
Thermocouples and Thermopiles	49
Lines and Connections	49
The Fuse and the Circuit Breaker	50
Fuse	50
Circuit Breaker	50
Ground	51
Ground Fault Circuit Interrupter or GFI	51
Switches	51
Switch Poles and Throws	52
Single Pole — Single Throw Switch (SPST)	52
Single Pole — Double Throw Switch (SPDT)	52
Double Pole — Single Throw Switch (DPST)	52
Double Pole — Double Throw Switch (DPDT)	52
Methods of Actuating Switches	52
Manual Switches	52
Mechanically Actuated Switches	52
Pressure Actuated Switches	53



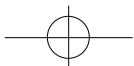


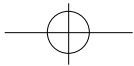
Temperature Actuated Switches	.53
Electromagnetically Actuated Switches (Relays)	.53
Normally Open or Normally Closed Switches	.53
Electrical Resistors	.54
Fixed Resistors	.54
Variable Resistors	.55
Rectifiers	.56
Load Components in Electrical Circuits	.56
Resistive Components	.56
The Incandescent Light	.56
Resistive Heating Elements	.57
Hot Surface Ignitors	.57
Capacitors	.57
Transformers	.57
Spark Gap	.57
Fluorescent Lamps and Ballasts	.58
Bells and Buzzers	.58
Motors	.59
Motor Starters and Start Switches	.59
Solenoids	.60
CHAPTER REVIEW	.61

VII. ELECTRICAL CIRCUIT DIAGRAMS	.71
Connection Diagram	.71
Schematic Diagram	.71
CHAPTER REVIEW	.73

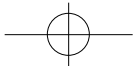
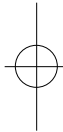
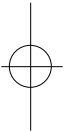
VIII. POLARITY	.74
Hot and Neutral Lines	.74
How to Determine Polarity	.75
CHAPTER REVIEW	.77

IX. TEST EQUIPMENT	.79
Test Lights	.79
Filament Bulb Test Light	.79





Neon Test Light	80
Jumper Wire	80
Continuity Tester	81
Volt-Ohm Meter	81
The Voltmeter	81
The Ohmmeter	83
Use of Volt Ohmmeters	84
The Ammeter	84
Millivoltmeter	85
Open Circuit Voltage	85
Closed Circuit Voltage	86
CHAPTER REVIEW	87
 X. APPLICATION	 92
DC Millivolt Circuits	92
Single Thermocouple Systems	94
Thermopile Systems	96
Low Voltage Circuits	97
Line Voltage Circuits	99
Limit Controls, Thermostats and Automatic Gas Control Valves	99
Motors	99
Timer Circuits	100
CHAPTER REVIEW	101
 XI. ELECTRICAL SAFETY	 106
CHAPTER REVIEW	107
 ANSWERS TO CHAPTER REVIEWS	 108
REFERENCES	115
GLOSSARY	117
APPENDIX Graphic symbols of Some Items Extracted From	
ANSI Y32.2 1975, Graphic Symbols for Electrical	
and Electronic Diagrams and Abbreviations for These Items . .	125



I. INTRODUCTION

Historical Background on Discovery of Electricity

Perhaps the first “electrical” experiment conducted by man was performed by the Greek Philosopher Thales (640–546 B.C.). Thales observed that when a piece of a natural resin called amber was rubbed with a cloth, the amber attracted light objects near it. Today we say that rubbing amber with cloth gives the amber a charge of static electricity. The term “electricity” comes from “electra,” the Greek word for amber.

Other substances also can be charged with static electricity by rubbing, such as a glass rod with silk, or hard rubber with fur. A familiar experience due to the creation of static electricity is the shock sometimes received in touching a door-knob or some other grounded object after walking across a carpet on a dry winter day. Static electricity, built up by tires rolling over pavement, dictates the use of a dangling chain or strap attached to trucks carrying flammable vapors to prevent sparks between the truck and the ground, which are a possible fire hazard.

Static electricity, as such, is not of primary interest here. However, the basic cause of its formation does have an important bearing on understanding the nature of electricity in forms, which are of practical interest.

To understand what happens, we must consider the structure of atoms, the smallest particles of matter. The **atom**, Figure 1, is made up of a positively charged central nucleus, around which

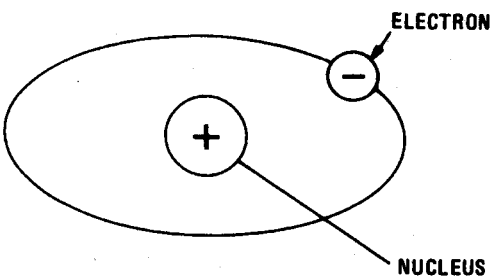


Fig. 1 Representation of a hydrogen atom. The negatively charged electron resides in an orbit around the positively charged nucleus.

whirl very small, negatively charged particles called **electrons**. The number of negatively charged electrons is the same as the number of positive charges on the nucleus, so that the atom is stable, that is, it is not charged electrically. However, if for some reason the number of electrons is greater than that of the positive charges on the nucleus, the atom is negatively charged. On the other hand, if the number of positive charges in the atom is greater than the number of electrons the atom is said to be positively charged. When a hard rubber rod is rubbed with fur, electrons are stripped from the fur atoms. As a result, the rubber gains electrons and becomes negatively charged. The fur loses electrons, so becomes positively charged.

Charged atoms naturally tend to return to the stable, uncharged state. If one of two bodies has more free electrons than the other, the first body is said to be negatively charged with respect to the second, and the second is said to be positively charged with respect to the first. If the two bodies are connected together by a wire, electrons flow from the electrically negative body to the positive one. (We speak of this flow of electrons as electricity.)

(* Words which appear in the text in bold face type are defined in the glossary starting on Page 117. See page 115 for sources of reference materials

Since the discovery of static electricity over 2500 years ago by Thales, many men have made other important electrical discoveries. Two of these discoveries have had a particularly important bearing on man's use of electricity.

In 1820, Hans Christian Oersted (1777–1851) discovered that a magnetic field surrounds a conductor carrying an electric current. This discovery led to the **electromagnet**, Figure 2, which is the

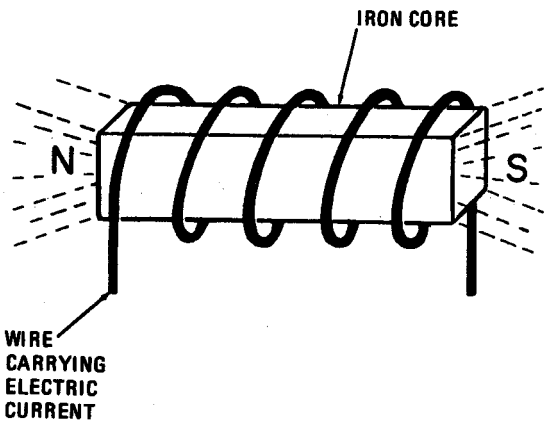


Fig. 2 When a wire carrying electric current is wrapped around a soft iron core, the iron becomes a magnet.

basis (among other things) for our solenoid-type gas controls of today. It also is a basic principle on which the development of electric motors was made possible. In 1831, Michael Faraday (1791–1867) discovered that an electrical current could be generated in a conductor, which was moved through a magnetic field, Figure 3. This discovery led to the development of

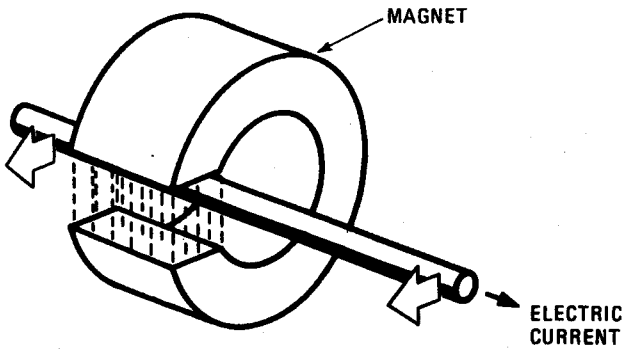


Fig. 3 Moving a wire through a magnetic field causes electricity to flow in the wire

the electrical **generator**. These electrical devices form the foundation of having electrical **energy** work for us.

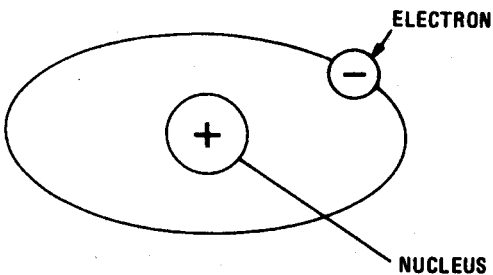
Use of Gas and Electricity together to improve the Way of Life for Everyone

Virtually all of today's gas appliances use some form of electricity in their operation. For example, the circulating air blower, driven by an electric motor, is a vital part of the forced warm-air gas furnace. Many of today's gas appliance controls are electrically operated, some by electricity from the home supply, others by electricity generated by heat from the gas. Together these two forms of energy, gas and electricity, provide improved performance, safety and convenience for appliance owners.

CHAPTER I REVIEW—
INTRODUCTION

Fill in the blanks from the work list on the right. Answers are at the end of this manual.

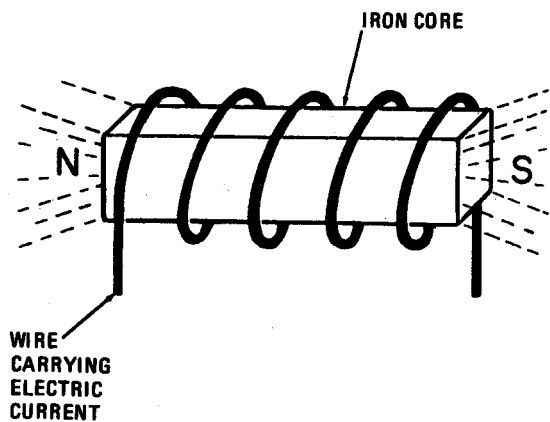
1. The first electrical experiment was performed between 640–546 B.C. Amber was rubbed with a cloth which caused a charge of static electricity to be stored in it. This attracted light objects near the amber to it. The term electricity comes from _____, the Greek word for amber. (p. 1)
2. A familiar experience due to the creation of static electricity is the shock sometimes received in touching a _____ object after walking across a carpet on a dry winter day. (p. 1)
3. Static electricity as such is not of primary interest here. However, the basic cause for its formation does have an important bearing on understanding the nature of _____ in forms which are of practical interest. (p. 1)
4. To understand what happens, we must consider the structure of atoms, the smallest particles of matter. The atom is made up of a positively charged nucleus around which whirl very small negatively charged particles called 1. _____. The number of 2. _____ charged electrons is the same as the number of positive charges on the nucleus so that the atom is stable. However, if the number of electrons is greater than the number of the positive charges on the 3. _____, the atom is 4. _____ charged. On the other hand, if the number of positive charges in the atom is greater than the number of electrons, the atom is said to be 5. _____ charged. (p. 1)



Representation of a hydrogen atom. The negatively charged electron resides in an orbit around the positively charged nucleus.

electricity
negatively
positively
grounded
negatively
electrons
electra
nucleus

5. When a hard rubber rod is rubbed with fur, electrons are stripped from the fur atoms. As a result, the rubber gains 1. _____ and becomes 2. _____ charged. The fur loses 3. _____ and becomes 4. _____ charged. (p. 1)
6. Since _____ the _____ discovery _____ of 1. _____ 2. _____ over 2,500 years ago, many men have made other important electrical discoveries. Two of these are of particular importance. (p. 2)
7. 1820 — H. Orsted discovered that a magnetic field surrounds a conductor carrying an electrical current. This discovery led to the _____. (p. 2)



8. 1831 — Michael Faraday discovered that an electrical current could be generated in a conductor which was moved through a magnetic field. This led to the development of the electrical _____. (p. 2)
9. Nearly all of today's gas appliances use some form of _____ in their operation. (p. 2)

positively

electricity

electrons

generator

electromagnet

electricity

static

negatively

electrons

II. HOW ELECTRICITY IS SUPPLIED

Potential Difference, Electromotive force (EMF) or Voltage

As stated earlier, electricity is the movement of electrons from a body that contains an excess of electrons to a body that has a deficiency of electrons. This movement of electrons is illustrated in Figure 4, in which a body with a number of free

depend on the difference of the number of free electrons in A compared to B. The greater the difference of free electrons, the greater will be the flow. The less the difference, the less will be the flow. This movement of free electrons from A to B will continue until each body contains the same number of free electrons (the bodies will be equally charged) and then electron flow will stop.

The relative charge on Bodies A and B of Figure 4 can be considered as a difference in electrical pressure between these two points, known as the **potential difference**. A water **analogy** to illustrate this potential difference and subsequent flow of electrons between two points is shown in Figure 5.

Consider the two reservoirs shown in Figure 5 (a), connected together, but with a closed valve in the connecting line. Reservoir A is filled with water to a higher level than reservoir B. As a result, a potential difference exists between the two reservoirs. In other words, the water in reservoir A exerts a greater pressure on its side of the valve than does the water in reservoir B on its side of the valve. This situation is comparable to a negatively charged and positively charged body (or less negatively charged body) isolated from each other. In figure 5 (b), the valve is opened. The greater water pressure from reservoir A at the valve causes water to flow into reservoir B through the connecting line and valve. This condition is like connecting two charged electrical bodies with a wire, with a resultant flow of electrons from the more negatively charged on to the other. When the water levels in

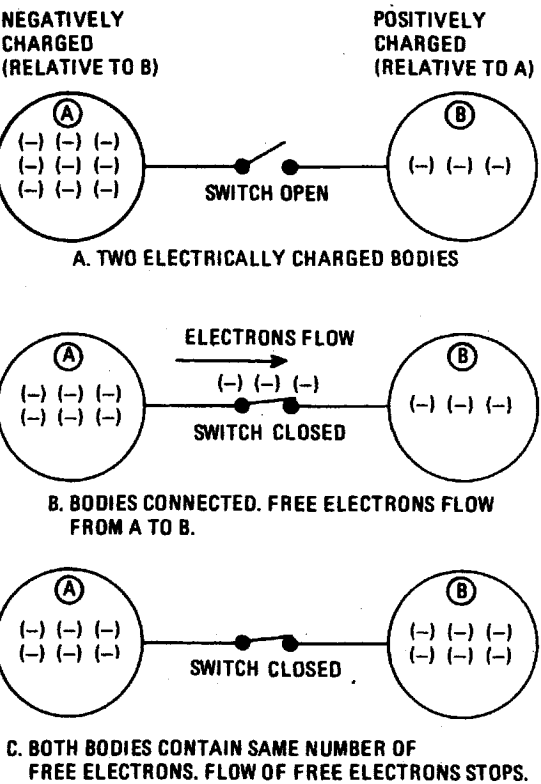


Fig. 4 Electron flow between two electrically charged bodies

electrons is connected to a body with a smaller number of free electrons by a copper wire. As shown by the arrows, electrons will flow from the body with the most electrons to the body with fewest electrons. Electron flow in this fashion is called electric current.

The amount of electron flow between Body A of Figure 4 to Body B will

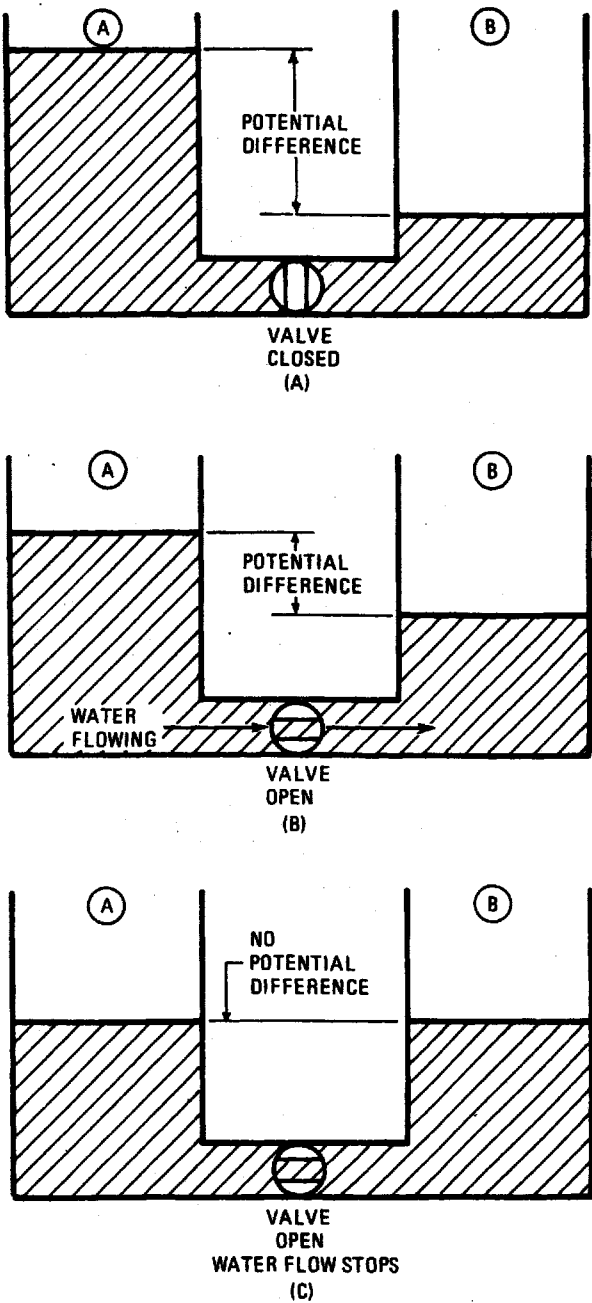


Fig 5 Water analogy of electrical potential difference and flow of electrons

reservoirs A and B reach the same height, Figure 5 (c), the potential difference has become zero (the pressures on either side of the valve are the same) and water flow stops. Similarly, with two electrically charged bodies, when each contains the same number of free electrons and are thus equally charged, electron flow from one to the other stops.

Thus far we have been dealing with static electricity, in which two bodies are charged only once, and then interact with each other when they are connected together. To relate this simple case to practical electrical **circuits** that are used in gas appliances, we must consider two additional factors. First, as indicated earlier, the natural state of atoms is neutral and uncharged. Hence some work must be done or energy used to create a potential difference between two bodies. In the case of charging a piece of hard rubber with static electricity by rubbing it with fur, this work or energy is provided by rubbing action. In the water analogy shown in Figure 5, we simply stated that the two reservoirs were filled initially to two different levels. Some work or energy must have been applied to fill these reservoirs. Electricity cannot be generated for nothing and when electrical energy is generated, some other form of energy is used up in producing it. Some form of energy, whether it is mechanical, chemical, etc., is converted to electrical energy.

Secondly, in practical electrical circuits, it is necessary to have a constant flow of electricity in the circuit when it is in use, rather than the one-shot affair discussed so far in relation to static electricity. Therefore, some source must continuously maintain a potential difference between two points in a circuit. Such a source provides what is commonly referred to as an **electromotive force**, abbreviated as **EMF**, which represents the same thing as a potential difference.

The source for EMF can be illustrated by expanding the water analogy of Figure 5 to include a pump, as shown in Figure 6.

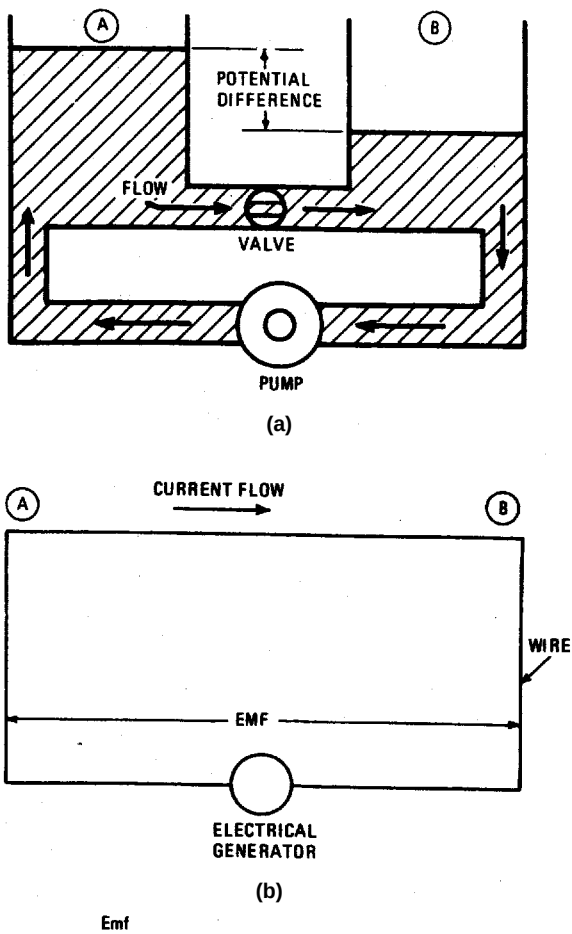


Fig. 6 Water analogy of a source providing a constant EMF to maintain flow of electricity in a system

In Figure 6, the difference in water height between the reservoirs produces a potential difference. With the valve open in the line connecting the two reservoirs, water flows from A to B as shown. However, if the pump (representing the source of EMF) withdraws water from B and returns it to A at the same flow rate as water is flowing from A to B through the valve, the water levels in the two reservoirs will remain unchanged. Hence water will continue to flow around the system at a constant rate as long as the pump is in operation. Since as much water is returned by the pump to reservoir A as flows out of A into B, the water levels in

the two reservoirs will remain constant. The potential difference between A and B will remain constant.

In an electric circuit, Figure 6 (b), an EMF source which could be a generator or battery “pumps” electrons, maintaining a potential difference between points A and B so that electrons continuously flow around the circuit. Note that some external energy or work must be applied or used up at the EMF source to keep it operating, just as work must be expended in driving the pump in 6 (a).

Devices to Provide an Electromotive Force (Voltage)

EMF sources use some sort of energy (mechanical, chemical, heat, etc.) to provide a potential difference in an electrical circuit. This potential difference is most often called **voltage**. Two methods of producing EMF or voltage most commonly encountered are the **chemical cell** (or **battery**) and the mechanical generator. Gas appliance designs also make considerable use of thermoelectric generators or thermocouples. **Piezo-electric** crystals have occasionally been used in appliances. A discussion of the general operating principles of these four methods of providing a voltage or EMF follows.

THE CHEMICAL CELL OR BATTERY

A chemical cell (or battery) converts chemical energy into electrical energy to provide a voltage in an electrical circuit.

A common type of chemical cell is the lead-acid cell, Figure 7, which is enclosed in a hard rubber or plastic case, containing a solution of sulphuric acid in water. This solution is referred to as the

electrolyte. Plates of sponge lead and lead peroxide (called the electrodes) are immersed in the electrolyte.

Chemical reactions between the electrolyte and the lead peroxide electrode consume electrons and thus create a deficiency of free electrons. This causes the lead peroxide electrode to become positively charged with respect to the spongy lead plate. Chemical reactions between the electrolyte and the spongy lead plate generate an excess of electrons thus causing the spongy lead plate to become negatively charged. Thus, a potential difference is established between the two electrodes.

Now let an external electrical circuit, consisting of a wire, switch and light bulb be connected to the battery electrodes, as shown in Figure 7. With the switch open, the electrical path through the external

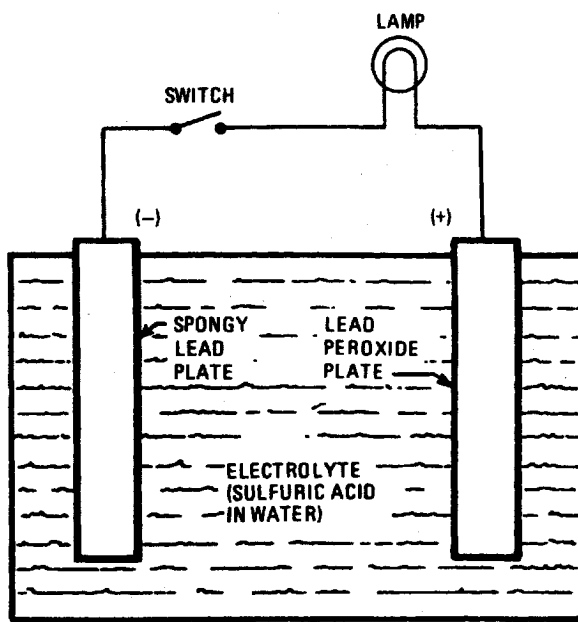


Fig. 7 Simple lead-acid chemical cell (battery)

circuit is broken and no electricity flows through it. However, when the switch is closed, the external path is completed.

Free electrons (electricity) flow from the negatively charged spongy lead electrode to the positively charged lead peroxide one through the external circuit, just as described earlier in relation to Figure 4. The lamp will glow, indicating that electricity is flowing.

Chemical reactions between the electrolyte and electrodes continue to take place. These reactions constantly replenish the supply of free electrons to the negative electrode and remove them from the positive electrode, so that electricity will continue to flow through the external circuit. Note that the free electrons in this case only travel in one direction, from the negative to the positive electrode. This type of electricity is known as **direct current (DC)**.

Electricity cannot be drawn indefinitely from a cell, for eventually the cell will run down. During the chemical action in the lead-acid cell, the active electrode materials are gradually changed to lead sulphate. If electricity is drawn from the cell until all the spongy lead and lead peroxide are changed to lead sulphate, the cell will be completely dead, and will supply no more electromotive force. Before this situation occurs, however, it is possible to recharge the cell. An external generator (recharger) is connected to the external circuit, with its negative pole connected to the negative electrode and positive pole connected to the positive electrode of the cell. In this way, electrons are driven back by the recharger through the negative electrode and through the electrolyte to the positive electrode. This external electricity applied to the cell converts most of the lead sulphate on the plates back into the

active spongy lead and the lead peroxide. The cell is thus restored to about its original condition and is said to be recharged. The ability of these cells to store energy in the form of chemical energy later to be released as electricity gives rise to the name storage batteries.

A battery is one or several cells combined to operate as a single source of electricity. Automobile batteries are one example. They consist of a number of lead-acid cells side by side in one container separated by sheets of hard rubber or plastic. A number of different combinations of electrode materials and electrolytes are used in cells. The familiar cells used in flashlights are commonly called batteries although they are each single cells. They are also referred to as **dry cells**, Figure 8, since the electrolyte is in the form of a moist paste instead of a liquid as in the lead-acid cell.

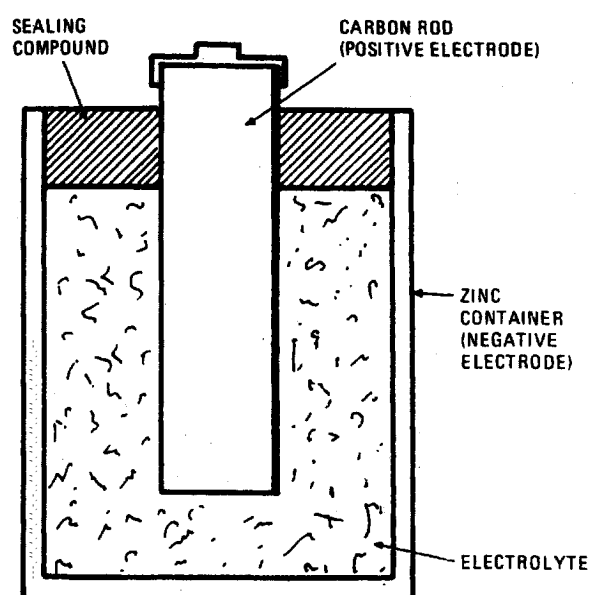


Fig. 8 Construction of a dry cell

Batteries are rarely, if ever, used in gas appliances. However, some instru-

ments used for troubleshooting service problems do use dry cells. Mechanical generators and thermoelectric devices produce most of the electricity used in gas appliances.

MECHANICAL GENERATORS

A very common source of voltage is provided by generators, which convert mechanical energy into electrical energy. Most of our so-called house current is produced by mechanically operated generators, commonly referred to as electrical generators or simply generators.

The invention of the electrical generator was made possible by Faraday's discovery that when a wire is moved across a magnetic field in a gap between the North-South poles of a magnet, a voltage is produced in the wire. Furthermore, it was found that the direction of motion of the wire across the gap (cutting across lines of magnetic force between the poles) affected the direction of flow of electricity in the wire. The same effect is obtained if the wire is held stationary and the magnet is moved, causing the lines of magnetic force to cut across the wire.

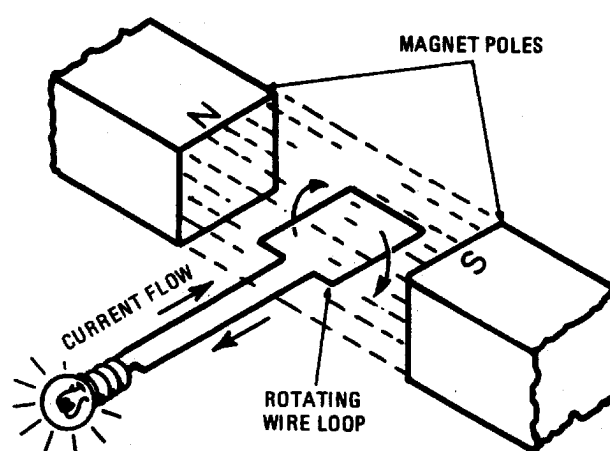


Fig. 9 Principle of operation of electric generator

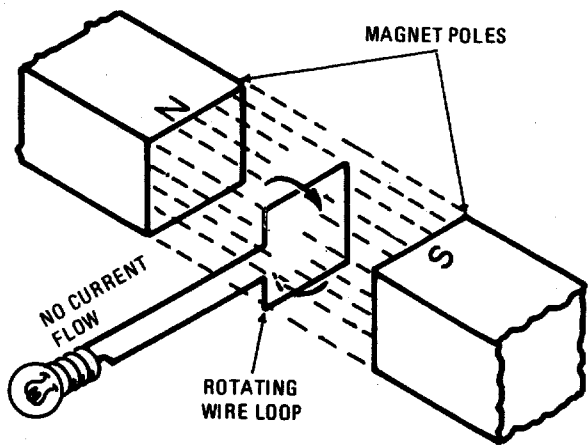


Fig. 10 Principle of operation of electric generator (cont'd)

When a loop of wire is rotated in a gap between the poles of a magnet, Figure 9, voltage is produced which will tend to make electricity flow in one direction in the loop during one half revolution and in the opposite direction during

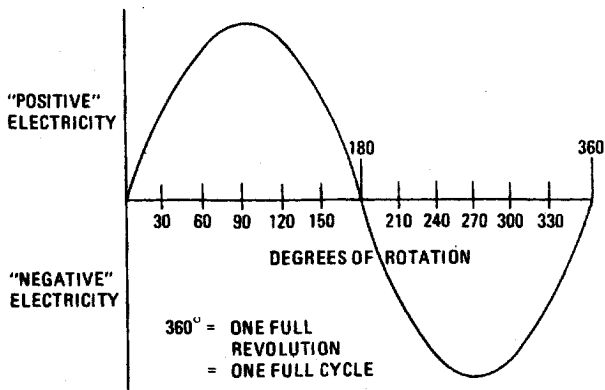


Fig. 11 Sine wave pattern of AC electricity

the second half revolution of the loop. When wires of the loop are traveling parallel to the magnetic lines of force (across the top and bottom of the gap) no voltage is produced in the loop, Figure 10. When the loop is closed completing a circuit and allowing electric current to flow, this alternating building up of voltage, drop-

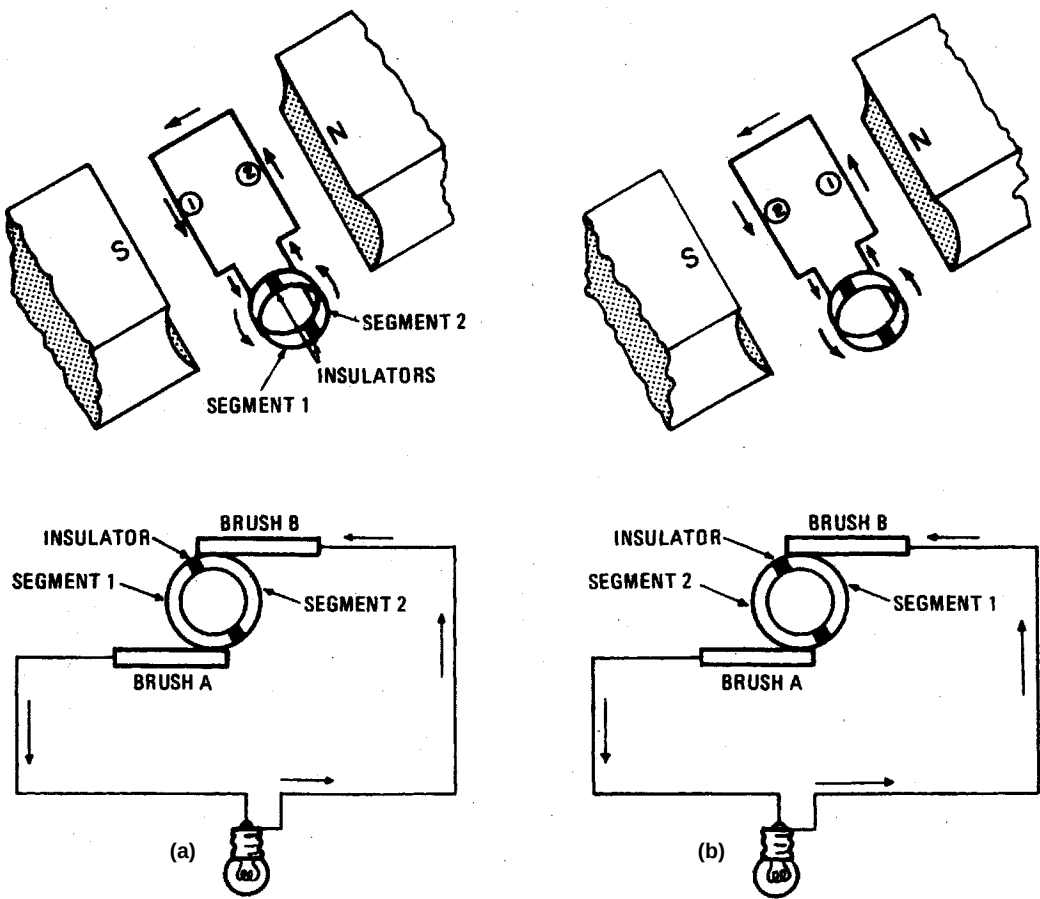


Fig. 12 DC generator with commutator

ping to zero and then building in the opposite direction causes the current to flow first one way then the other in the wire. The result is what we call **alternating current (AC)** electricity. If electrical flow in one direction in the loop is called positive and in the other direction negative, the pattern of electrical flow with degrees of rotation is the so-called sine wave shown in Figure 11.

Direct current (DC) electricity is produced by a generator through the use of a simple device called a **commutator**.

A split ring is attached to the loop of wire and brushes (Figure 12) rub against it. When the rotating loop is in the position shown in Figure 12(a), current flows out of conductor 1 (attached to segment 1 of the split commutator ring) into conductor 2 attached to segment 2 of the commutator ring. Thus, current flows in the external circuit from brush A (which is riding on segment 1) to brush B, riding on segment 2. When the loop rotates to the position shown in Figure 12(b), current flow reverses in the loop as shown, flowing out of conductor 2 and into conductor 1. However, the commutator ring has rotated so that segment 2 is now under brush A and segment 1 under brush B, so that current still flows in the external circuit in the same direction as before from brush A to brush B. In an actual DC generator a number of loops, with a corresponding number of commutator ring segments are used to provide a steady DC current flow.

The simple generator described above, using a single wire loop, would only generate a small voltage. Using more wire loops increases voltage output and a stronger magnet with more concen-

trated lines of magnetic force. In commercial generators used to provide substantial electrical power, a great many loops are used, wound around an iron core that increases and concentrates the magnetic flux. Together those loops and core form what is called an **armature**. The electric output of the generator is picked off by brushes riding on **collector rings** attached to the ends of the rotating loops to be applied to an external circuit.

The generator armature is rotated by some external driver to produce electricity. This driver may be, for example, a steam turbine, an internal combustion engine, or a water-driven turbine in hydroelectric generators. The generator converts a portion of the mechanical energy supplied by these drivers into electrical energy.

The magnetic field in which the generator armature rotates may be provided by permanent magnets, such as in **magnetos**. Most generators use electromagnets for this purpose, formed by wrapping coils of wire around metal poles. As indicated previously, when electricity is passed through these coils, a magnetic field is set up around the wires, causing the metal pole pieces to become magnets. These electromagnets are called **field coils** of the generator. Alternating current generators must have electricity supplied to their field coils by an external source. Often the armature remains stationary while the field revolves which allows smaller moving contacts since the field current is small.

The number of times per second, which the electrical output of an AC generator goes through the one complete cycle shown in Figure 11, is known as the

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electrical **frequency**. This frequency depends on the number of pairs of magnetic poles (called North and South) used in the generator and the speed of rotation of the armature. With a single pair of poles, a generator rotating at 3600 revolutions per minute (rpm) would produce 60 cycles per second (also referred to as **60 Hertz**) AC electricity. This frequency is the one most commonly used in the United States. In Europe and elsewhere, 50 Hertz AC electricity is most commonly used. Electrical devices must be operated at their design frequency. For example, an electric clock designed for 60 Hertz operation would run slow if supplied with 50 Hertz AC electricity. In some instances, damage can result if the wrong frequency electricity is used.

THERMOELECTRIC SOURCES OF VOLTAGE

In 1822 Thomas J. Seebeck (1770–1831) discovered that when two wires or strips of different metals were joined together at one end and this end was heated while the other end kept cool, a voltage was produced across the open ends. This

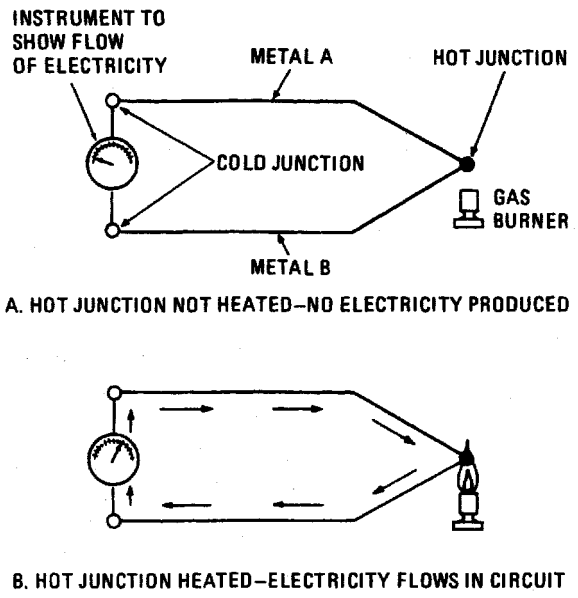


Fig. 13 The thermoelectric effect

effect has been called the thermoelectric effect and a single pair of wires used for such a purpose called a **thermocouple**. Figure 13 illustrates the thermoelectric effect in a heated thermocouple.

The junction of the two wires in a thermocouple that is heated to produce electricity is called the **hot junction**. The connection of the other two ends of the thermocouple wires is called the **cold junction**. In a thermocouple used in a gas appliance the cold junction usually is located only a few inches from the hot junction and conductors are attached to the cold junction leads to carry current to a load.

The magnitude of the voltage produced thermoelectrically depends on the two materials used in the thermocouple, and on the temperature *difference* between the hot and cold junctions. The greater this temperature difference, the larger is the voltage produced.

The voltage produced by a single thermocouple consisting of a single pair of wires or strips usually is very small. However, this device has been used for at least two very practical purposes in the gas industry.

First, a thermocouple can be used as a very sensitive temperature-measuring device. For any given pair of different wires used for the thermocouple, the voltage produced will always be the same for the same temperature difference between the hot and cold junctions. Tables have been prepared for various pairs of metals relating this temperature difference to the voltage produced. Thus, the hot junction can be placed in a fluid or connected to a

surface whose temperature is to be measured, and the voltage produced measured with a sensitive instrument. The temperature of the fluid (water, air, etc.) or surface is then found in the appropriate table, knowing the cold junction temperature.

Of even greater importance in the gas industry is the widespread use of thermocouples in gas controls, such as in **automatic pilot safety devices**, Figure 14. The flame of a gas pilot heats the hot

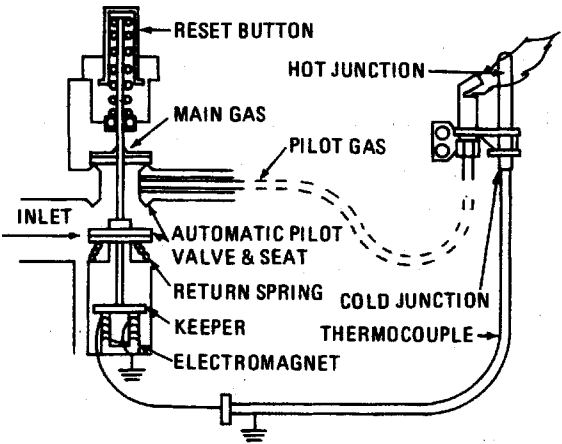


Fig. 14 Use of thermocouple in automatic pilot device

junction of an automatic pilot device. The electrical output of a single thermocouple is quite small. However, it still produces an electric (magnetic) field around a wire as the DC electricity flows through the wire. This wire can be wrapped around a metal core, creating a small electromagnet. This electromagnet will hold open an automatic pilot valve (opened manually by pressing a metal part of the valve against the electromagnet) as long as the pilot flame heats the hot junction adequately. If the pilot flame is extinguished, the hot junction of the thermocouple cools; the voltage produced by the ther-

mocouple falls off to zero; the electromagnet becomes deenergized; and the spring-loaded automatic pilot valve closes, shutting off the gas supply to the appliance.

Thermoelectric voltage output can be substantially increased by using a number of pairs of thermocouples in a single device, called a **thermopile**, Figure 15. The increased voltage can be used to cre-

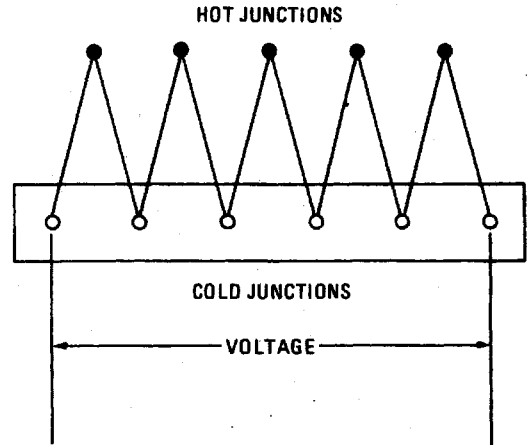


Fig. 15 A thermopile is composed of many thermocouples connected together so that the electrical effect is additive

ate a more powerful electromagnet than with a single thermocouple. Thermostatically controlled automatic gas valves can be powered by thermoelectrically generated voltages and not require AC voltage from the house circuit. Thermocouples and thermopiles will be discussed further in later sections.

PIEZOELECTRIC SOURCES OF VOLTAGE

If certain materials, such as quartz and Rochelle crystals or barium titanate, are compressed in a certain direction, electrons in the material shift, creating a voltage across two surfaces of the material, Figure 16. This is called the piezoelectric effect and substances that exhibit it are

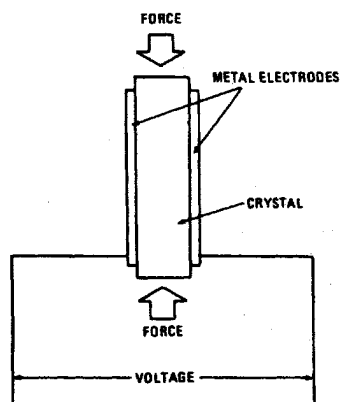


Fig. 16 When a force is applied as shown by the arrows, a voltage is generated across the piezoelectric crystal

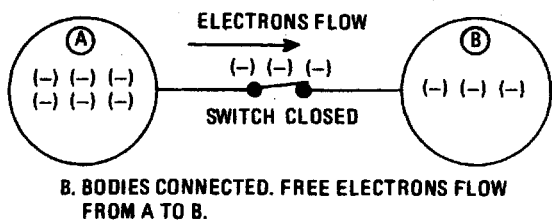
called piezoelectric materials. The amount of the voltage created depends on the rate of change of pressure applied and on how high a pressure is applied. A voltage is not generated by a steady pressure on the material, but rather by a rapid squeezing or striking. Higher voltages are generated by rapidly applying greater pressures to the crystal.

Piezoelectric materials have been used to provide spark ignition, such as in camping equipment, and barbeque grills.

CHAPTER II REVIEW—
HOW ELECTRICITY IS SUPPLIED

Fill in the blanks from the word list on the right. Answers are at the end of this manual.

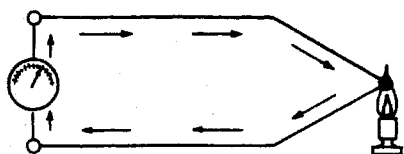
10. As stated earlier, electricity is the movement of electrons from a body which contains an 1. _____ of electrons to a body which has a deficiency of 2. _____. (p. 5)



11. The amount of electron flow between “A” & “B” when the switch is closed depends upon the difference of the number of free 1. _____ in “A” compared to “B.” The greater the difference, the 2. _____ will be the flow. (p. 5)
12. In practical electrical circuits it is necessary to have a 1. _____ flow of electricity in the circuit when it is in use rather than the one shot situation discussed in 2. _____ 3. _____. Therefore, some source must continuously maintain a 4. _____ 5. _____ between two points in a circuit. Such a source provides what is commonly referred to as an 6. _____ force (EMF), which represents the same thing as a potential difference. (p. 6)
13. The two most commonly encountered EMF sources are the chemical cell or 1. _____ and the mechanical 2. _____. (p. 7)
14. Two other devices to generate EMF are thermoelectric generators or 1. _____ and piezoelectric 2. _____. (p. 7)

generator
battery
static
crystals
greater
electrons
electricity
difference
potential
constant
electrons
thermocouples
electromotive
excess

15. Mechanical generators, depending upon their construction, generate either 1. _____ current or 2. _____ current. (p. 9–11)
16. Alternating current changes its electrical charge from positive to negative within each complete rotation of the armature. This is known as a 1. _____. The completion of 60 cycles in one second is equal to one 2. _____. Generators in the United States are generally driven at 3600 revolutions a minute which produces 3. _____ hertz. (p. 12)
17. Thermoelectric sources of voltage are constructed by joining two wires of different metals together at one end. If this end is heated and the other end kept cool, a 1. _____ will be produced across the open ends. A single pair of wires used for such a purpose is known as a 2. _____. (p. 12)



B. HOT JUNCTION HEATED—ELECTRICITY FLOWS IN CIRCUIT

18. The magnitude of the voltage produced depends on the two 1. _____ used in the thermocouple and on the temperature 2. _____ between the hot and cold junctions. The greater the temperature difference, the larger the 3. _____ produced. (p. 12)
19. The thermocouple can be used as a very sensitive _____ measuring device. (p. 12)
20. Of even greater importance in the gas industry is the widespread use of thermocouples in gas controls such as automatic _____ safety devices. (p. 13)
21. Thermoelectric voltage output can be substantially increased by using a number of pairs of thermocouples in a single device called a _____. (p. 13)

materials

voltage

pilot

difference

temperature

voltage

thermopile

thermocouple

60

cycle

direct

Hertz (Hz)

alternating

22. Piezoelectric sources of voltage. Certain materials such as quartz and rochelle crystals or barium titanate are compressed in a certain direction, electrons in the material shift, creating a voltage across two surfaces of the material. This is called the 1. _____ effect. The amount of voltage created depends on the rate of change of pressure applied and on how much pressure is applied. Voltage is not generated by steady pressure but by a rapid squeezing or 2. _____. Higher voltages are generated by 3. _____ applying greater 4. _____ to the crystal. (p. 13–14)

striking
pressure
rapidly
piezoelectric

III. ELECTRICAL TERMS

Thus far electricity has been considered in terms of flow of electrons (flow of electricity) and voltage (potential difference or EMF). In practical uses of electricity it is necessary to be able to measure quantities of electron flow and voltage and other properties of electricity. Certain terms are used to express those measurements and must be clearly understood to provide a foundation for working successfully with electrical devices.

In the early years of study of the subject, electricity was thought of as a fluid flowing through a wire as water flows through a pipe. Although it has certain

limitations, a water analogy sometimes is useful to define certain basic electrical terms.

Figure 17 shows a closed loop of pipe filled with water. Water is circulated around through the pipe by a pump. As water flows through the system, shown in Figure 17, friction of the pipe walls and any restrictions in the pipe offer resistance to the flow of water. If the pump is turned off, water flow through the system stops because of this resistance. However, when it is going, the pump provides enough pressure to offset these resistances in the pipes to maintain flow of water in the system.

Flow of electricity in an electrical circuit is like the flow of water in the system shown in Figure 17. Electrical flow is called **current** and is expressed in **amperes** (named after the French scientist, Andre M. Ampere, 1775–1836). Wires and other devices in an electrical circuit offer resistance to current flow, just as the pipe walls and any restrictions in a water system resist flow of the water. In electrical terms, this factor is called **resistance**, and is expressed in **ohms**, (named after the German physicist, George S. Ohm, 1787–1854). Acting as the pump does in the water system of Figure 17, the source of EMF provides an electrical pressure or voltage, to offset resistances and maintain current flow. The term electrical pressure means essentially the same thing as voltage, EMF and potential difference used in previous sections. The basic practical unit of voltage is the volt, named after the Italian physicist, Allesandro Volta (1745–1827).

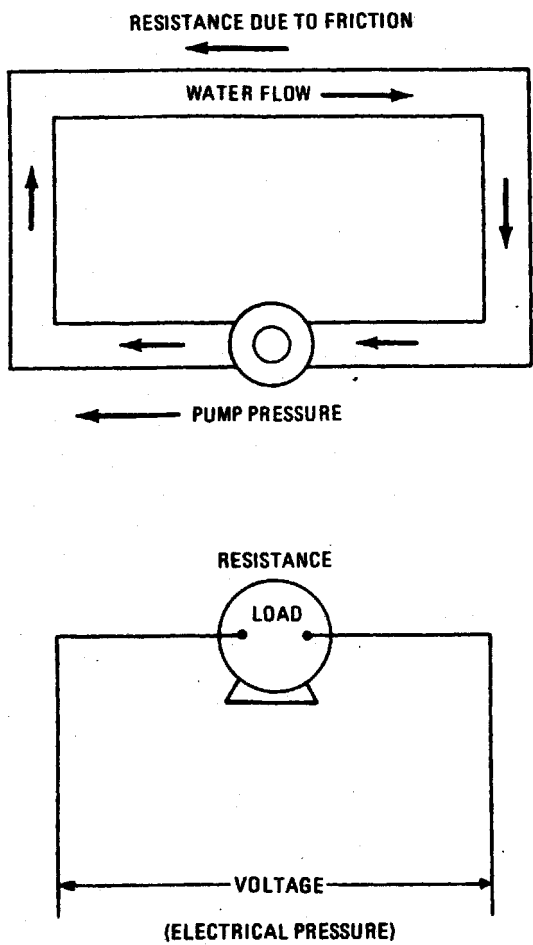


Fig. 17 Water analogy illustrating fundamental electrical terms

The Volt

The basic unit of voltage, the volt, can be defined in terms of the other two fundamental electrical quantities of current and resistance. *One volt is required to cause one ampere of current to flow against a resistance of one ohm.* Explanations of ampere and ohm follow in succeeding sections. Several levels of voltage may be encountered in working with gas appliances.

MILLIVOLT SYSTEMS (DC)

Automatic pilot safety devices are the most common type of **millivolt** systems likely to be encountered in working with gas appliances. These systems have a thermocouple or thermopile heated by the gas pilot. The DC voltages produced by single thermocouples will usually be of the order of 20–30 millivolts, when the voltage is measured at the thermocouple terminals without the automatic pilot device in the circuit (called the open circuit voltage). The prefix milli- means thousandths, so that single thermocouples generate a voltage of about 20/1000 to 30/1000 of one volt. Thermopiles (in their most common application spoken of as pilot generators) produce open circuit voltages ranging from perhaps 100–1000 millivolts (about 0.1 to 1.0 volt).

24-VOLT SYSTEMS

To use relatively inexpensive wiring to room thermostats, and provide added safety, many automatic gas control valves are operated with 24 volts AC. This voltage is obtained by reducing house voltage (120 volts) by means of a **transformer**. The transformer is a device which takes AC voltage at one level and

reduces (step-down) or raises it (step-up) to a different level. Figure 18 illustrates a simple step-down transformer.

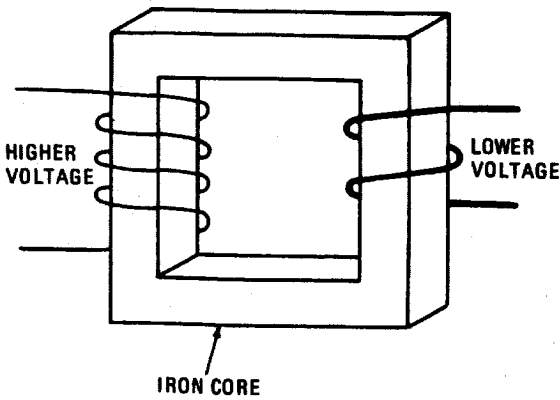


Fig. 18 Simple electrical step-down transformer

The step-down transformer shown consists of two coils of wire both wound around a soft iron-core. The primary winding has more turns of wire than the secondary winding. Recall that a magnetic field surrounds a current-carrying wire. When an AC voltage is supplied to the primary winding, current fluctuates between zero and some maximum value as shown in Figure 11. As a result of this fluctuation in current, the induced magnetic field around the primary winding builds up and collapses during each cycle. These lines of magnetic force (magnetic flux), flowing through the iron, cut across the turns of the secondary winding, inducing an electrical current in the secondary winding.

As indicated earlier in the discussion on mechanical generators, voltage output depends on the number of turns in a coil cutting lines of magnetic force. Therefore, with fewer turns in the secondary winding, the output voltage will be lower than the voltage input to the pri-

mary winding with more turns. The ratio of the two voltages (input and output) will be equal to the ratio of the number of turns in the two windings. For example, if 120 volts are applied to 50 turns in the primary winding, the output from a secondary winding having 10 turns will be 24 volts ($10/50 \times 120 = 24$). Most actual transformers have the primary and secondary windings wrapped around an iron core. This arrangement minimizes losses by containing the fluctuating magnetic field in the iron.

120 VOLT, 240-VOLT SYSTEMS

These two voltage systems are the most common voltage levels found in the home (called **line voltages**), particularly the nominal 120-volt system. They are supplied to the home by local utilities. Most of our common electrical home appliances and services operate on 120-volt service, such as lighting systems, electric clocks, vacuum cleaners, and electric mixers. Some homes are wired for 240 volts (or 220 volts) for electrical ranges and water heaters. Some other voltages are used in commercial and industrial establishments.

HIGH VOLTAGES

Sometimes voltages as high as 5000–10,000 volts may be used for specific applications. Perhaps the most common use of such voltages is in the ignition systems of automobiles, where several thousand volts are provided to create a spark across the gaps of spark plugs. Some high-voltage electric spark ignition systems are used in gas appliances. The necessary high voltages can be produced by electronic components or by step-up transformers.

In a step-up transformer, the number of turns in the secondary winding is large, compared to those in the primary winding. Again, the voltage produced in the secondary winding depends on the ratio of the number of secondary turns to primary turns. If 120 volts are applied to 10 turns in a primary winding, the voltage produced in 500 turns in the secondary winding will be 6,000 volts ($500/10 \times 120 = 6000$).

The Ampere

Flow of electricity in an electrical circuit is like the flow of water in a pipe system, such as shown earlier in Figure 17. However, flow is normally expressed in units of volume per unit time, such as gallons per minute in a water flow system. In an electrical flow, the amount of current is determined by the number of free electrons flowing past a point in the circuit per unit time. However, a flow of one electron per second is a very, very tiny electrical flow. If we used this definition of flow, we would have to use huge numbers to express electrical flow in a practical system.

Instead, we use the unit ampere for electrical current. One ampere represents the flow of 6.25×10^{18} electrons per second past a given point in the electrical circuit. This number represents a flow of 6.25 million, million, million electrons per second.

The Ohm

In a water flow system, friction in the pipes and pipe restrictions act to reduce water flow in the system with a given potential difference (pressure) acting to

induce water flow as shown in Figure 19.

Imagine two reservoirs, with the water level in reservoir A above that in reservoir B. The difference in these water levels represents the potential difference (head) in the water system and is like the voltage in an electrical system. In Figure 19(a), a relatively large pipe connects the two reservoirs, which offers only small

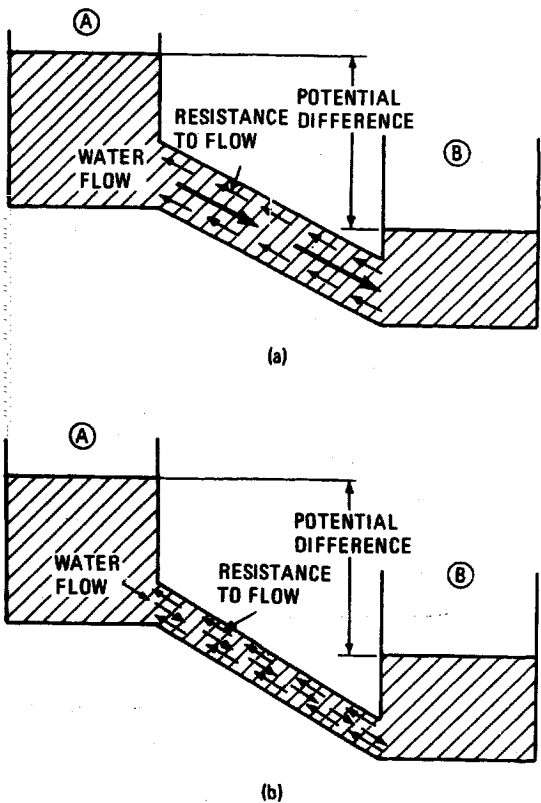


Fig. 19 Water analogy illustrating electrical resistance

frictional resistance to water flow takes place from A to B. The frictional resistance to water flow in this analogy is equivalent to electrical resistance, the water flow to electrical current. In Figure 19(b), a relatively small pipe connects the two reservoirs, which offers a greater frictional resistance to water flow than in Figure 19(a). Therefore, with the same

potential difference, less water flow (gallons per minute) will take place in Figure 19(b) than in figure 19(a). In the same manner, with a given voltage, less current will flow in an electrical circuit with a greater electrical resistance.

In Figure 11 the pattern of alternating electricity was shown to be a sine wave. This type of wave applies to rising and falling voltage as well as the reversing current flow in an AC electric circuit. Furthermore, in a purely resistive circuit the sine wave representing AC voltage will be in **phase** with the sine wave representing the corresponding AC current. In other words, in one cycle (representing 360 degrees of rotation of the generator producing the AC electricity), at those points representing 0, 180 and 360 degrees of rotation, both voltage and current will be zero. At the point in time represented by 90 degrees rotation, voltage and current values will both reach their maximum values in what can be called a positive direction, and at 270 degrees, both will reach their maximum values in what can be called a negative direction. The importance of this fact will become more apparent in later discussions of the shift of voltage-current relationships in inductors and capacitors and in determining electrical power being supplied to or used by an electrical device.

The electrical resistance (R) of a circuit is expressed in ohms. The ohm is defined as the resistance which will cause a potential difference (voltage drop) of one volt to occur when one ampere of current flows through it.

All materials conduct electricity to some degree. This capability for conduct-

ing current is referred to as **conductance**, and is the opposite of resistance. Some materials will allow electrical current to flow through them with very little resistance. Others will offer more resistance to electrical flow. Thus, materials can be categorized in terms of their electrical conductance or resistance as being **conductors, resistors or insulators**.

CONDUCTORS

A conductor is any material that readily allows free electron flow to take place through it when a voltage is applied across the material. These materials generally contain many free electrons weakly held in their orbits about the atomic nucleus. Most metals are classified as conductors. There is some evidence that the outer electrons of metal atoms are continuously exchanging places between neighboring atoms. One theory pictures clouds of free electrons drifting among copper atoms, so that when an electrical potential is applied to copper there is a large flow of electrons (current) induced in the metal. Silver, copper and aluminum are excellent conductors. Copper is widely used in electrical circuits as conductors (wires) because of its excellent conductance. Other factors such as cost and strength are considered in selecting material for use as conductors.

RESISTORS

Sometimes it is necessary to add some resistance to limit electric current flow at a given point in an electrical circuit. Devices used for this purpose are called resistors. Resistors are poor conductors designed with high resistance to reduce current flow to some desired level. Some metal alloys are used as resistor materi-

als. Various copper-nickel alloys have resistances ranging from 10 to 30 times that of copper; and some nickel-chromium alloys (nichrome), have resistances ranging from 60 to 70 times that of copper. Other resistor materials such as carbon offer higher resistances to electrical current flow (400 to 2,400 times that of copper).

Commercially made resistors are of two general types, depending on the materials they are made from: **wire-wound resistors** for carrying relatively high electric currents, and **composition resistors** for carrying relatively low currents.

INSULATORS

In an appliance it is necessary to contain the electrical flow within proper paths within the circuit itself. In other words, it is necessary to insulate the circuit. If this precaution is not taken, the circuit may not perform its function properly or an unsafe condition may exist.

For example, in a millivolt control circuit, if one of the conductors is allowed to touch the other (a so-called **short circuit** or short) the proper amount of current will not flow to the electromagnet of the automatic pilot safety device and the latter will act to shut off gas supply to the appliance. Uninsulated conductors carrying line voltage (120 or 240 volts) are hazardous. If these conductors touch, shorting out the normal resistance of the circuit, excessive current can flow in the circuit. Either some component(s) in the system will burn out, or the safety fuse will blow. The human body also conducts electricity. If contact is made with uninsulated parts of the circuit, an electrical shock may be sus-

tained, perhaps even a fatal one. For all of these reasons, insulators are necessary in electrical circuits.

An insulator is a material that contains few free electrons and hence permits relatively little current to flow through the material. Glass, plastics and rubber are examples of insulators. Perhaps the most familiar application of an insulator is the coating or tubing that surrounds a copper wire conductor. Lacquer is commonly used as an insulator to separate individual wires in the windings of a generator armature.

Insulation is intended to prevent short circuits in conductors (wires). However, provisions are made to protect insulated wires carrying line voltages from physical damage that might destroy the effectiveness of the insulation. Two common approaches, the use of electrical steel **conduit** and steel-armored **cable** are illustrated in figure 20.

Figure 20(a) shows insulated wires drawn through a metal tube (or pipe), while taking care not to scrape the insulation. A junction box, shown at the left, is provided to allow ready access to the enclosed wires for splicing and/or attachment of electrical outlets at these points. In armored cable systems (such as BX), insulated conductors are assembled inside a protective armor made of spirally wound steel strip. This arrangement provides a flexible cable that is easier to install than rigid tubes.

Capacitance

Electrical resistance is a property of a circuit that opposes current flow in that cir-

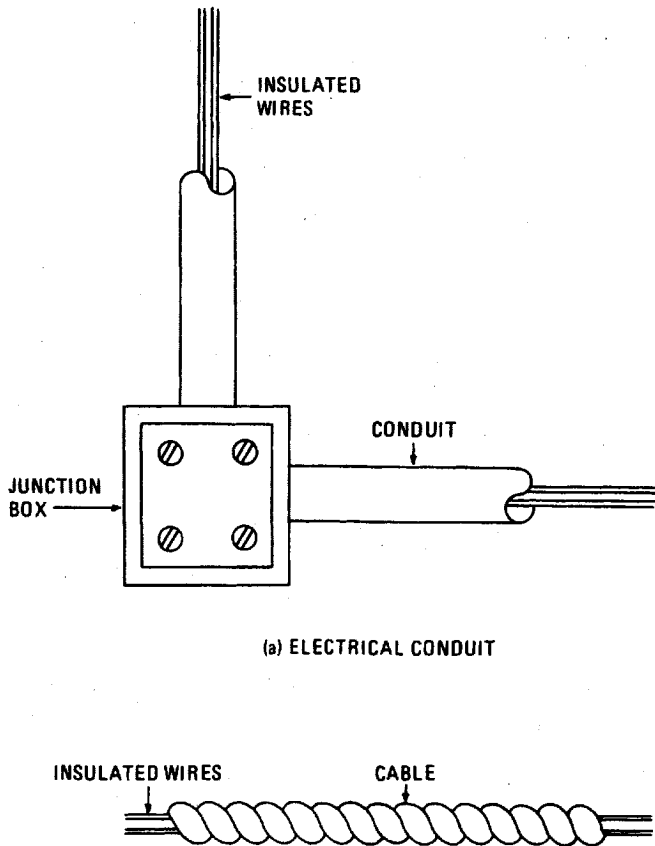


Fig. 20 Protection of insulation by conduits and BX

cuit. A second property of electrical circuits, **capacitance**, creates certain effects which can be used to the advantage in DC and AC electrical and **electronic** circuits.

A **capacitor** basically consists of two plates of conducting materials (which can readily accept or give up free electrons) separated by an insulation material, called the **dielectric**. A capacitor acts to store electrical energy in an electric field.

Figure 21 illustrates a simple capacitor that is being supplied electrical energy from a DC voltage source.

Figure 21(a) shows the capacitor in an uncharged state. When a DC source is connected to the capacitor, Figure 21(b), current flows in the circuit. Free electrons

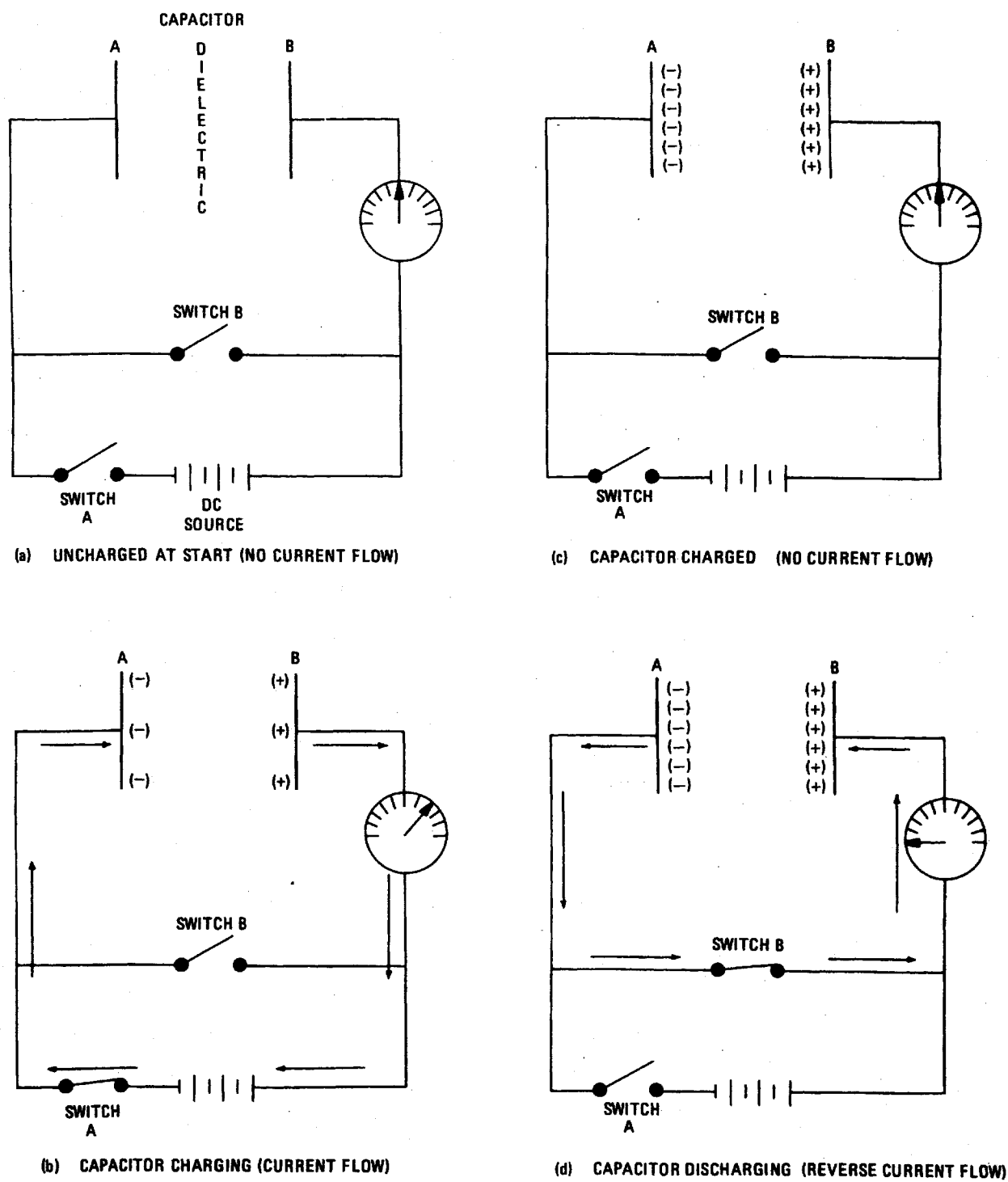


Fig. 21 Illustration of charging and discharging a capacitor with a DC source

collect on Plate A to make it negatively charged and electrons are removed from Plate B to make it positively charged. As free electrons collect on Plate A they act

to build up a voltage, resisting the further flow of free electrons from the source to Plate A. Flow of electrons continues until the voltage on Plate A equals the voltage

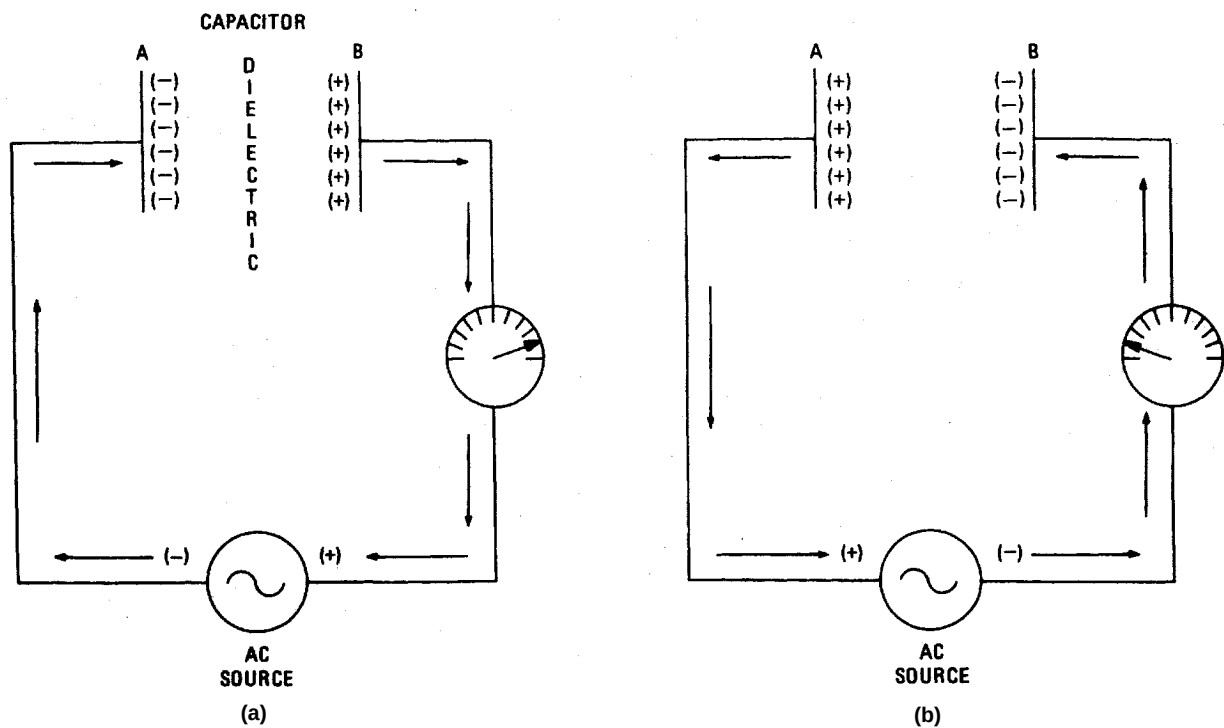


Fig. 22 Illustration of a capacitor in an AC circuit

output of the source. At this point current flow stops. The potential difference between Plates A and B is equal to that of the source. Switch A can then be opened, Figure 21(c), leaving electrical energy stored in the capacitor. If Switch B is then closed, Figure 21(d), the voltage difference between Plates A and B causes a flow of free electrons from A to B (current flow) through the line containing Switch B. Discharging the capacitor in this manner returns it to the uncharged state shown in Figure 21(a).

A capacitor can be charged slowly and, depending on its size, may hold a large amount of energy. When the capacitor is discharged, this energy is released in a very short time. If the discharge occurs across an air gap, an intense spark can be produced. Some spark fuel ignitor systems are based on this principle. The charged capacitor is discharged through a

device called an **induction coil** to create a high voltage, which will jump a spark across the ignitor gap.

Capacitors are most often encountered in AC motor starting circuits. They are also used to prevent arcing across contact points of switches.

Figure 22 illustrates what happens when AC electricity is applied to a capacitor.

From a source of AC electricity, current flows for half a cycle in one direction in the circuit and then in the opposite direction during the second half of a cycle. In Figure 22(a), free electrons are flowing (current) from the AC source to Plate A and free electrons are being withdrawn from Plate B during one half of a cycle. In the other half cycle, Figure 22(b), the free electrons are withdrawn from Plate A and flow to Plate B. Thus,

there is a constant flow of current back and forth in the circuit, even though it does not pass from A to B through the dielectric between them. Note then that while a capacitor in a DC circuit acts to block current flow, in an AC circuit, it acts as though it were a conductor.

An important feature of AC circuits that have capacitors is that the current and voltage are *out of phase* with each other. Figure 11 showed a typical sine wave pattern of AC electricity. Both the voltage and current vary in the same pattern in any one full cycle. In a circuit containing only electrical resistance, the voltage and current are said to be *in phase* with each other. This means that when the voltage is zero, the current is zero, and when the voltage reaches a peak value, the current also reaches a peak value. This in-phase relationship of voltage and current is illustrated in Figure 23.

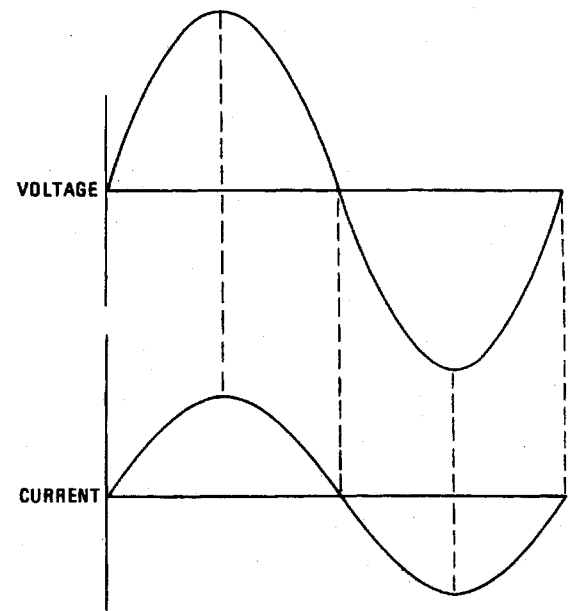


Fig. 23 In-phase relationship of voltage and current in a purely resistive AC circuit

In a purely capacitive circuit, the current *leads* the voltage by 90 degrees (one-quarter of a cycle). In other words, when voltage is zero, current is at its maximum value, and when voltage reaches its maximum, current is equal to zero. This out-of-phase relationship in a purely capacitive circuit is shown in Figure 24.

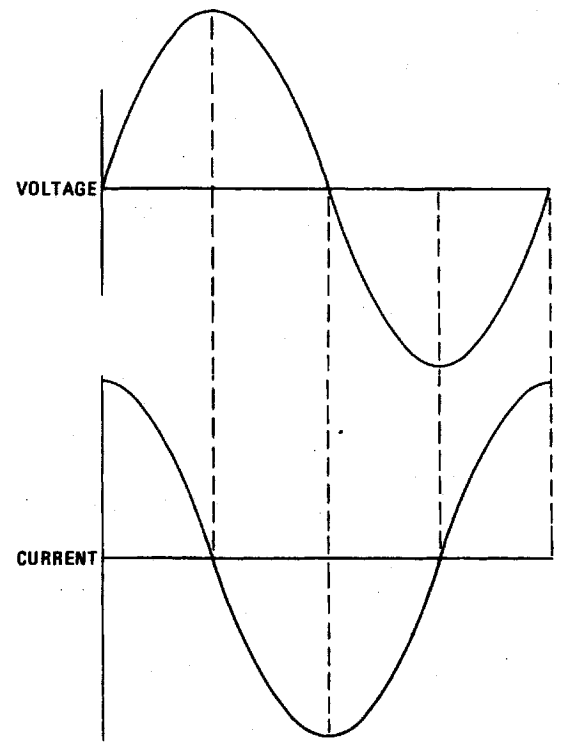


Fig. 24 Illustration of current leading voltage by 90 degrees (quarter-cycle) in a purely capacitive AC circuit

The way in which current is at its maximum when voltage is at zero and how current is zero when the voltage is at its maximum value in a purely capacitive circuit can be shown by a water analogy, shown in Figure 25.

In Figure 25, the two reservoirs represent the two plates of a capacitor, ready to accept or give up water to the other (electrons). The pump represents a source of AC voltage which, by reversing, pro-

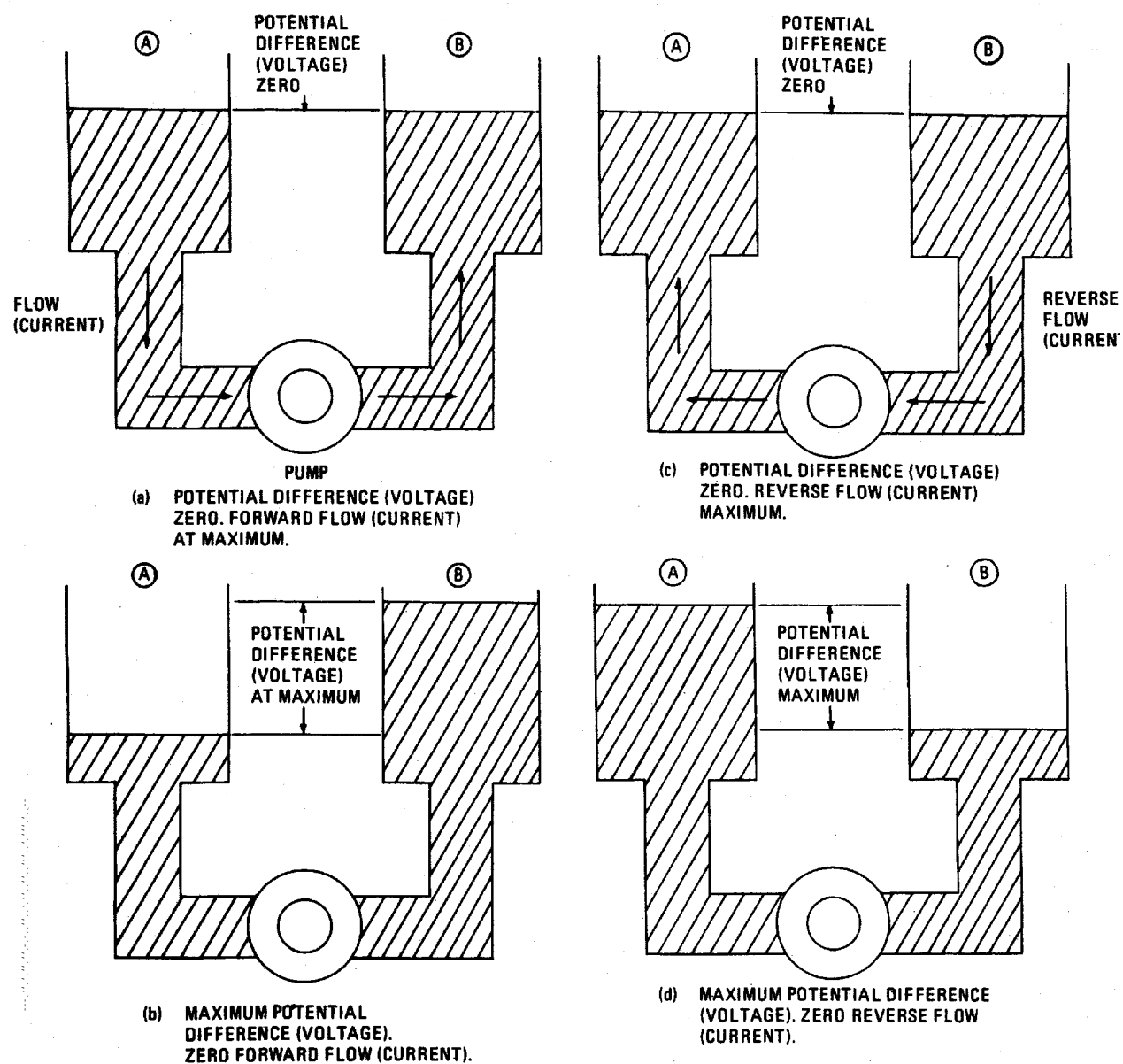


Fig. 25 Water analogy demonstration out-of-phase relationship in a purely capacitive AC circuit between current and voltage

duces a pressure (voltage) that varies in the form of a sine wave from zero to a maximum, back through zero to a maximum in the opposite direction, etc.

In Figure 25(a), the water levels in the two reservoirs are the same (capacitor uncharged), exerting no backpressure (voltage on the source. At this instant, potential difference across the capacitor plates is zero (difference in water levels

is zero) and “forward” flow (from A to B) is at a maximum since the voltage of the capacitor acting against the voltage source is zero. The water level in B rises while that in A lowers, until the potential difference (difference in water levels) equals the maximum pressure (voltage) put out by the pump (Figure 25(b)). Water flow ceases (current flow equals zero). At this point the pressure output of

the pump drops off (as in a sine wave) and is incapable of supporting the water level in reservoir B as shown in Figure 25(b). The water then starts to flow in a reverse direction from B to A while the pressure exerted by the pump opposing this flow drops off to zero. When the water in the two reservoirs is again at the same level (zero potential) as shown in Figure 25(c), the water flow rate (current flow) is again at a maximum as it was in Figure 25(a), but this time in the reverse direction (from B to A). At this point the direction of the pressure output of the pump (voltage) reverses, continuing to sustain water flow for B to A. The pressure from the pump in direction A builds up, but so does the water level in reservoir A, opposing the pump pressure. Finally, the water level in A above that in B creates a back pressure equal to the maximum pressure output (voltage) of the pump and water flow stops, as shown in Figure 25(d). Again the pressure output of the pump begins to fall off (as in a sine wave pattern) and is unable to sustain the water level in reservoir A. Water flow again reverses and starts to flow from A to B until the condition shown in Figure 25(a) is reached, completing one full cycle.

It is in this fashion that current flow in a purely capacitive AC circuit is at a maximum when voltage is zero, and current is zero when voltage reaches its maximum value. In an actual AC circuit containing capacitance, there will also be some resistance, so that current will lead voltage by somewhat less than 90 degrees.

Inductance

As has been noted previously, when an electrical current flows in a coil of wire,

a magnetic field is created about that wire. Also, if a coil of wire is placed in a magnetic field that builds up and collapses, an electrical flow will be induced in the coil. These two principles are applied in a transformer in which an AC current flow in one coil (primary coil) creates a fluctuating magnetic field, which in turn induces an electrical flow in a nearby secondary coil. This same action takes place in a single coil as well, a process called **self-induction**. As an AC current in one direction in the coil builds up to its peak, the magnetic field it creates around the coil induces a voltage in the opposite direction (called a back voltage). On the other hand, when the AC current reverses itself, the collapsing magnetic field tends to build up a voltage that acts to keep current flowing in the original direction.

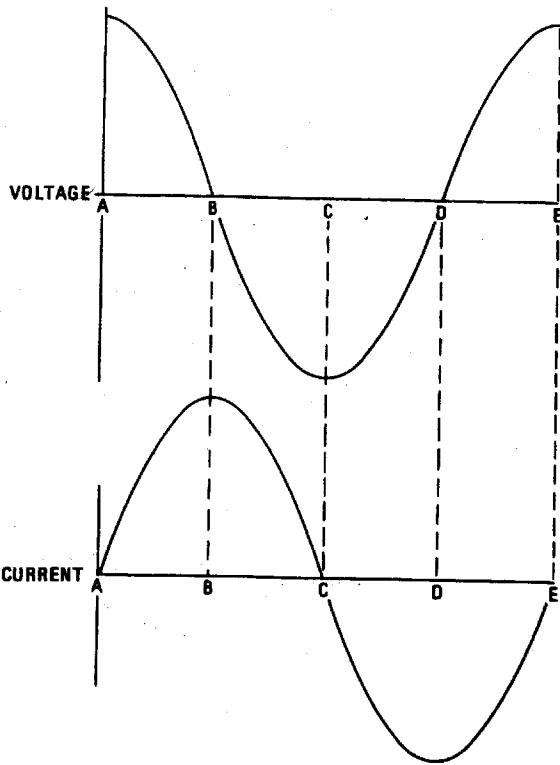


Fig. 26 Illustration of voltage leading current by 90° (quarter-cycle) in a purely inductive AC circuit

This property of a circuit that opposes any change in the rate of current flow is known as **inductance**.

This inductive action can be considered to be like an electrical **inertia**. Inertia is the tendency for bodies at rest to remain at rest, and bodies in motion to remain in motion. Because of the electrical inertia in an *inductive* circuit, *the voltage leads the current*. Note that this condition is just the opposite to that of a capacitive circuit.

Figure 26 illustrates this phase difference between voltage and current in an electrical inductor.

At the beginning of the cycle shown in Figure 26 (point A), voltage is at its maximum value, while current is zero. At Point B voltage has dropped to zero and current reached its maximum value in a “positive” direction. Again, at Point C, voltage has reached its maximum “negative” value, while current flow is zero. At Point D voltage has returned to zero and current is at its maximum value in the opposite (“negative”) direction. Point E is a return to the starting point of the cycle, with voltage at a maximum “positive” value and current zero.

In an actual AC electrical circuit, an inductor will exhibit resistance as well as inductance. Therefore, the voltage will lead the current by some angle less than 90 degrees as in a theoretical purely inductive circuit.

The Watt (Electrical Power)

Power is the rate of doing work, or the rate at which energy is transferred in some process or device. The basic unit of electrical power is the **watt**, named after the Scottish inventor James Watt (1736–1819). The unit of power most commonly used in the gas industry is **Btu** per hour. One watt of electrical power is equivalent to 3.413 Btu per hour. It is sometimes more convenient to think of the relationship in terms of a **kilowatt** (1,000 watts) to Btu per hour. One kilowatt is equivalent to 3413 Btu per hour.

If ten 100-watt light bulbs are operated for one hour, the energy supplied to the electrical circuit in that hour is equivalent to 3413 Btu (10 x 100 watts x 1 hour = 1 **kilowatt hour** = 1 KWH = 3413 Btu).

CHAPTER III REVIEW-
ELECTRICAL TERMS

Fill in the blanks from the word list on the right. Answers are at the end of this manual.

23. Thus far electricity has been considered in terms of flow of electrons (flow of electricity) and voltage (potential difference or EMF). In practical uses of electricity it is necessary to be able to measure _____ of electron flow and voltage and other properties of electricity. (p. 18)	resistance
24. Flow of electricity in an electrical circuit is like the flow of water in a closed loop of pipe containing water with a pump to circulate it. Electrical flow is called 1. _____ and is expressed in 2. _____. Wires and other devices in an electrical circuit offer 3. _____ to current flow just as the pipe walls and any restrictions in the water system resist flow of the water. In electrical terms, this factor is called resistance and is expressed in 4. _____. (p. 18)	1000
25. Acting as the pump in the water system, the source of EMF provides an electrical pressure or voltage to offset resistance and maintain 1. _____ flow. The term electrical pressure means essentially the same thing as voltage, EMF, and potential difference used in previous sections. The basic practical unit of EMF is the 2. _____. (p. 18)	ohms
26. The volt can be defined in terms of the other two fundamental electrical quantities of current and resistance. One 1. _____ is required to cause one 2. _____ of current to flow against a 3. _____ of one ohm. (p. 19)	current
27. With less turns in the secondary coil, the output voltage will be _____ than the voltage input to the primary with more turns. (p. 19)	amperes
28. Automatic pilot safety devices are the most common application of 1. _____ systems to be encountered in working with gas appliances. The DC voltage generated by a single thermocouple is between 20 and 30 2. _____ open circuit reading. Thermopiles produce open circuit readings from approximately 100 to 3. _____ millivolts. (p. 19)	quantities
	volt
	lower
	millivolts
	current
	resistance
	volt
	ampere
	millivolt

29. Many automatic gas control valves are operated with 1. _____ volts AC. This voltage can be obtained by reducing the usual house voltage of 2. _____. volts, by means of a 3. _____. The 4. _____ is a device which takes AC voltage at one level and will either step up or step down the voltage according to its design. (p. 19)
30. 120/240 volt systems are the most common voltage levels found in the home. They are called line voltages. The 1. _____ volt system is by far the most common. Many homes are wired for 240 volts for electrical 2. _____ and 3. _____. (p. 20)
31. HIGH VOLTAGES — Voltages as high as 5,000 to 10,000 may be used for specific application. Some electric 1. _____ ignition systems are used in gas appliances. The high voltages can be produced by 2. _____ transformers or by other electronic components. (p. 20)
32. THE AMPERE — Flow of electricity in an electrical circuit is like the flow of water in a piping system. However, instead of expressing it in gallons per minute, as in water, it is expressed by the number of free 1. _____ flowing past a point in the circuit per second. To express this low figure as a flow of current it is expressed in 2. _____. Each ampere represents a flow of 6.25×10^{18} electrons per second past a given point. (p. 20)
33. THE OHM — In a water flow system friction in the pipes and other pipe restrictions act to reduce water flow in the system with a given potential difference acting to induce water flow. The electrical resistance (R) of a circuit is expressed in 1. _____. The ohm is defined as the resistance which will cause a voltage 2. _____ of one volt to occur when one 3. _____ of current flows through it. (p. 21)
34. Materials can be categorized in terms of their electrical conductivity or resistance as being either conductors, _____ or insulators. (p. 22)

ranges

spark

electrons

ohms

24

ampere

transformer

resistors

water heaters

120

step-up

amperes

drop

transformer

120

35. A conductor is any material which readily allows free 1. _____ flow to take place through it when a 2. _____ is applied across the material. Most metals are classified as conductors. Silver, copper and aluminum are excellent conductors. (p. 22)
36. Resistors are poor conductors designed with high resistance to reduce 1. _____ flow to some designed level. Various copper-nickel alloys have resistances ranging from 10 to 30 times that of copper. 2. _____ alloys have resistances from 60 to 70 times that of copper. Other resistor materials offer higher resistances. (p. 22)
37. Wire-wound resistors are for carrying relatively high electrical currents. _____ resistors are for carrying relatively low electric currents. (p. 22)
38. If one of the conductors in a millivolt circuit is allowed to touch the other, a so-called 1. _____ circuit, the proper amount of current will not flow to the 2. _____ of the safety pilot device and the main burner gas supply will shut off. (p. 22)
39. In an appliance, it is necessary to contain the electrical flow in proper paths within the circuit itself. In other words, it is necessary to _____ the circuit. (p. 22)
40. An insulator is a material which contains few free electrons and hence permits relatively little _____ to flow through the material. Glass, plastics and rubber are examples of insulators. (p. 23)
41. Insulation is intended to prevent _____ circuits in conductors (wires). However, provisions are made to protect insulated wires carrying line voltage from physical damage which might destroy the effectiveness of the insulation. Two common approaches are the use of steel conduit and steel armored cable. (p. 23)
42. Electrical resistance is a property of a circuit that opposes current flow in that circuit. A second property of electrical circuits, _____ creates certain effects which can be used to advantage in DC and AC electrical and electronic circuits. (p. 23)

current

insulate

capacitance

short

electromagnet

composition

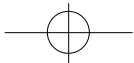
short

nichrome

voltage

electron

current



43. A 1. _____ basically consists of two plates of conducting materials (which can readily accept or give up free electrons) separated by an insulating material called the 2. _____. A capacitor acts to 3. _____ electrical energy in an electrical field. (p. 23)
44. If the discharge of a capacitor occurs across an air gap, an intense 1. _____ can be produced. Some spark fuel ignitor systems are based on this principle. The charged capacitor is discharged through a device called an 2. _____ coil to create a high voltage which will jump a spark across the ignitor gap. (p. 25)
45. INDUCTANCE — When an electric current flows in a coil of wire, a 1. _____ field is created about that wire. If a coil of wire is placed in a magnetic field that builds up and collapses, and electrical flow will be 2. _____ in the coil. These two principles are applied in a transformer in which an AC current flows in the primary coil creating a 3. _____ magnetic field which in turn induces an electrical flow in a nearby secondary coil. This same action takes place in a single coil as well, a process called self induction. (p. 28)
46. AC current in one direction in the coil builds up to its peak; the magnetic field it creates around the coil induces a voltage in the opposite direction (called a 1. _____ voltage). On the other hand, when the AC current reverses itself, the collapsing 2. _____ field tends to build up a voltage to keep current flowing in the original direction. This property of a circuit which opposes any change in the rate of current flow is known as 3. _____. (p. 28–29)
47. The watt (electrical power) - is the rate of doing work or the rate at which 1. _____ is transferred in some process or device. The basic unit of electrical power is the 2. _____. The unit of power most commonly used in the gas industry is Btu per hour. One watt of electrical power is equivalent to 3.413 Btu/hr. One kilowatt is equivalent to 3. _____ Btu per hour. (p. 29)

magnetic

induction

fluctuating

induced

store

capacitor

back

energy

3413

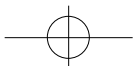
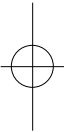
spark

dielectric

magnetic

inductance

watt



IV. ELECTRICAL RELATIONSHIPS

Ohm’s Law

In the water analogies used thus far to describe the fundamentals of electricity (voltage, current and resistance), it has been noted that the water flow rate in a system depends on the pressure (potential difference) and on the resistance to flow by the pipes.

Figure 27 presents a water analogy to illustrate the relationships between

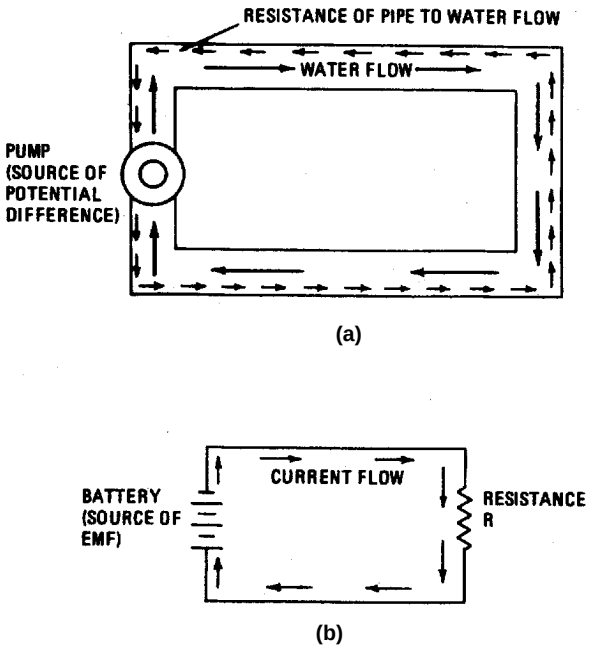


Fig. 27 Water analogy to illustrate relationship between EMF (E), current (I) and resistance (R) in an electrical circuit

voltage (E), current (I) and resistance (R) in an electrical circuit.

In Figure 27(a) the pump shown is the source of potential difference (pressure) in the closed pipe system, equivalent to the battery in the electrical circuit shown in figure 27(b). With the pump operating, water flows through the pipe system

(equivalent to current flow in Figure 27(b)). The pipes (through wall friction, restrictions, etc.) offer a resistance to the flow of water, just as the conductors in the electrical system offer some resistance to electrical flow. To simplify the explanation, in figure 27(b) all of the resistance in the circuit (including that in the battery) is considered to be lumped into a single resistance, labeled R in the figure.

With steady flow in the water system, the pump will produce just enough potential difference (pressure) to overcome the total pipe resistance in the system for a given flow of water. In other words, the pressure increase through the pump will just equal the total pressure drop in the system. Likewise, the voltage produced by the battery will just equal the potential drop (voltage drop) through the electrical circuit.

The relationships of voltage, current and resistance in a DC electrical circuit are summed up in **Ohm’s Law** that can be expressed three different ways by mathematical equations:

$$E = IR$$

Where:
E = voltage, in volts
I = current, in amperes
R = resistance, in ohms

This equation states that the voltage in volts in a circuit is equal to the current in amperes times the resistance in ohms. To illustrate its use, consider the simple circuit shown in Figure 27(b). Assume that the resistance (R) shown is 5 ohms. We measure the current flow to be 2